CMPSCI 370: Intro to Computer Vision
Image formation

University of Massachusetts, Amherst
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Instructor: Subhransu Maji

Administrivia

- **Homework 1** posted on Moodle
  - Due Feb ~~4~~ 9, 11:30am (before the class)
  - Submit a single pdf file with code and details via Moodle

- Sign up for discussion on Piazza
  - https://piazza.com/umass/spring2016/cmpsci370

- Does Monday 3-5pm CS274 work as OH?
  - If not alternate times?

Overview of the next two lectures

- **The pinhole projection model**
  - qualitative properties
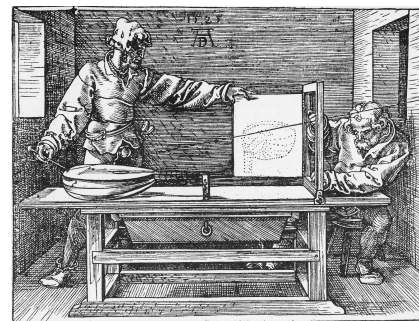 - perspective projection matrix
- **Cameras with lenses**
  - Depth of focus
  - Field of view
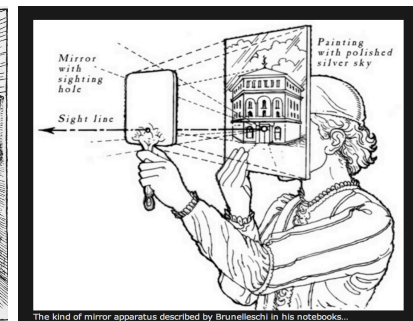 - Lens aberrations
- **Digital cameras**
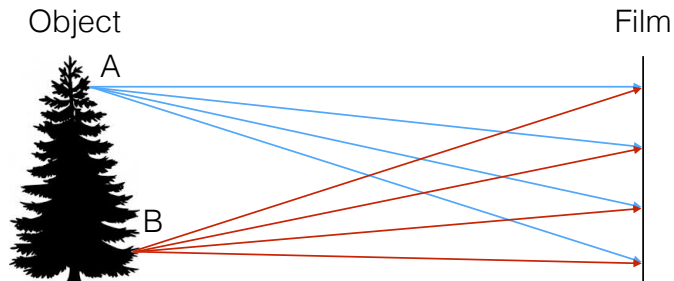 - Sensors
  - Colors
  - Artifacts

Cameras
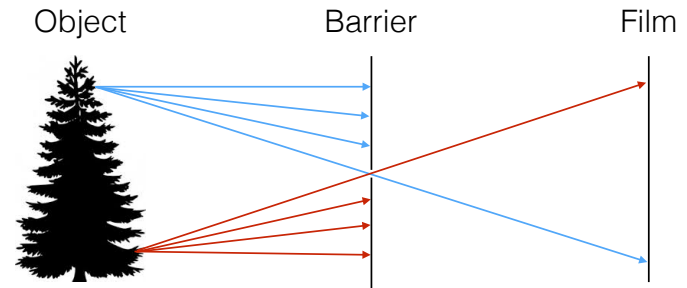

Albrecht Dürer early 1500s

Brunelleschi, early 1400s

Lets design a camera

Object   Film

A

B

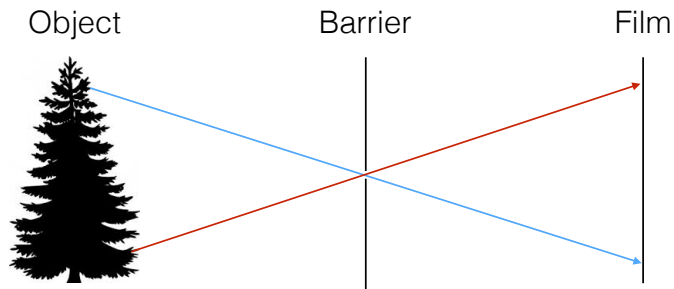**Idea 1:** Lets put a film in front of an object
Do we get a reasonable image?

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Pinhole camera

Object   Barrier   Film

Add a barrier to block of most rays
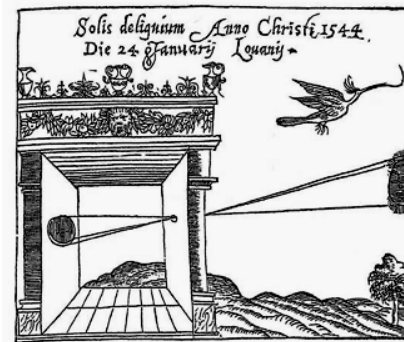
6

Pinhole camera

Object   Barrier   Film

- Captures **pencil of rays** - all rays through a single point:
  aperture, center of projection, focal point, camera center
- The image is formed on the **image plane**

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Camera obscura

Gemma Frisius, 1558

- Basic principle known to Mozi (470-390 BCE), Aristotle (384-322 BCE)
- Drawing aids for artists: described by Leonardo Da Vinci (1452-1519 AD)

"Camera obscura" Latin for "darkened room"

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Pinhole cameras are everywhere

Tree shadow during a solar eclipse
photo credit: Nils van der Burg
http://www.physicstogo.org/index.cfm

Accidental pinhole cameras

My hotel room,
contrast enhanced.   The view from my window

Accidental pinholes produce images that are
unnoticed or misinterpreted as shadows

A. Torralba and W. Freeman, **Accidental Pinhole and Pinspeck Cameras**, CVPR 2012
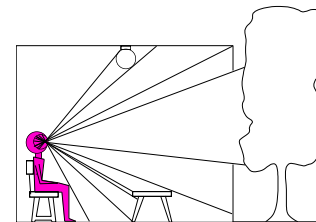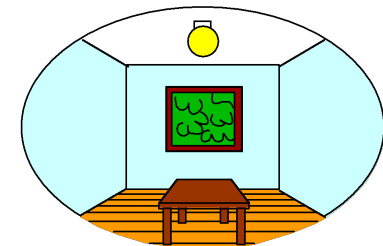
Home-made pinhole camera

http://www.pauldebevec.com/Pinhole

Dimensionality reduction: 3D to 2D

3D world   2D image

Point of observation
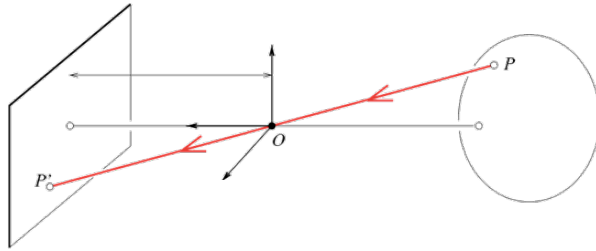
- **What is preserved?**
  - Straight lines, incidence
- **What is not preserved?**
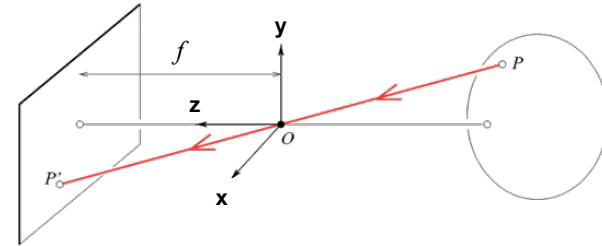 - Angles, lengths

Modeling projection

- To compute the projection *P'* of a scene point *P*, form a **visual ray** connection P to the camera center *O* and find where it intersects the image plane
  - All scene points that lie on this visual ray have the same projection on the image
  - Are there points for which this projection is not defined?

Modeling projection

- **The coordinate system**
  - The optical center (***O***) is at the origin
  - The image plane is parallel to the xy-plane (perpendicular to the z axis)
- **Projection equations**
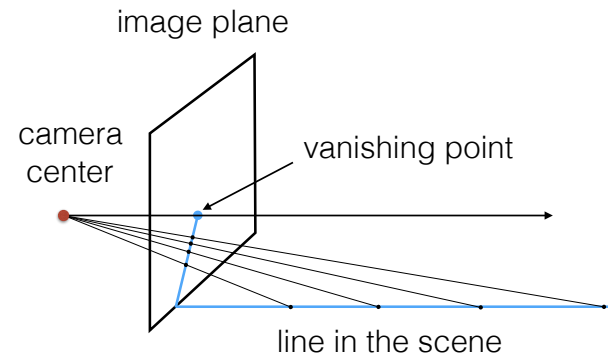 - Derive using similar triangles $(x, y, z) \rightarrow (-\dfrac{fx}{z}, -\dfrac{fy}{z})$

Coordinate geometry review …

- Equation of line in 2D

- Equation of line in 3D

Projection of a line
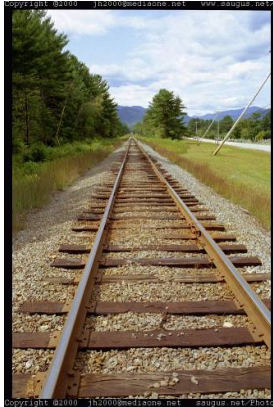
image plane

camera center

vanishing point

line in the scene

- What if we add another line parallel to the first one?
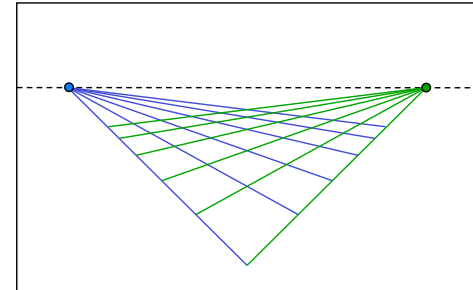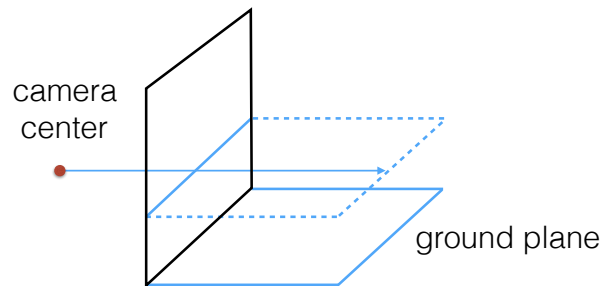
Vanishing points

- Each direction in space has its own vanishing point
  - All lines going in the that direction converge at that point
  - **Exception**: directions that are parallel to the image plane

Vanishing points

- Each direction in space has its own vanishing point
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  - **Exception**: directions that are parallel to the image plane
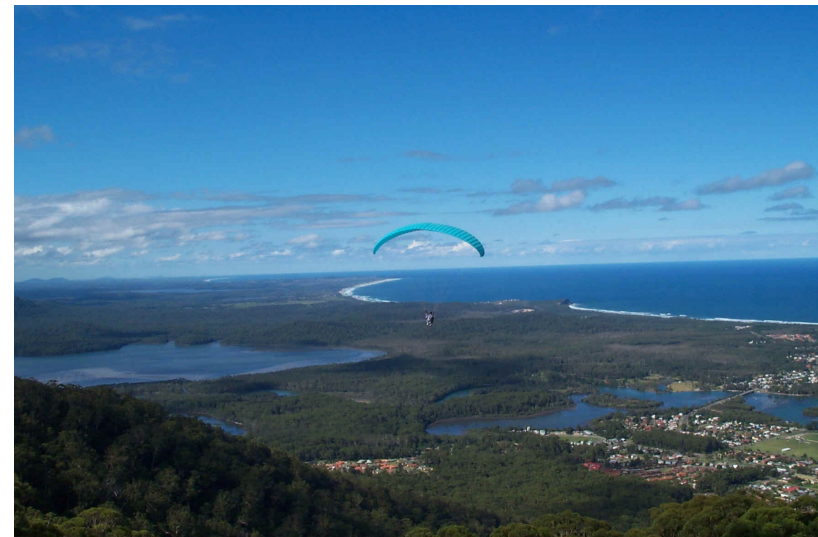- What about the vanishing point of a plane?

The horizon

camera center

ground plane

- Vanishing line of the ground plane
  - All points at the same height of the camera project to the horizon
  - Points above the camera project above the horizon
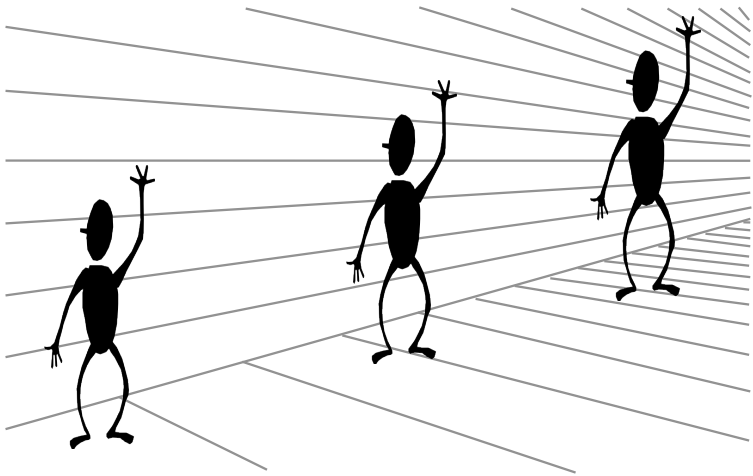 - Provides a way of comparing heights of objects

The horizon

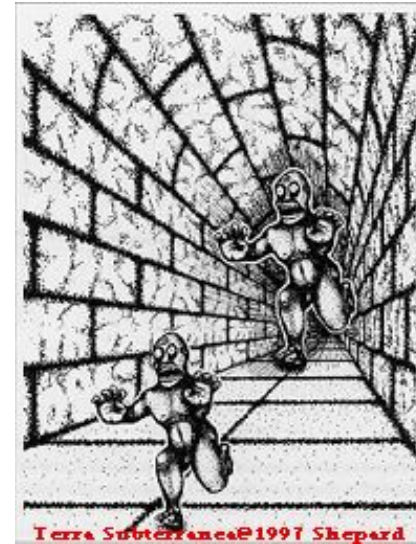Is the person above or below the viewer?
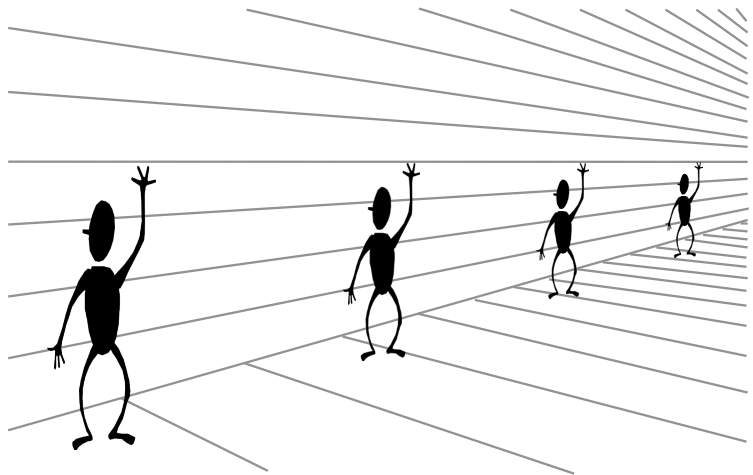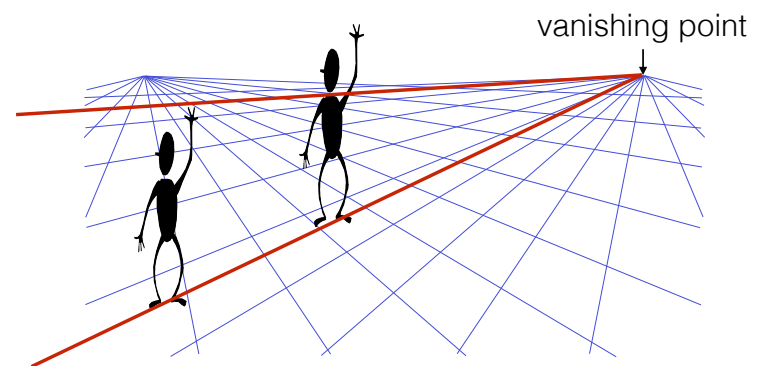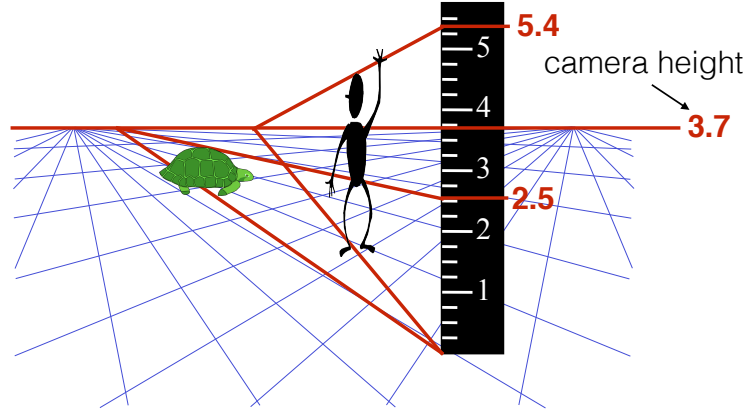
Perspective cues

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Perspective cues

Terra Subterranea©1997 Shepard

22

Perspective cues

23

Comparing heights

vanishing point

24

Measuring heights

5.4

5

camera height

4

3.7

3

2.5
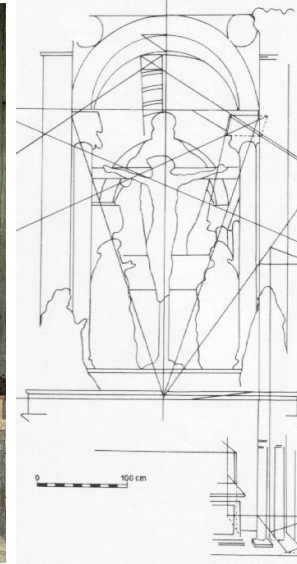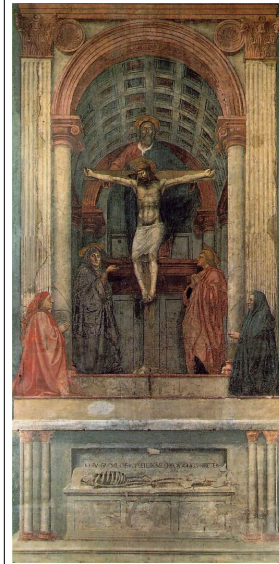
2

1

What is the height of the camera?

Perspective in art

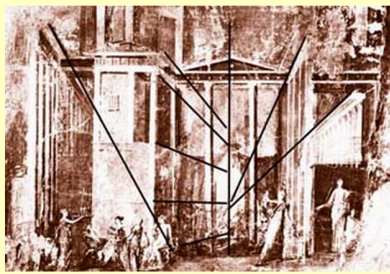Masaccio, *Trinity*, Santa Maria Novella, Florence, 1425-28

One of the first consistent uses of perspective in Western art

Perspective in art

(At least partial) Perspective projections in art well before the Renaissance

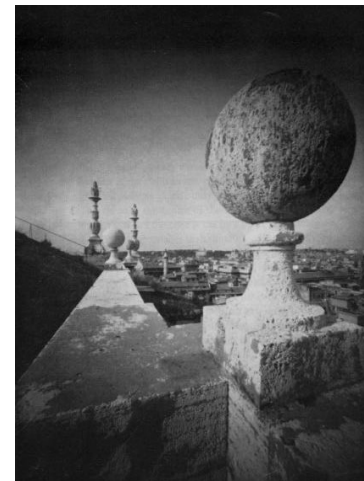Several Pompei wallpaintings show the fragmentary use of linear perspective:

From ottobwiersma.nl

Also some Greek examples,
So apparently pre-renaissance…

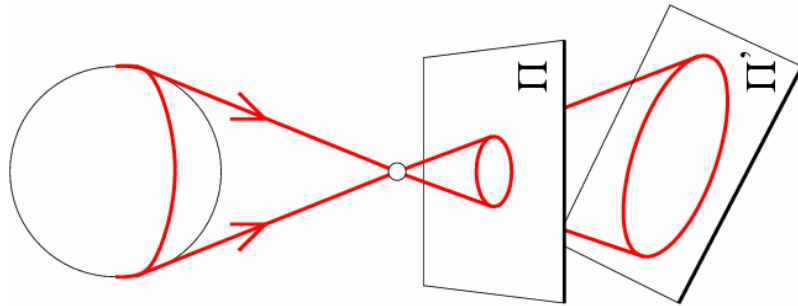## Perspective distortion

- What does a sphere project to?

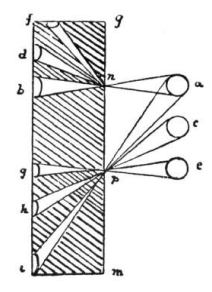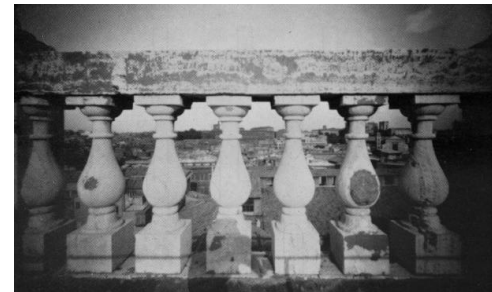M. H. Pirenne

Perspective distortion

- What does a sphere project to?

Perspective distortion

- The exterior looks bigger

- The distortion is not due to lens flaws
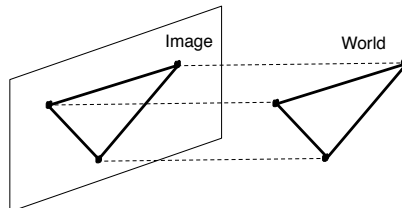
- Problem pointed out by Da Vinci

Orthographic projection

- Special case of perspective projection
  - Distance of the object from the image plane is infinite
  - Also called the "parallel projection"

Orthographic projection

- Special case of perspective projection
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More readings and thoughts

- **History of optics**, Wikipedia

- A. Torralba and W. Freeman, **Accidental Pinhole and Pinspeck Cameras**, CVPR 2012

- DIY **http://www.pauldebevec.com/Pinhole**