Optics for Dummies
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Basic Pinhole Camera
- Make a tiny hole a piece of paper
- Place a screen in a darkened area behind paper
- See picture on board
- Result: Flipped (top/bottom, right/left) reproduction of scene in miniature

Pinhole Camera Equations
- Idealize pinhole as a point
- All rays producing image must pass through this point
- Assume:
  - Pinhole is origin
  - Image plane is distance $z'$ from pinhole
  - Subject is in a plane with offset distance $z$ from pinhole
- Reasoning from similar triangles:
  \[
  \frac{x'}{x} = \frac{y'}{y} = \frac{z'}{z}
  \]

Magnification
- Determine scale from ratio of $z'$ to $z$
  \[
  \frac{x}{x'} = -mx \\
  \frac{y}{y'} = -my \\
  m = \frac{z}{z'}
  \]
- Note that $z'$ and $z$ have opposite signs

Why Aren't all Cameras Pinhole Cameras?
- Inefficient use of light
- No flexibility in size/design
- Deep (infinite) depth of field (both a pro and con)
Depth of Field

- Range of depths that are acceptably sharp
- Depends upon viewing conditions
- Powerful tool for photographers
- Mostly an annoyance for roboticists
- Can be used to get depth from focus in some cases

http://www.ri.cmu.edu/projects/project_365.html

Perspective

- Why do parallel lines seem to "meet at infinity" ???

\[ x' = \frac{z'}{z} = -mx \]
\[ y' = \frac{y}{z} = -my \]
\[ m = -\frac{z'}{z} \]

- What is constant?
- What changes?

Thin Lenses

- Simplified model of lenses
- Ignores thickness of lens – properties derived from shape of material surface (typically assumed to be arcs) only
- An actual camera "lens" is composed of multiple individual lenses called "elements"
- OK approximation

Thin Lens Equations

- Lens collects rays from a point at depth \( z \)
  - Contrast with pinhole
  - See example on board
- Focuses these rays on a point at depth \( z' \)

\[ \frac{1}{z} - \frac{1}{z'} = \frac{1}{f} \]

- \( f \) is the focal length of the lens (can be derived from curvature and index of refraction of material)
How Does a Camera Focus?

- Move the lens (most common), or...
- Move the image(r) plane

Determining Focal Length Experimentally

- Focus camera at “infinity”
- Measure distance from lens to image
- What is the focal length of a pinhole camera?

Focal Length and Magnification

- Similar triangles idea still applies
- Combine:
  \[
  \frac{1}{z'} + \frac{1}{z} = \frac{1}{f}
  \]

- With
  \[
  x' = \frac{z'}{z} x = -mx
  \]
  \[
  y' = \frac{z'}{z} y = -my
  \]
  \[
  m = -\frac{z'}{z}
  \]