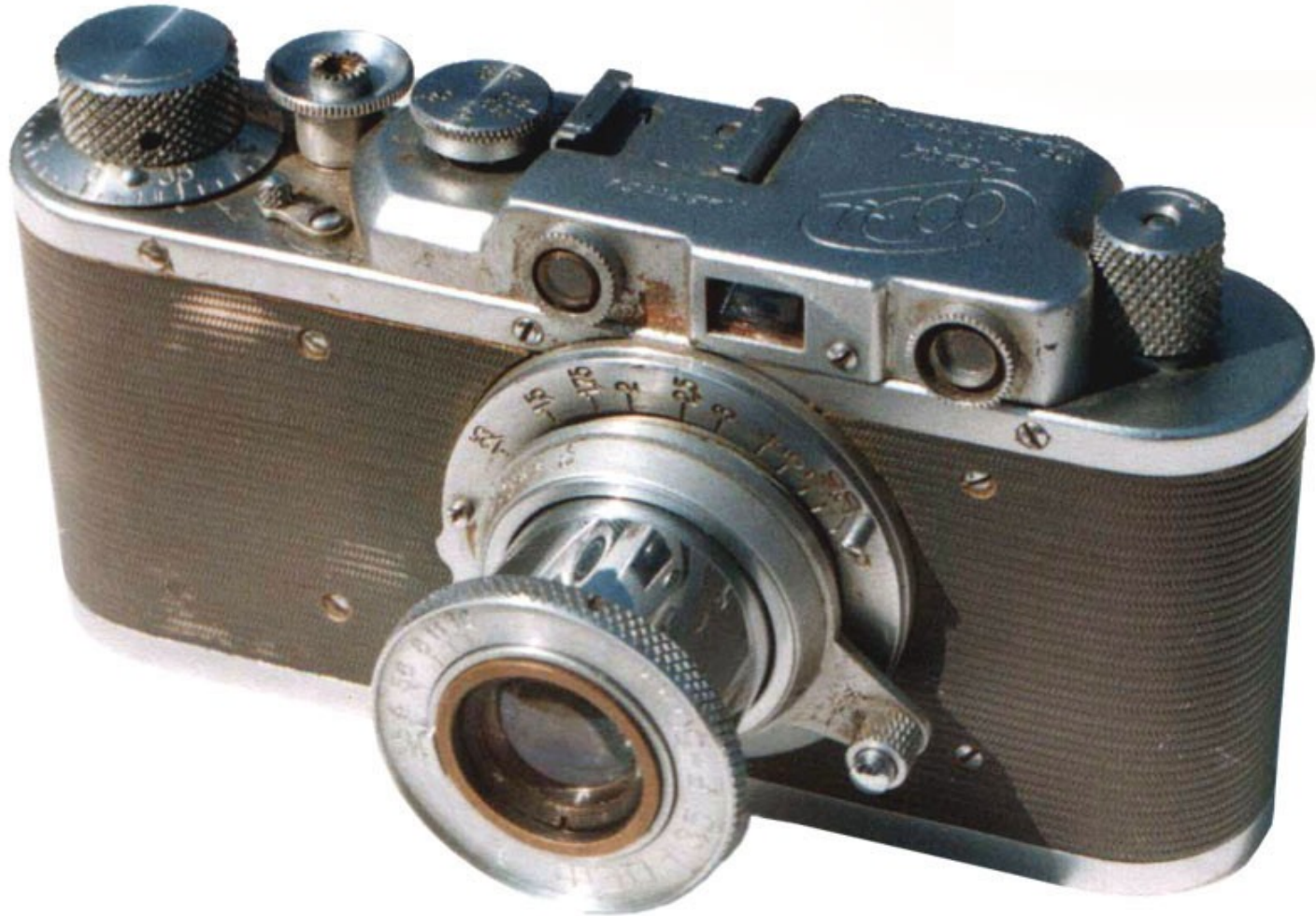


The Camera

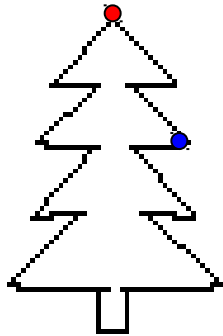


Overview

- The pinhole projection model
 - Qualitative properties
 - Perspective projection matrix
- Cameras with lenses
 - Depth of focus
 - Field of view
 - Lens aberrations
- Digital cameras
 - CCD vs. CMOS
 - Color sensors

How do we see the world?

object



film



Let's design a camera

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

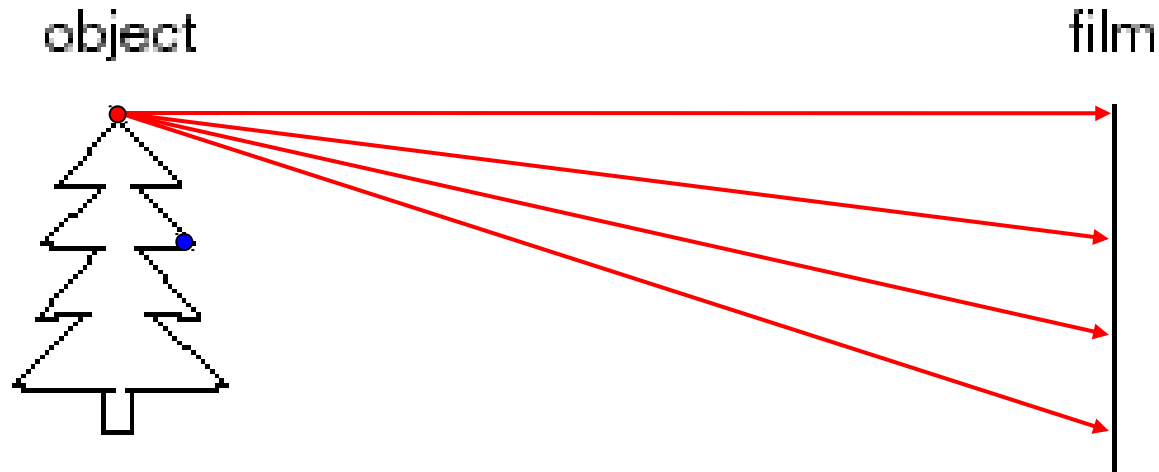
How do we see the world?



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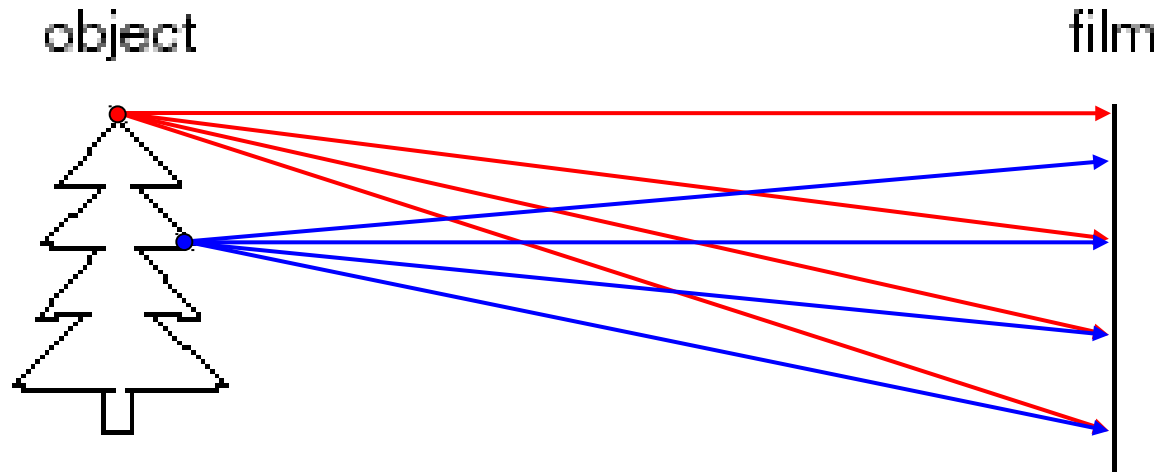
How do we see the world?



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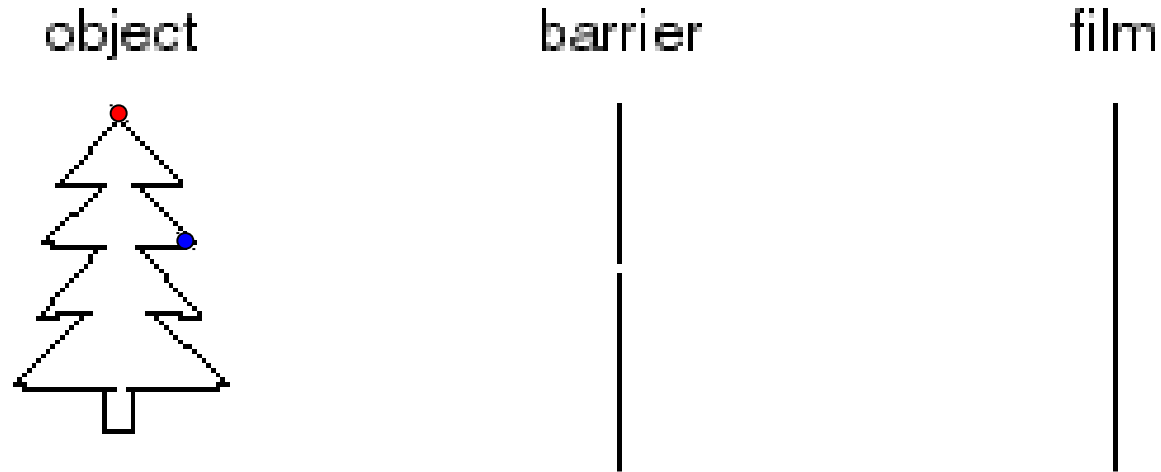
How do we see the world?



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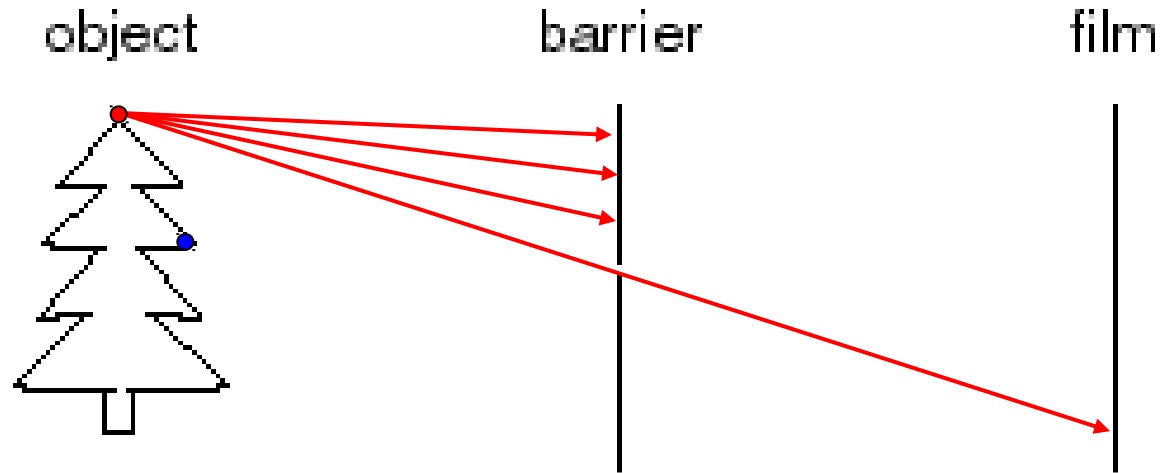
Pinhole camera



Add a barrier to block off most of the rays

- This reduces blurring
- The opening known as the **aperture**

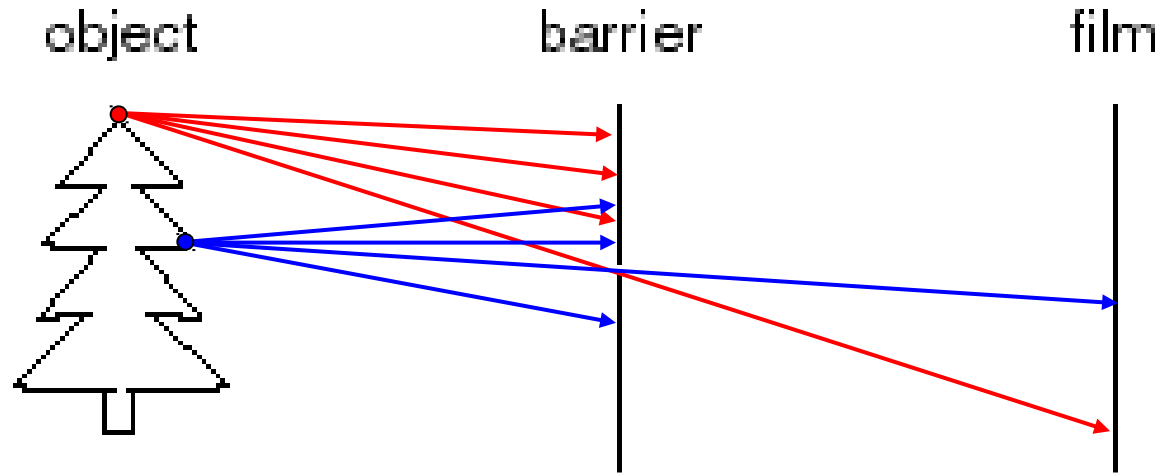
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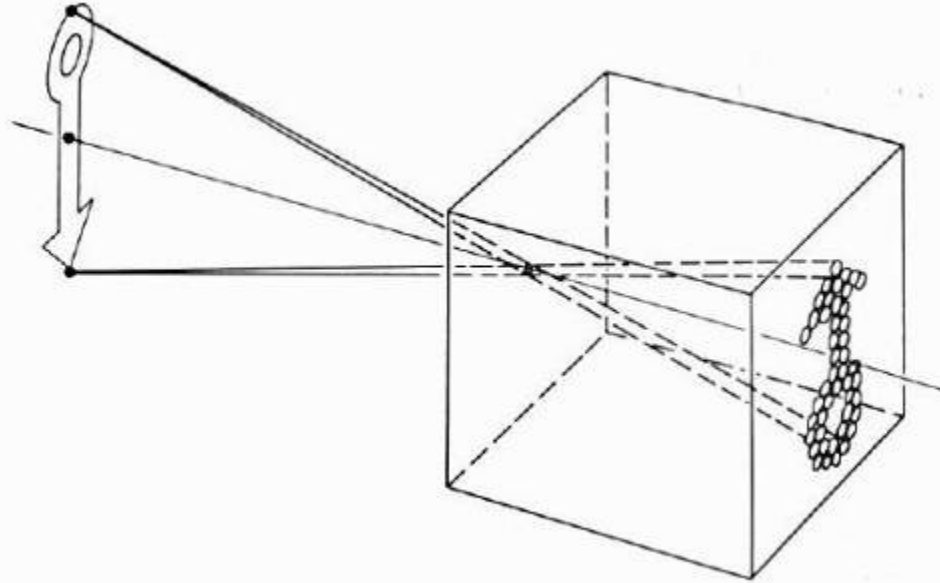
Pinhole camera



Add a barrier to block off most of the rays

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Pinhole camera model

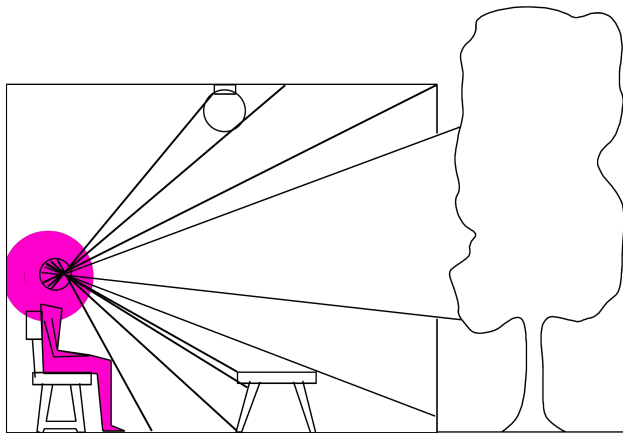


Pinhole model:

- Captures **pencil of rays** – all rays through a single point
- The point is called **Center of Projection (focal point)**
- The image is formed on the **Image Plane**

Dimensionality Reduction Machine (3D to 2D)

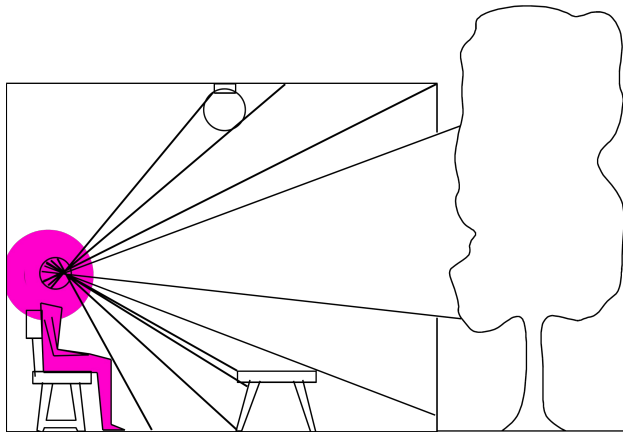
3D world



Point of observation

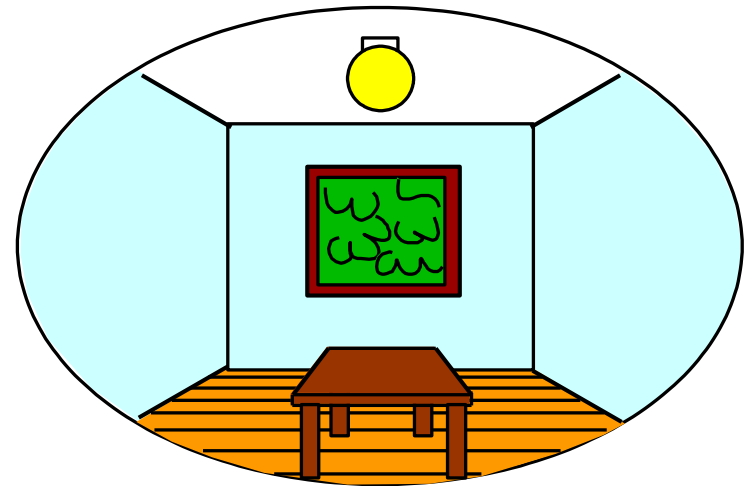
Dimensionality Reduction Machine (3D to 2D)

3D world



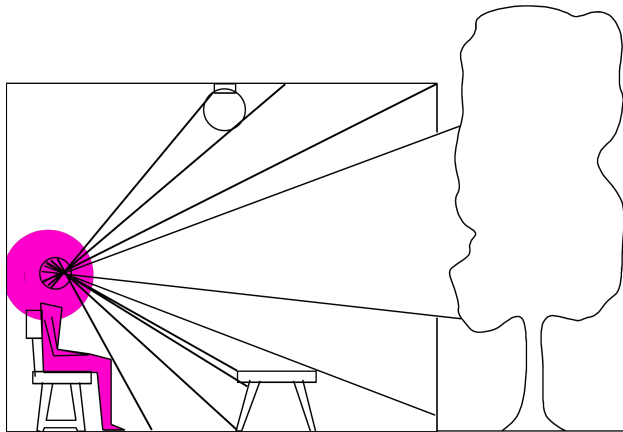
Point of observation

2D image



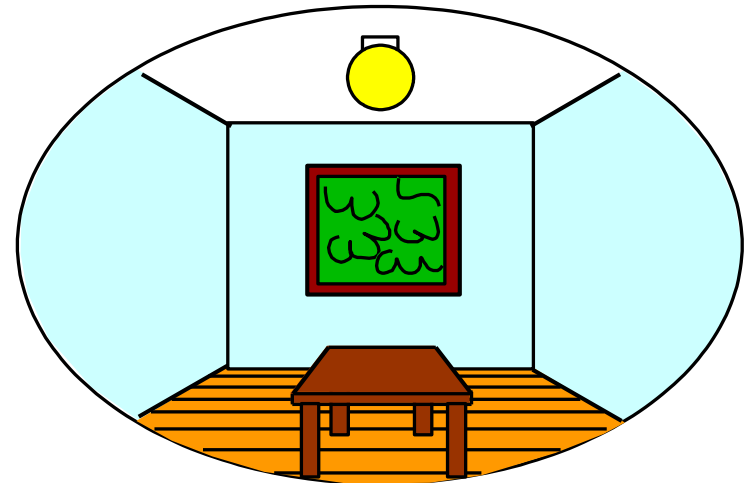
Dimensionality Reduction Machine (3D to 2D)

3D world



Point of observation

2D image



What have we lost?

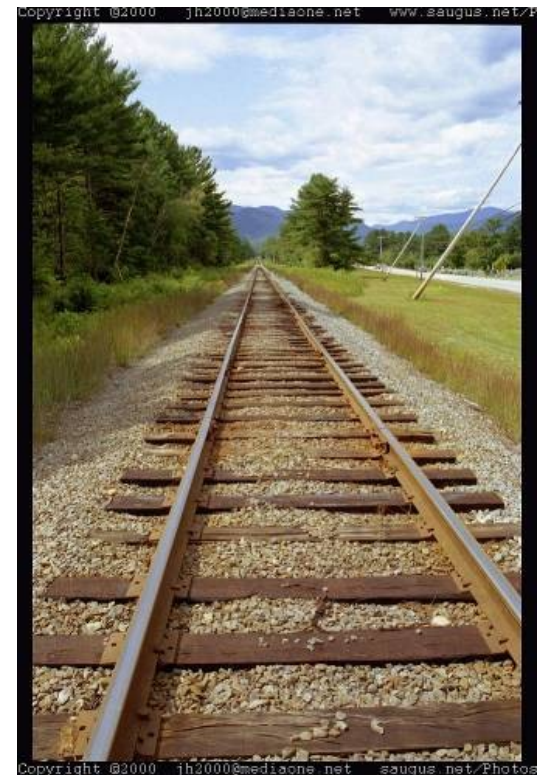
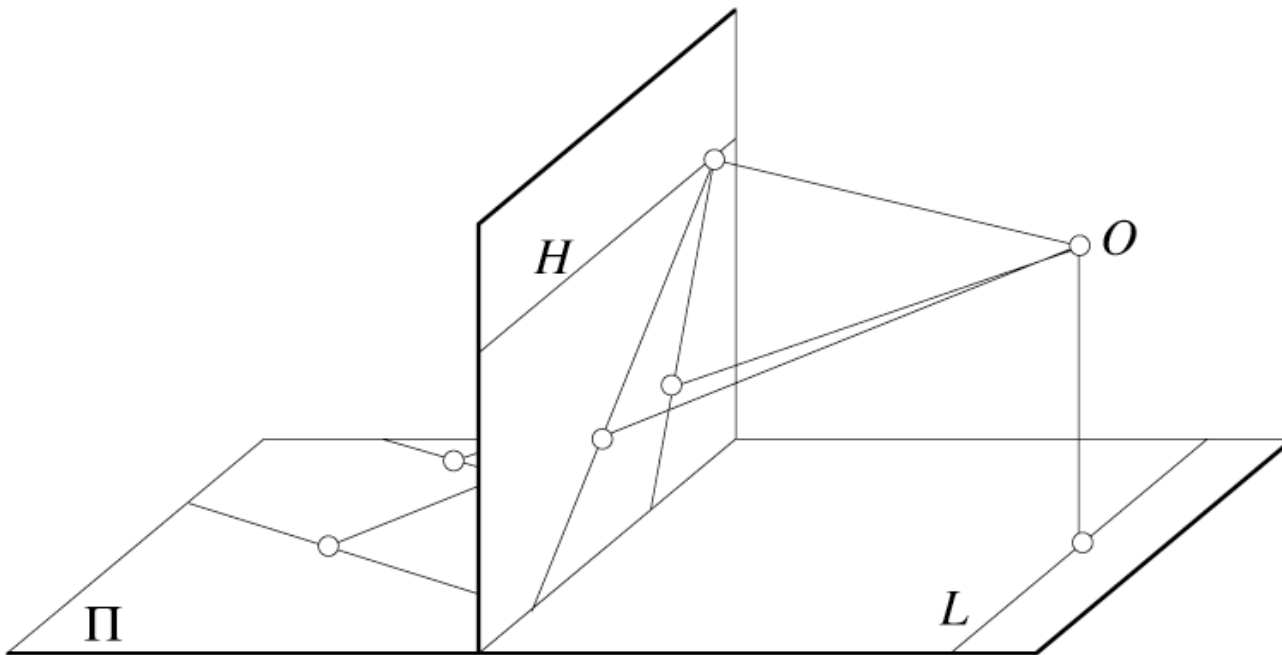
- Angles
- Distances (lengths)

Projection properties

- Many-to-one: any points along same ray map to same point in image
- Points \rightarrow points
 - But projection of points on focal plane is undefined
- Lines \rightarrow lines (collinearity is preserved)
 - But line through focal point projects to a point
- Planes \rightarrow planes (or half-planes)
 - But plane through focal point projects to line

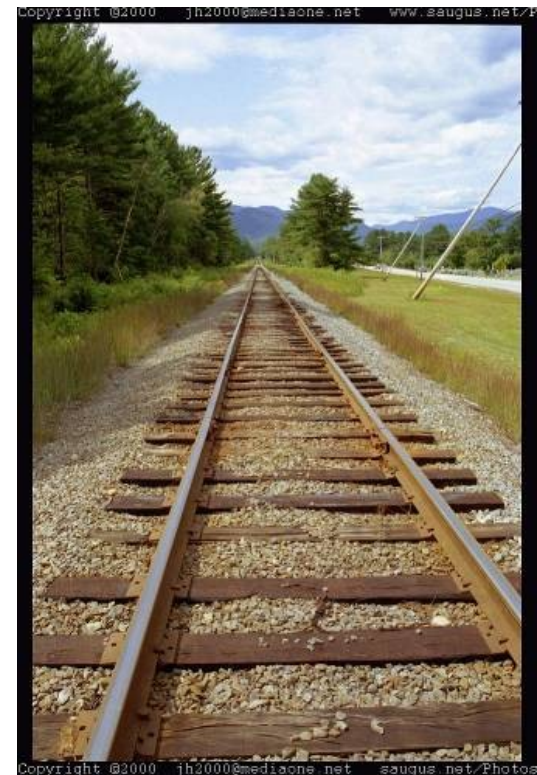
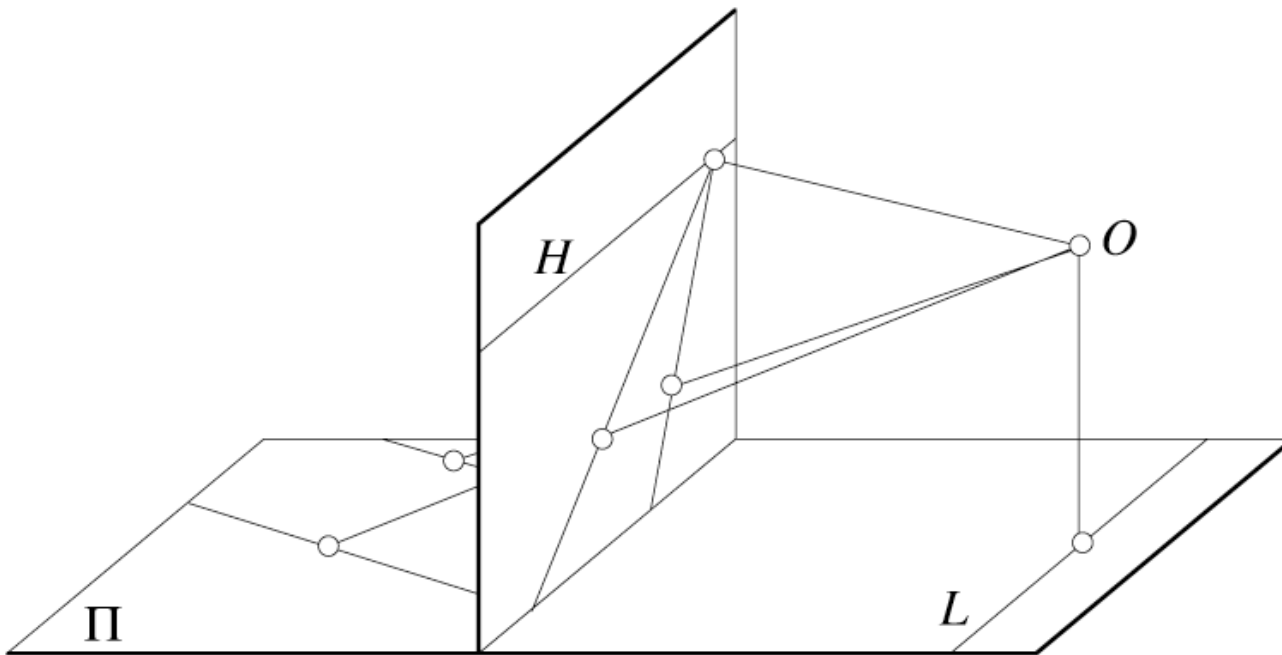
Projection properties

- Parallel lines converge at a vanishing point
 - Each direction in space has its own vanishing point
 - But parallels parallel to the image plane remain parallel



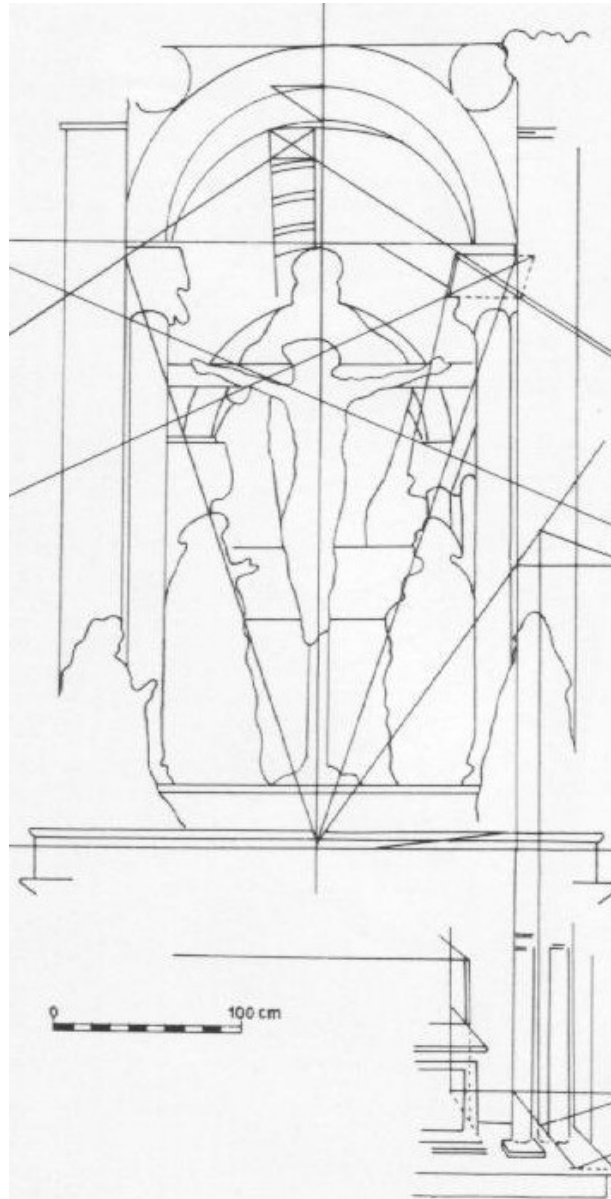
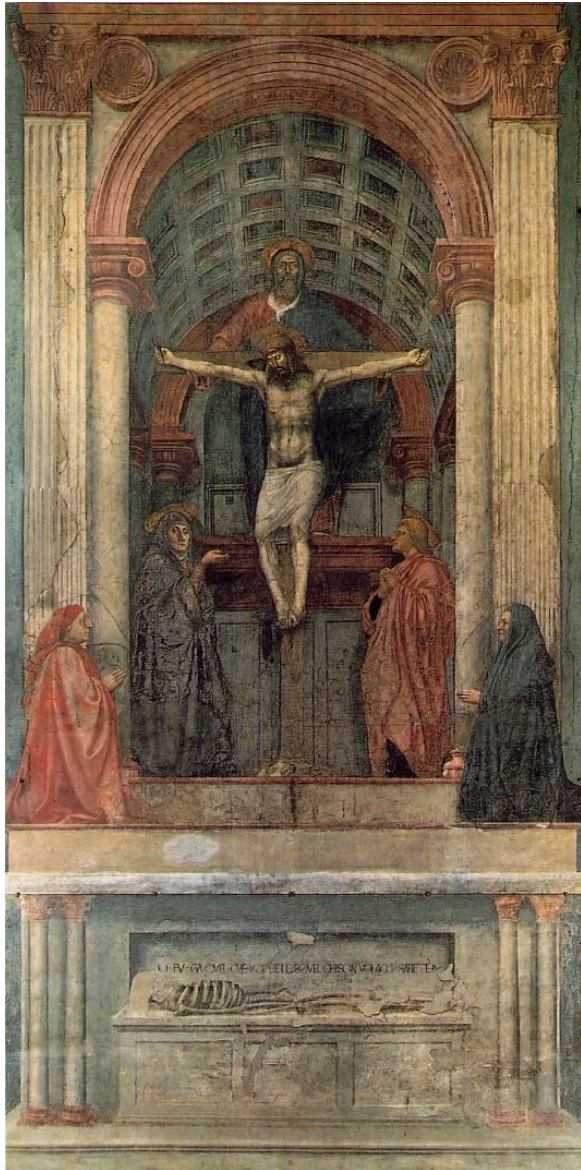
Projection properties

- Parallel lines converge at a vanishing point
 - Each direction in space has its own vanishing point
 - But parallels parallel to the image plane remain parallel



How do we construct the vanishing point?

One-point perspective



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

First consistent use of perspective in Western art?

Perspective distortion

- What does a sphere project to?

Perspective distortion

- What does a sphere project to?

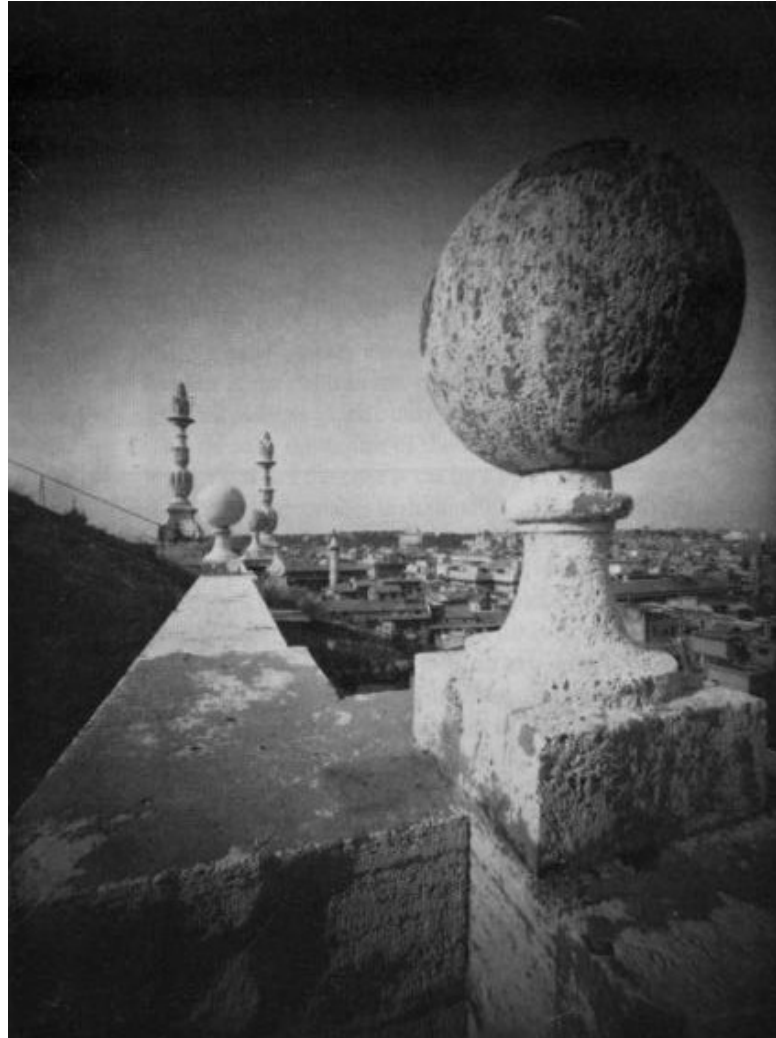
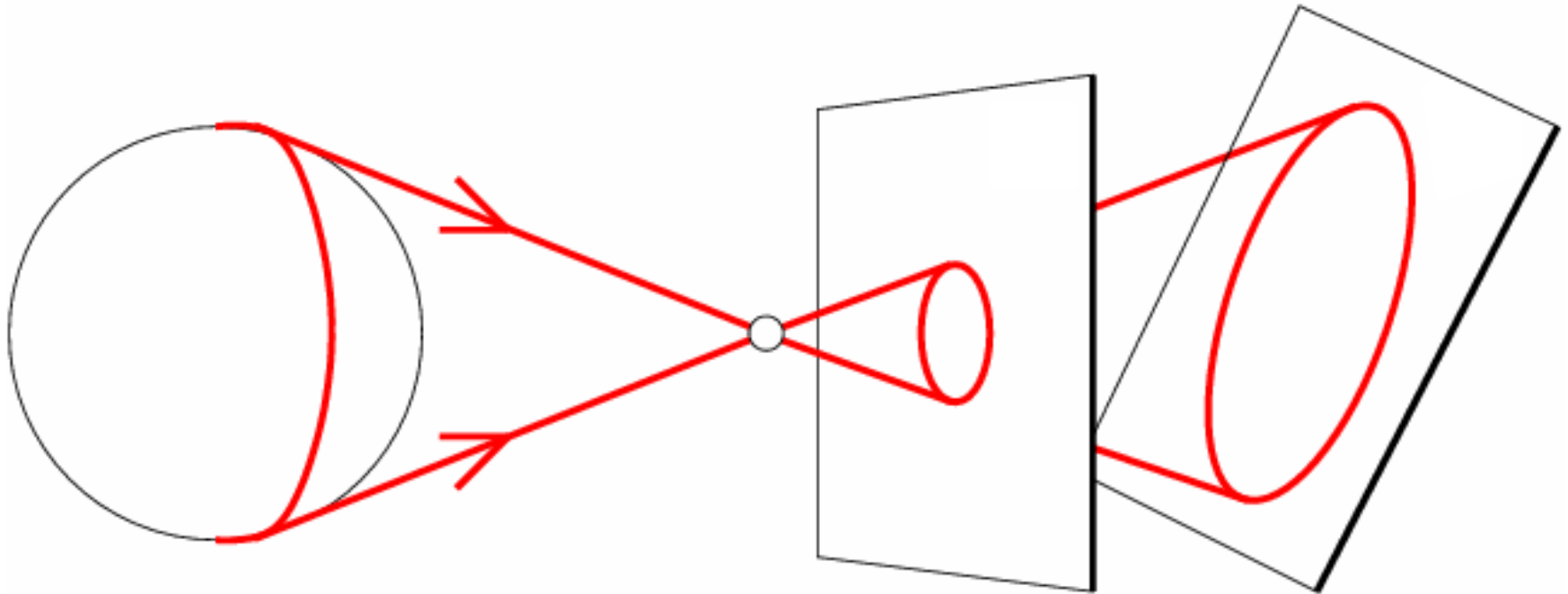


Image source: F. Durand

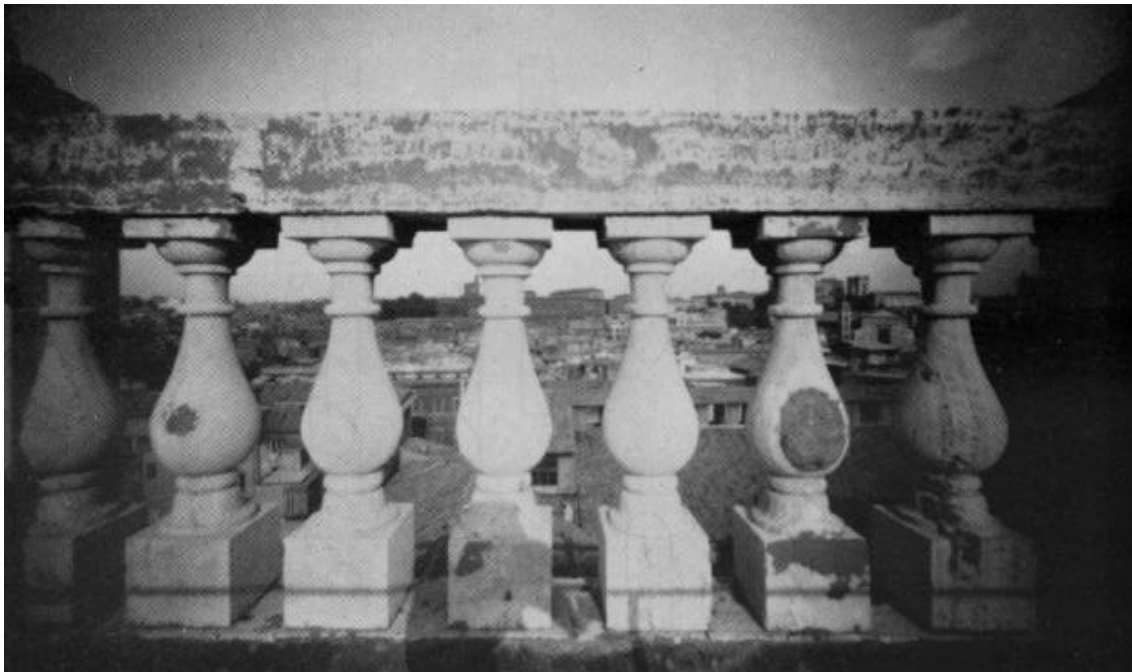
Perspective distortion

- What does a sphere project to?



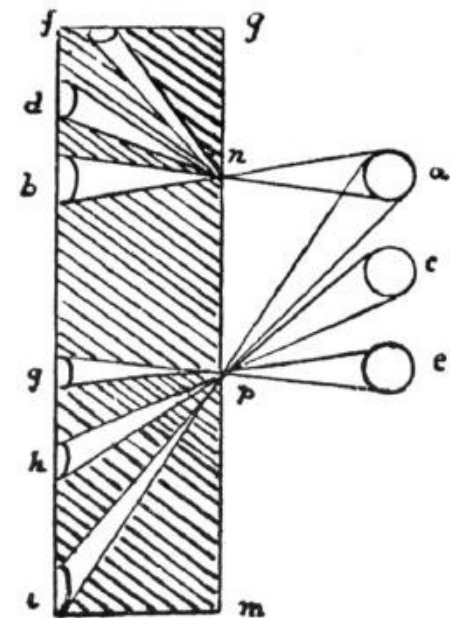
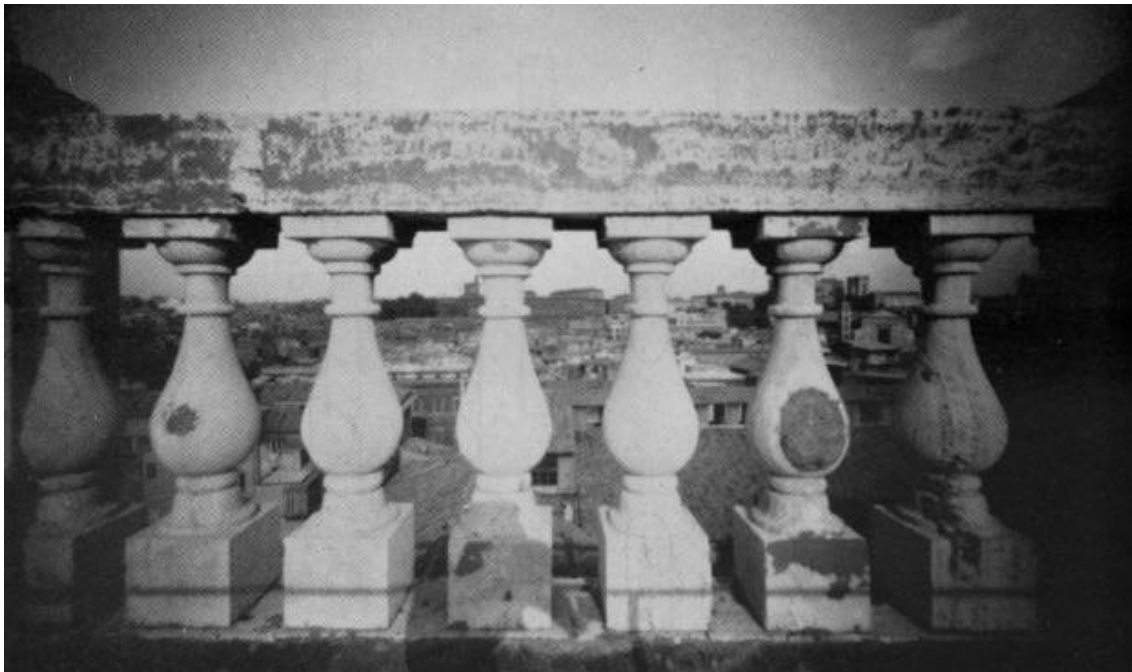
Perspective distortion

- The exterior columns appear bigger
- The distortion is not due to lens flaws
- Problem pointed out by Da Vinci



Perspective distortion

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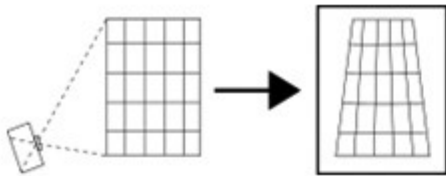
Perspective distortion

- Problem for architectural photography: converging verticals

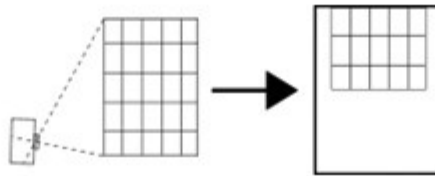


Perspective distortion

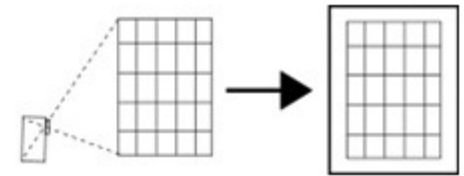
- Problem for architectural photography: converging verticals



Tilting the camera upwards results in converging verticals

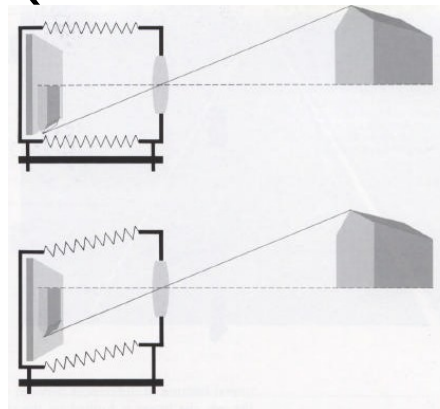
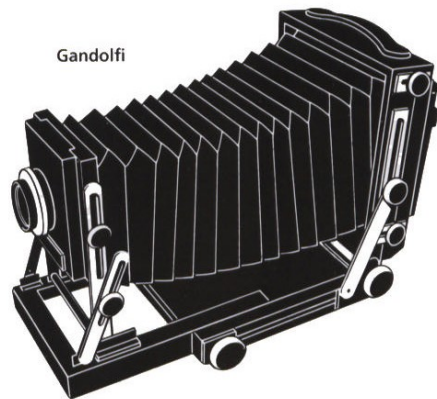


Keeping the camera level, with an ordinary lens, captures only the bottom portion of the building



Shifting the lens upwards results in a picture of the entire subject

- Solution: view camera (lens shifted w.r.t. film)



Perspective distortion

- Problem for architectural photography: converging verticals
- Result:

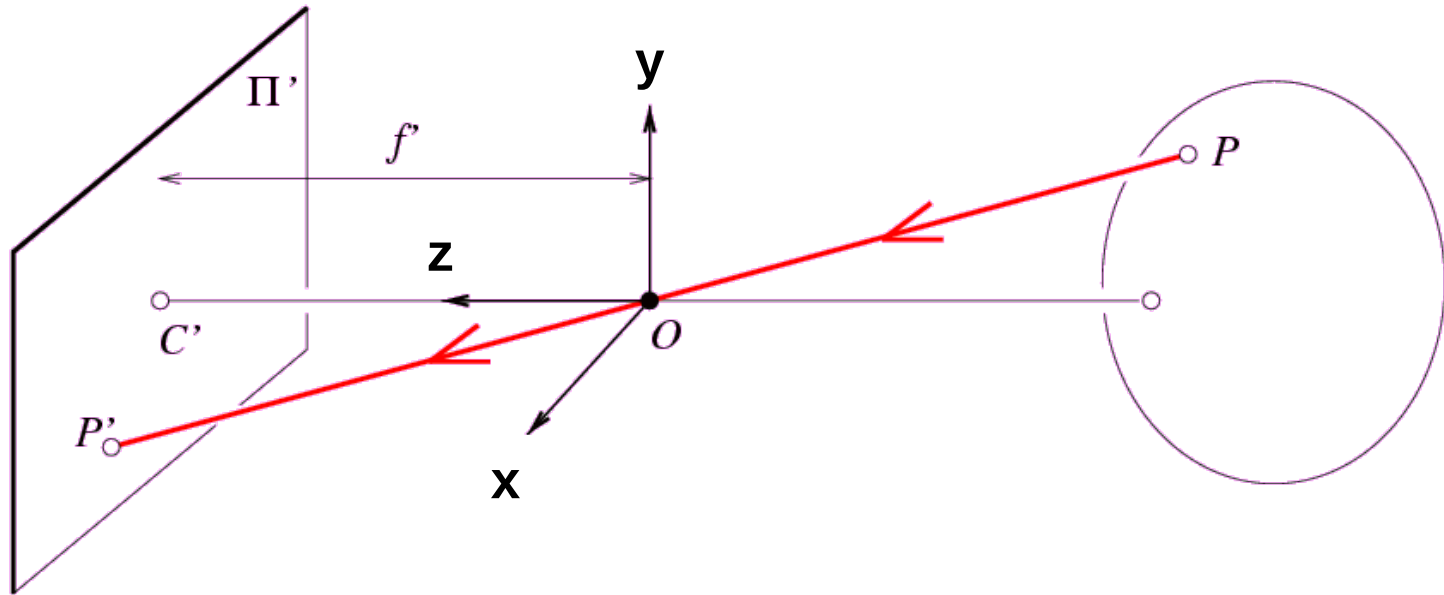


Perspective distortion

- However, converging verticals work quite well for horror movies...



Modeling projection



The coordinate system

- We will use the pinhole model as an approximation
- Put the optical center (O) at the origin
- Put the image plane (Π') *in front of* O