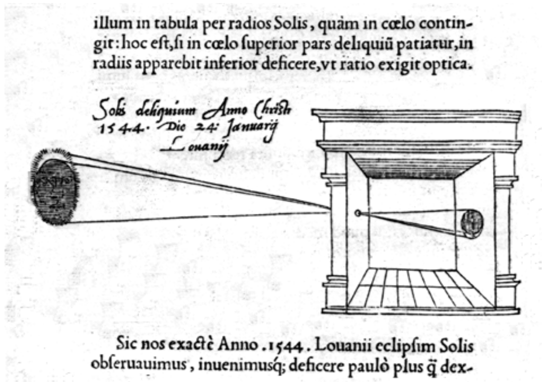
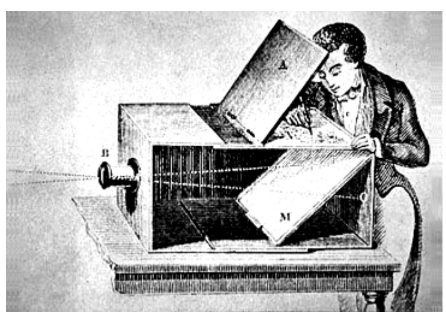
# Camera Obscura




"When images of illuminated objects ... penetrate through a small hole into a very dark room ... you will see [on the opposite wall] these objects in their proper form and color, reduced in size ... in a reversed position, owing to the intersection of the rays".

*Da Vinci*

http://www.acmi.net.au/AIC/CAMERA_OBSCURA.html (Russell Naughton)



- Used to observe eclipses (eg., Bacon, 1214-1294)
- By artists (eg., Vermeer).


Jetty at Margate England, 1898.

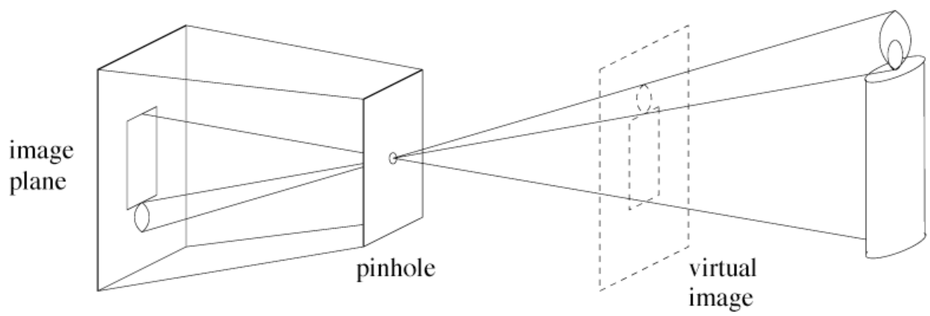
http://brightbytes.com/cosite/collection2.html (Jack and Beverly Wilgus)

# Cameras

- First photograph due to Niepce
- First on record 1822

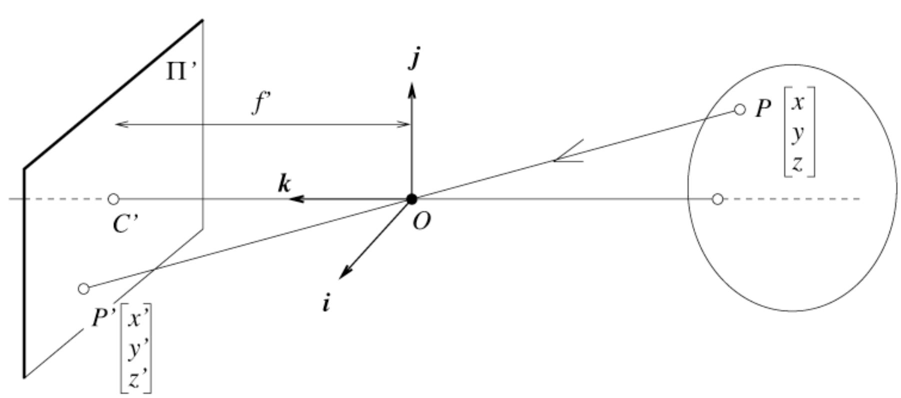
# Pinhole cameras

- Abstract camera model - box with a small hole in it
- Pinhole cameras work in practice




(Forsyth & Ponce)

# The equation of projection



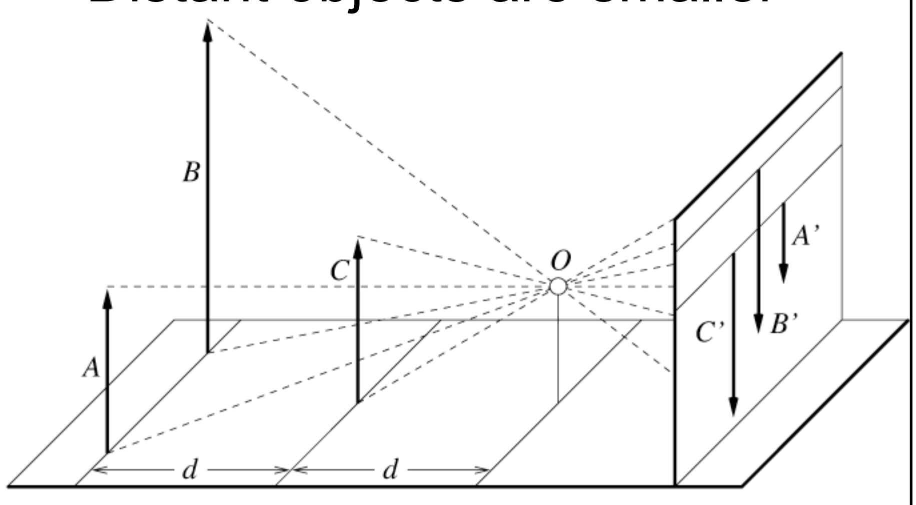

(Forsyth & Ponce)

# The equation of projection

- Cartesian coordinates:
  - We have, by similar triangles, that (x, y, z) -> (f x/z, f y/z, f)
  - Ignore the third coordinate, and get

$$(x, y, z) \rightarrow (f\frac{x}{z}, f\frac{y}{z})$$

# Distant objects are smaller



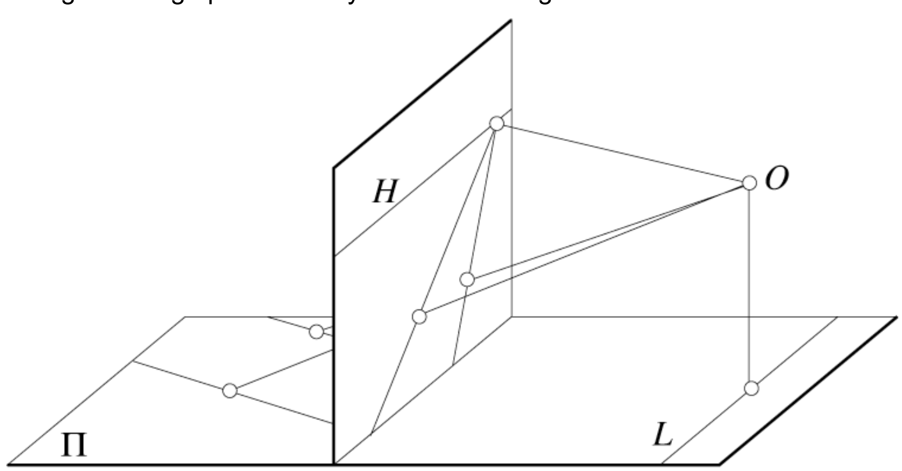

(Forsyth & Ponce)

For example, consider one line segment from (x,0,z) to (x,y,z), and another from (x,0,2z) to (x,y,2z). These are the same length.

These project in the image to a line from (fx/z,0) to (fx/z, fy/z) and from (fx/z,0) to (fx/2z, fy/2z), where we can rewrite the last point as: (1/2)(fx/z,fy/z). The second line is half as long as the first.

# Parallel lines meet

Common to draw image plane *in front* of the focal point.
Moving the image plane merely scales the image.




(Forsyth & Ponce)

# Vanishing points

- Each set of parallel lines meets at a different point
  - The *vanishing point* for this direction
- Sets of parallel lines on the same plane lead to *collinear* vanishing points.
  - The line is called the *horizon* for that plane

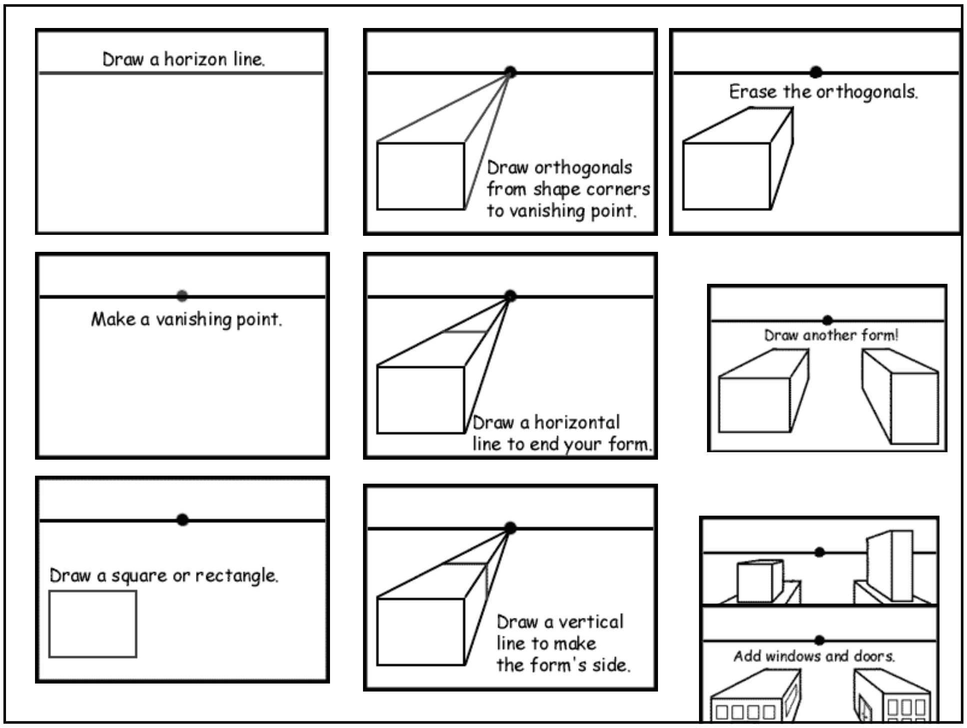
For example, let's consider a line on the floor. We describe the floor with an equation like: $y = -1$. A line on the floor is the intersection of that equation with $x = az + b$. Or, we can describe a line on the floor as: $(a, -1, b) + t(c, 0, d)$ (Why is this correct, and why does it have more parameters than the first way?)

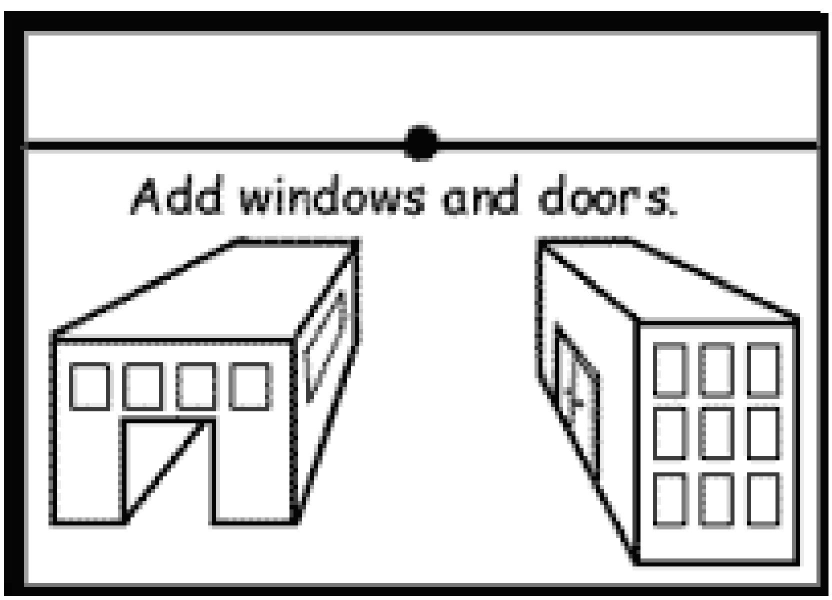
As a line gets far away, $z \to$ infinity. If $(x,-1,z)$ is a point on this line, its image is $f(x/z,-1/z)$. As $z \to$ infinity, $-1/z \to 0$. What about $x/z$? $x/z = (az+b)/z = a + b/z \to a$. So a point on the line appears at: $(a,0)$. Notice this only depends on the slope of the line $x = az + b$, not on b. So two lines with the same slope have images that meet at the same point, $(a,0)$, which is on the horizon.

## Properties of Projection

- Points project to points
- Lines project to lines
- Planes project to the whole image
- Angles are not preserved
- Degenerate cases
  - Line through focal point projects to a point.
  - Plane through focal point projects to line
  - Plane perpendicular to image plane projects to part of the image (with horizon).

Take out paper and pencil

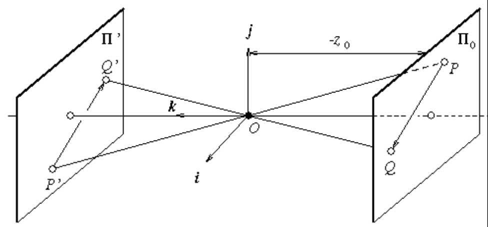



http://www.sanford-artedventures.com/create/tech_1pt_perspective.html

# Weak perspective (scaled orthographic projection)

- Issue
  - perspective effects, but not over the scale of individual objects
  - collect points into a group at about the same depth, then divide each point by the depth of its group




(Forsyth & Ponce)

# The Equation of Weak Perspective

$$(x, y, z) \rightarrow s(x, y)$$

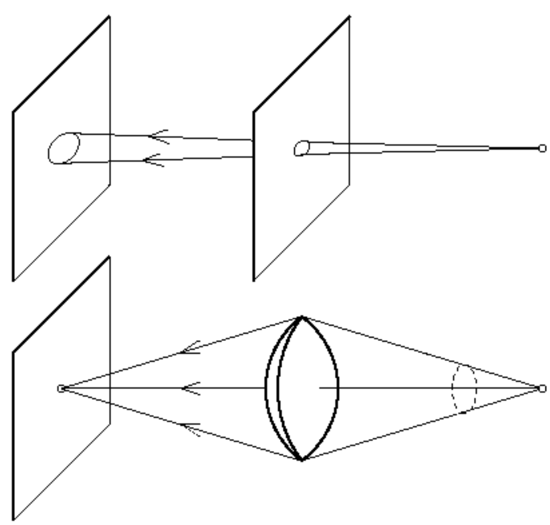
• *s* is constant for all points.

• Parallel lines no longer converge, they remain parallel.

## Pros and Cons of These Models

- Weak perspective much simpler math.
  - Accurate when object is small and distant.
  - Most useful for recognition.
- Pinhole perspective much more accurate for scenes.
  - Used in structure from motion.
- When accuracy really matters, must model real cameras.

## Cameras with Lenses

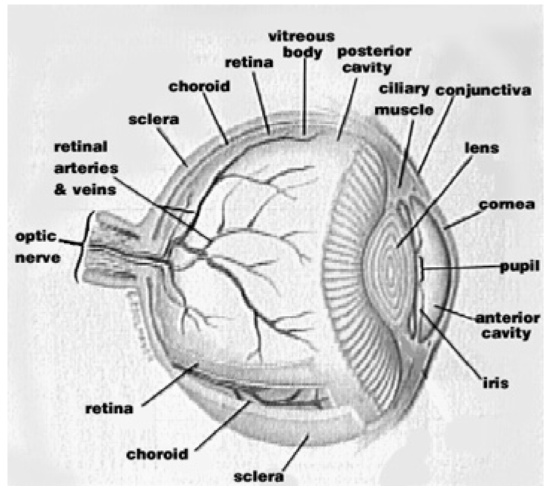


(Forsyth & Ponce)

# Human Eye

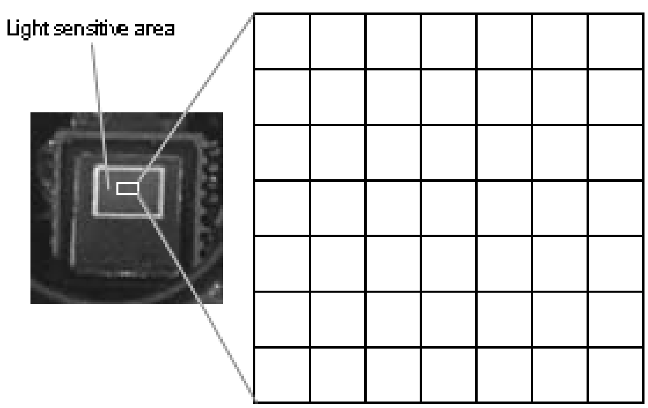
- Lens.
- Fovea, and surround.

(see *The Island of the Colorblind* by Oliver Sacks)




http://www.cas.vanderbilt.edu/bsci111b/eye/human-eye.jpg

# CCD Cameras




http://huizen.ddsw.nl/bewoners/maan/imaging/camera/ccd1.gif

# New Camera Design

http://fizbin.eecs.lehigh.edu/~tboult/TRACK/LOTS.html (Terry Boult)

# Summary

- Camera loses information about depth.
  - A model of the camera tells us what information is lost.
- This will be important when we want to recover this information. Examples:
  - Motion: with multiple images.
  - Recognition: using a model.
  - Shape: how is boundary of smooth object related to its image?