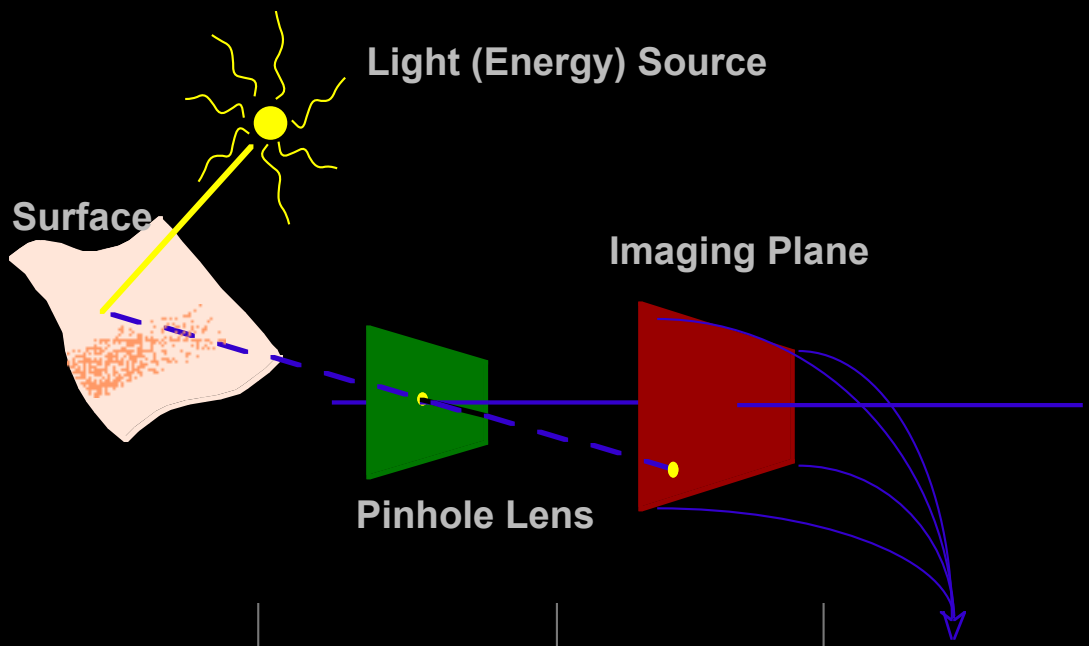
Image Formation



World	Optics	Sensor	Signal
		B&W Film	Silver Density
		Color Film	Silver density in three color layers
		TV Camera	Electrical

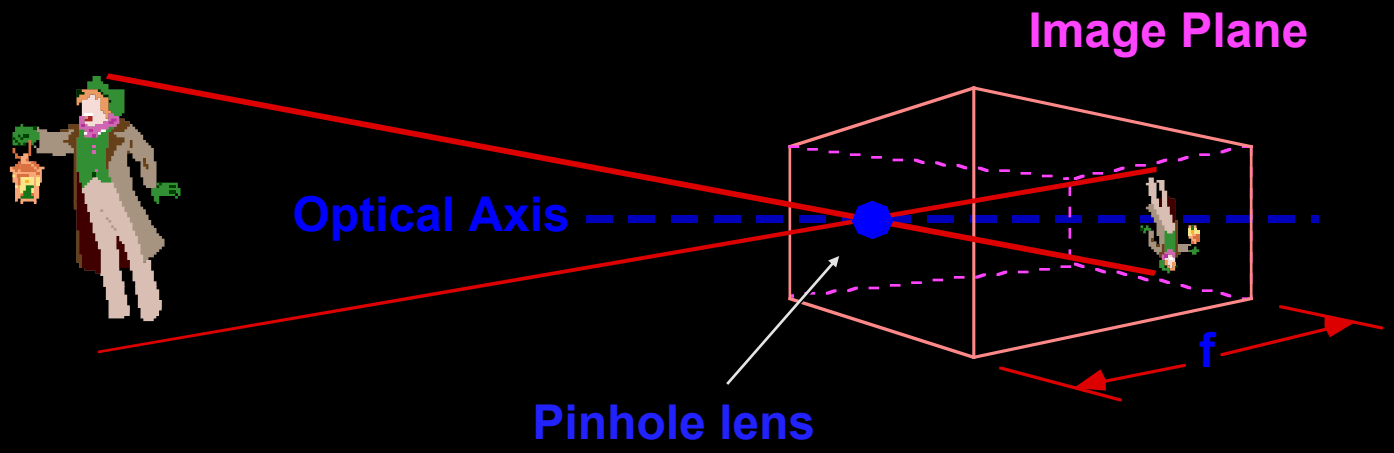
Today

- Optics:
  - Pinhole
  - Lenses
- Artificial sensors
  - 1 sensor array vs. 3 sensor arrays
  - Bayer patterns

Basic Optics

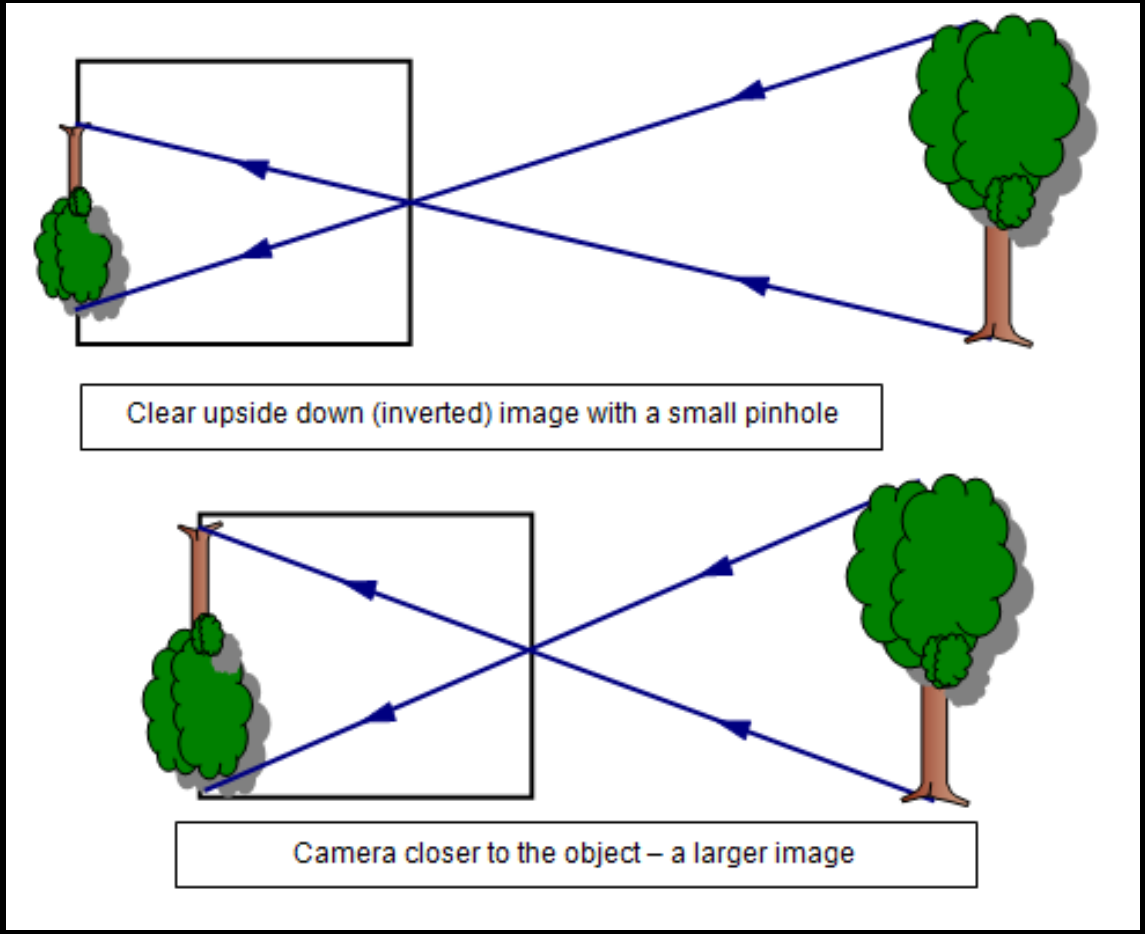
- Two models are commonly used:
  - Pin-hole camera
  - Optical system composed of lenses
- Pin-hole is the basis for most graphics and vision
  - Derived from physical construction of early cameras
  - Mathematics is very straightforward
- Thin lens model is first of the lens models
  - Mathematical model for a physical lens
  - Lens gathers light over area and focuses on image plane.

Pinhole Camera Model



- World projected to 2D Image
  - Image inverted
  - Size reduced
  - Image is dim
  - No direct depth information
- f called the focal length of the lens
- Known as perspective projection

Pinhole images



http://www.schoolphysics.co.uk/age11-14/Light/text/Pinhole_camera/index.html

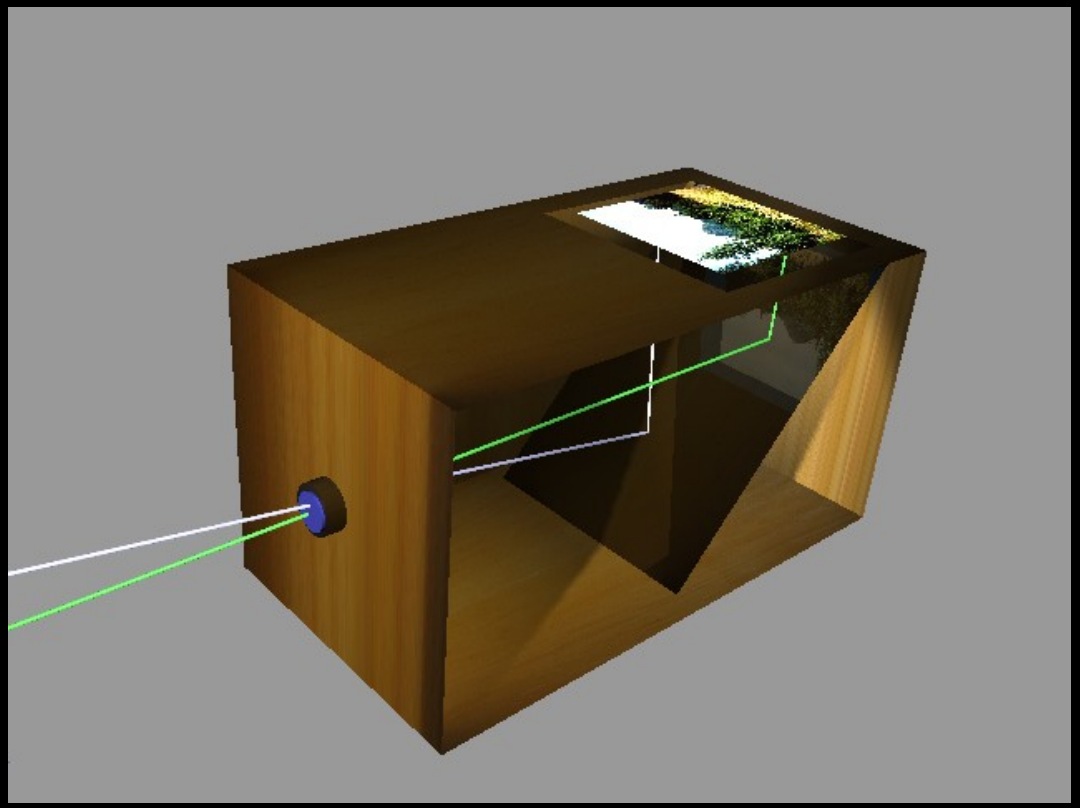
Introduction to Computer Vision

- Imagine being inside a pinhole camera....

Mike's Maze Camera Obscura

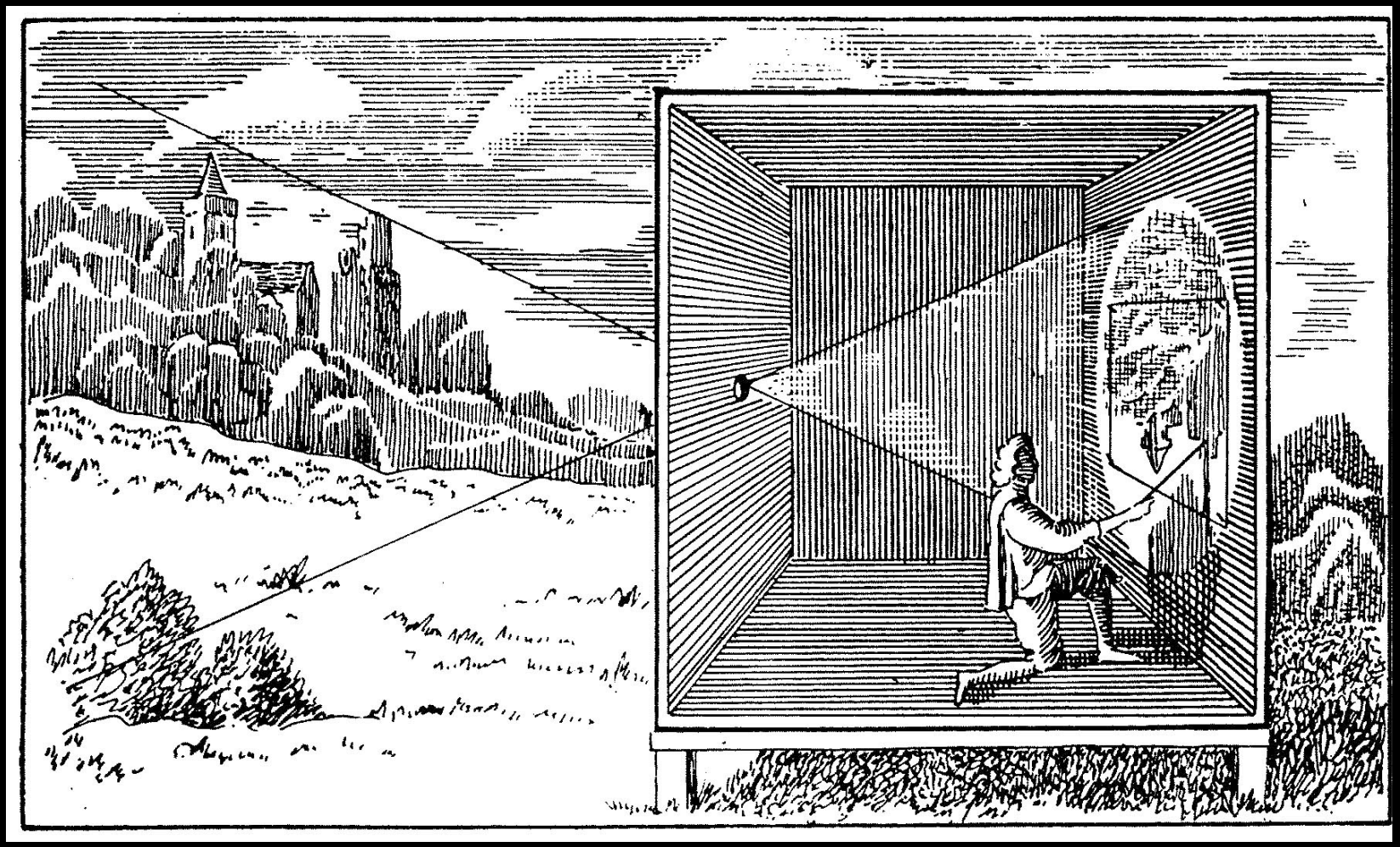
Camera Obscura

Camera Obscura



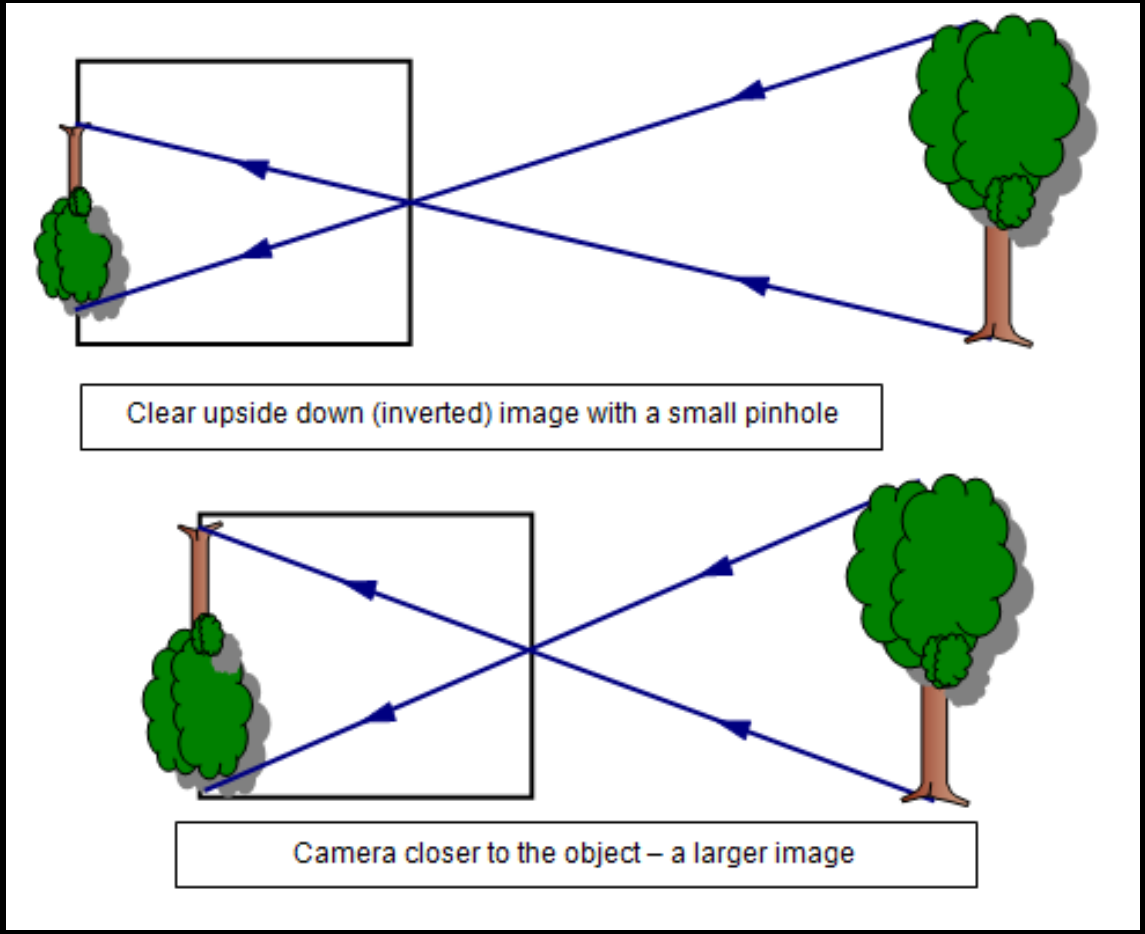
- http://upload.wikimedia.org/wikipedia/commons/2/26/Camera_obscura_box.jpg

Camera Obscuras in art



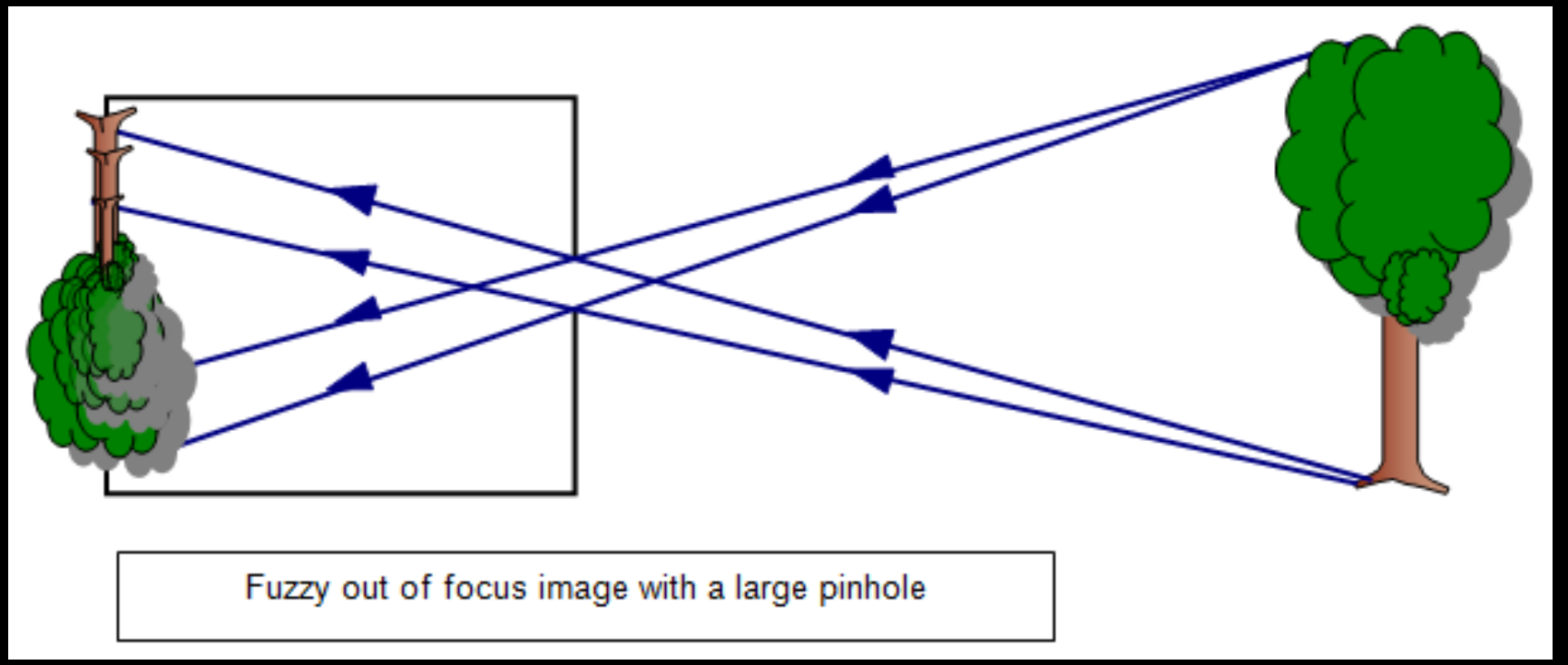
http://1stpersontech.wordpress.com/2012/03/10/shooting-formats-0-1-camera-obscura/

Pinhole images



http://www.schoolphysics.co.uk/age11-14/Light/text/Pinhole_camera/index.html

Fuzzy pinhole camera



Fuzzy out of focus image with a large pinhole

http://www.schoolphysics.co.uk/age11-14/Light/text/Pinhole_camera/index.html

Introduction to
Computer Vision

Matlab demo

Pinhole camera image

Amsterdam

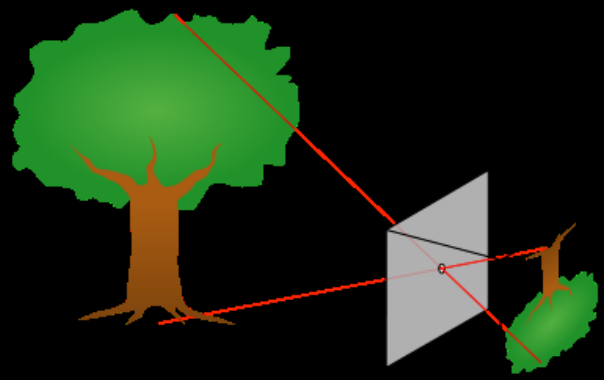
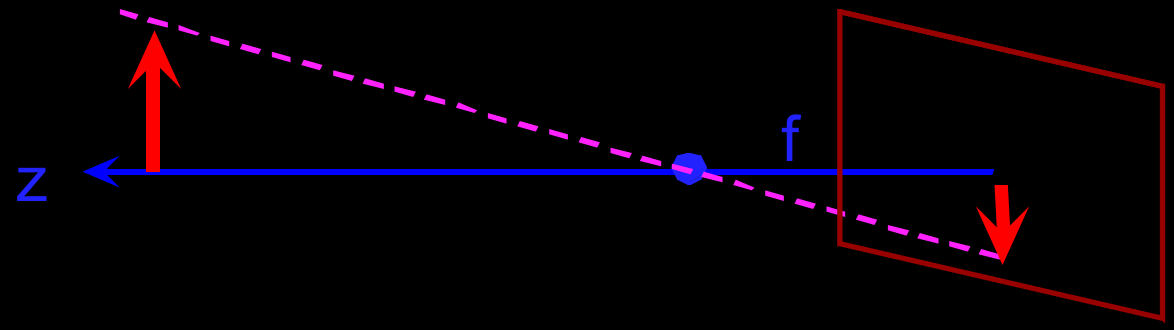


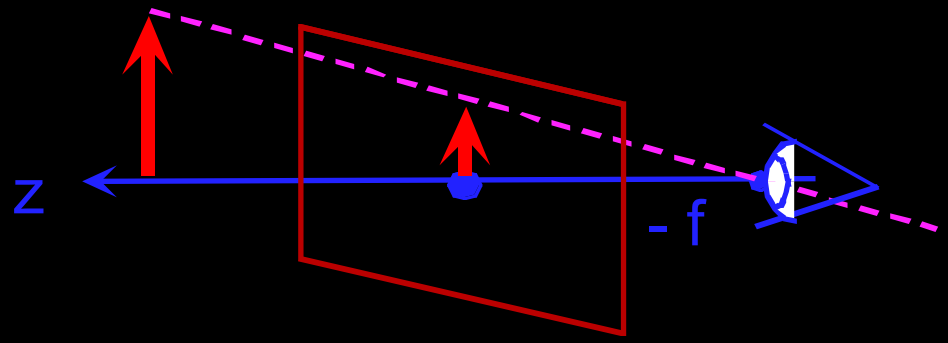
Photo by Robert Kosara, robert@kosara.net
http://www.kosara.net/gallery/pinholeamsterdam/pic01.html

Equivalent Geometry

- Consider case with object on the optical axis:



- More convenient with upright image:

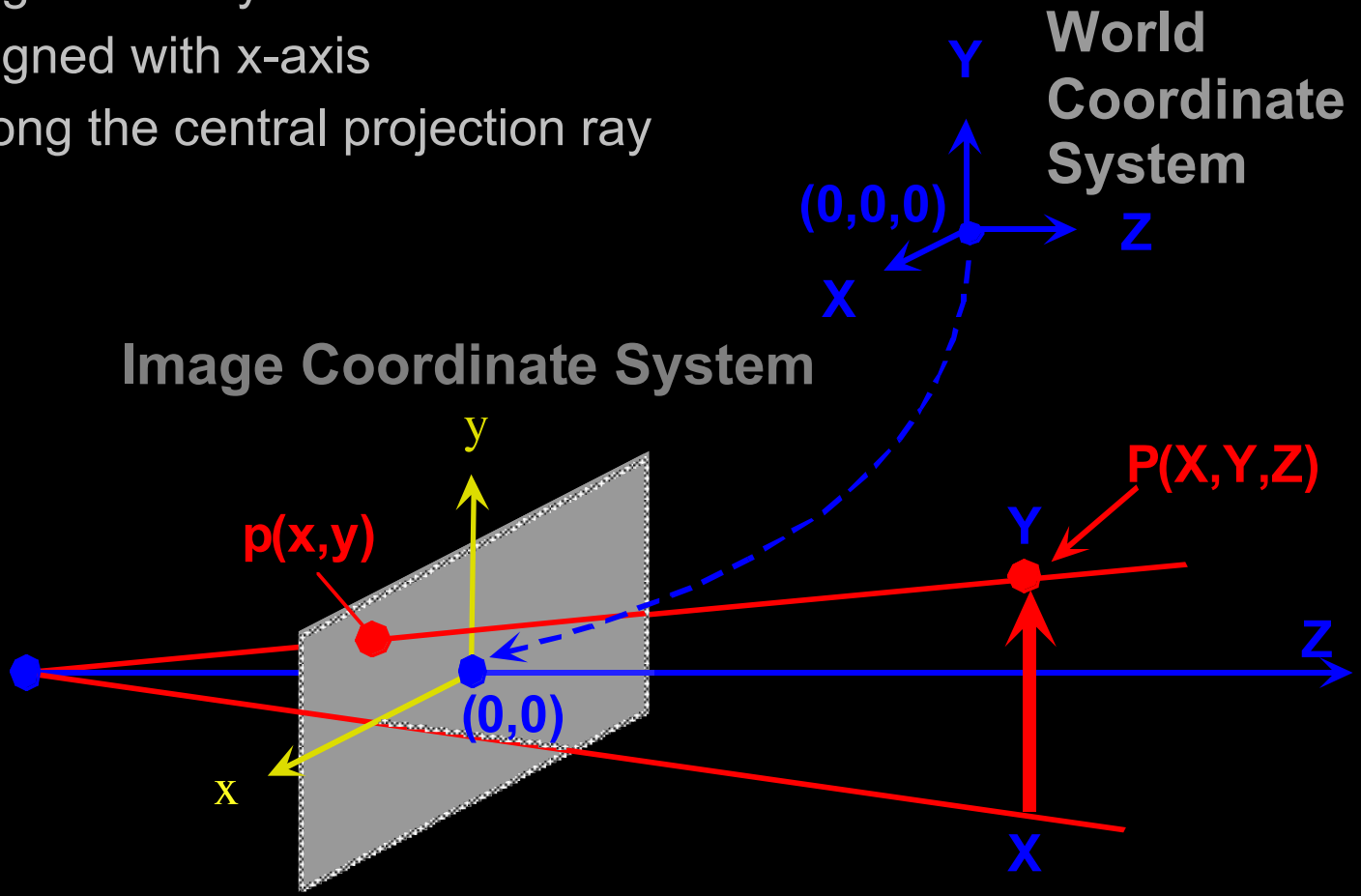


Projection plane z = 0

- Equivalent mathematically

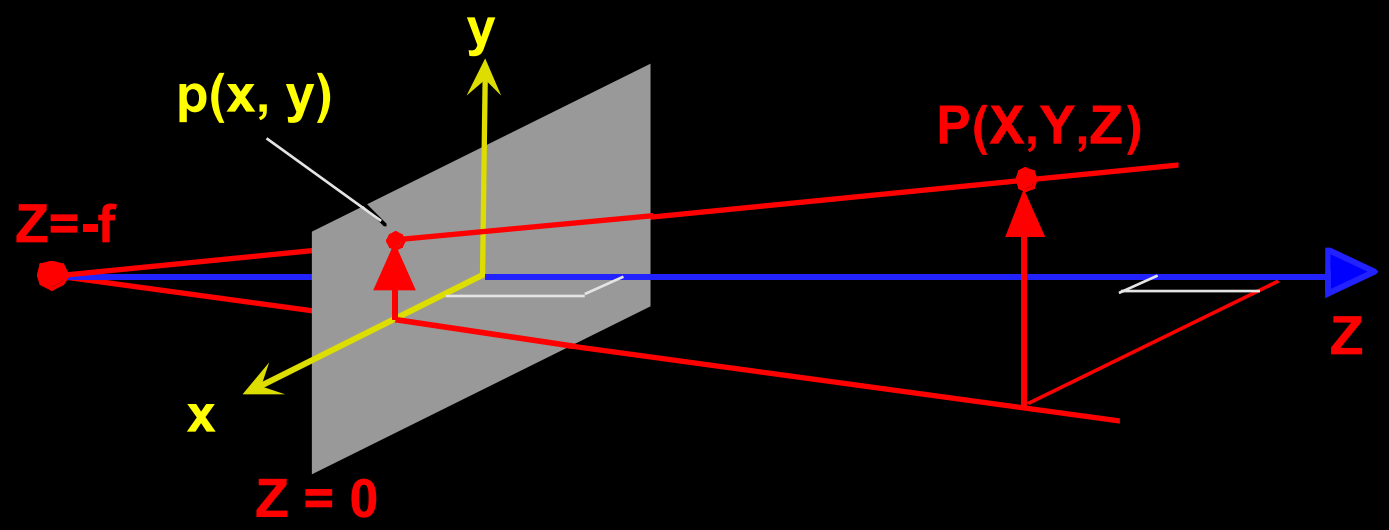
Coordinate System

- Simplified Case:
  - Origin of world and image coordinate systems coincide
  - Y-axis aligned with y-axis
  - X-axis aligned with x-axis
  - Z-axis along the central projection ray



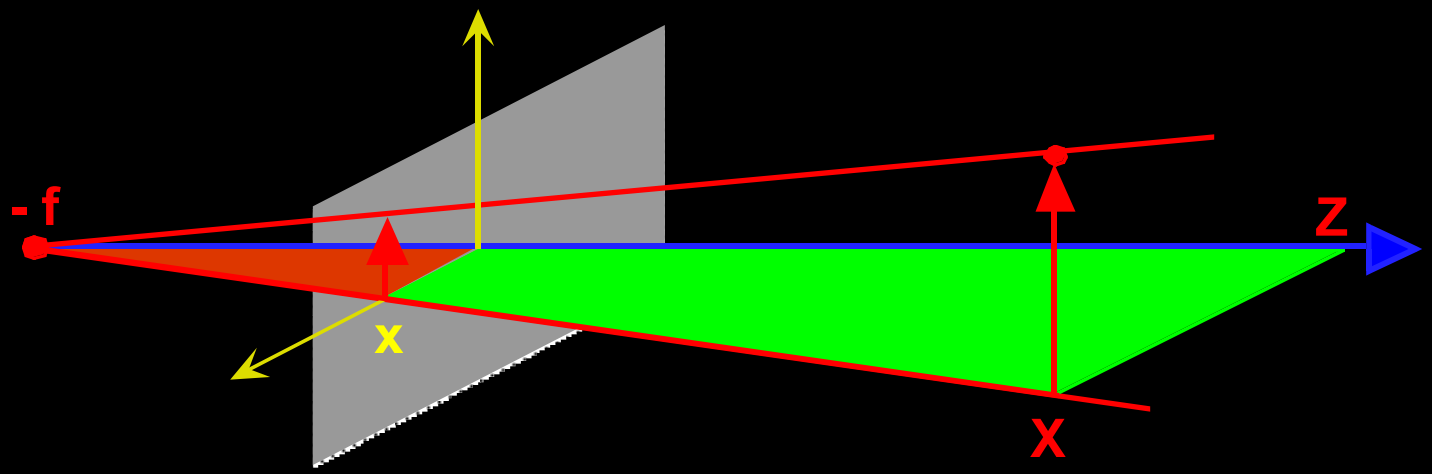
Perspective Projection

- Compute the image coordinates of p in terms of the world coordinates of P.



- Look at projections in x-z and y-z planes

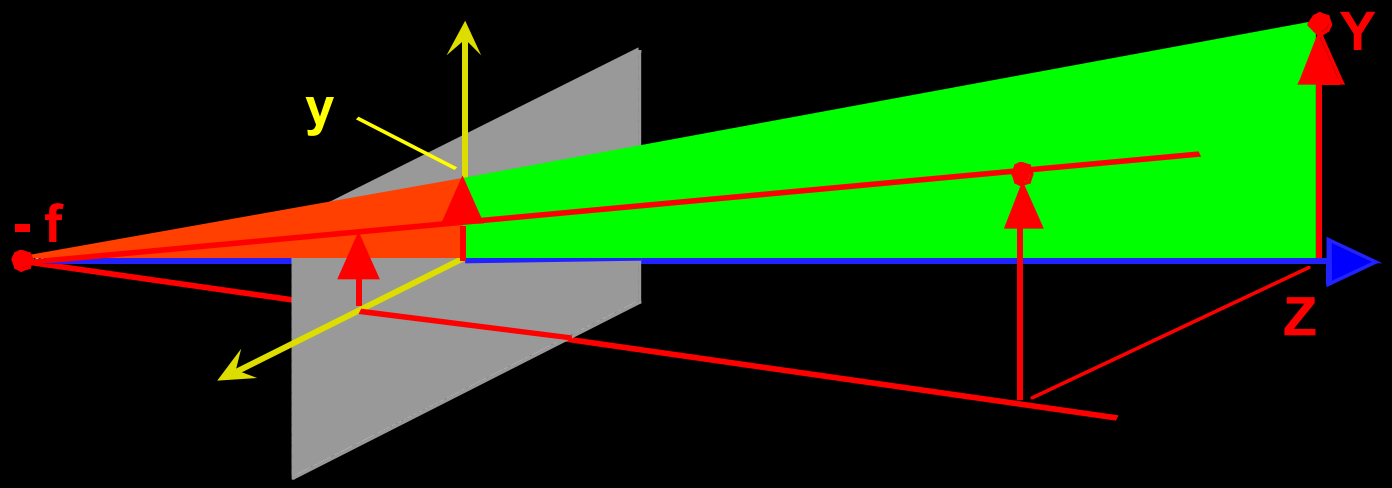
X-Z Projection



- By similar triangles: $\frac{x}{f} = \frac{X}{Z+f}$

$$x = \frac{fX}{Z+f}$$

Y-Z Projection



- By similar triangles: $\frac{y}{f} = \frac{Y}{Z+f}$

$$y = \frac{fY}{Z+f}$$

Perspective Equations

- Given point P(X,Y,Z) in the 3D world
- The two equations:

$$x = \frac{fX}{Z+f} \qquad y = \frac{fY}{Z+f}$$

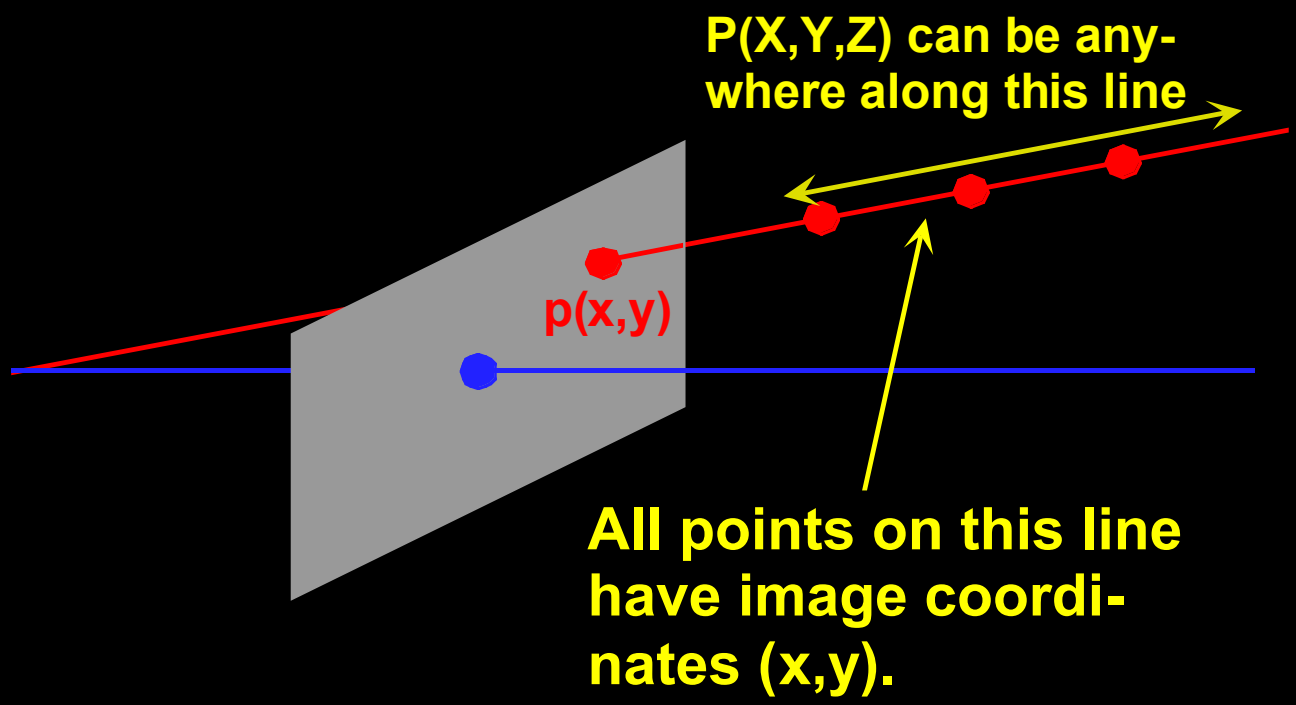
- transform world coordinates (X,Y,Z)
  into image coordinates (x,y)

Practice Problem

- How tall will an object be in a pinhole camera?

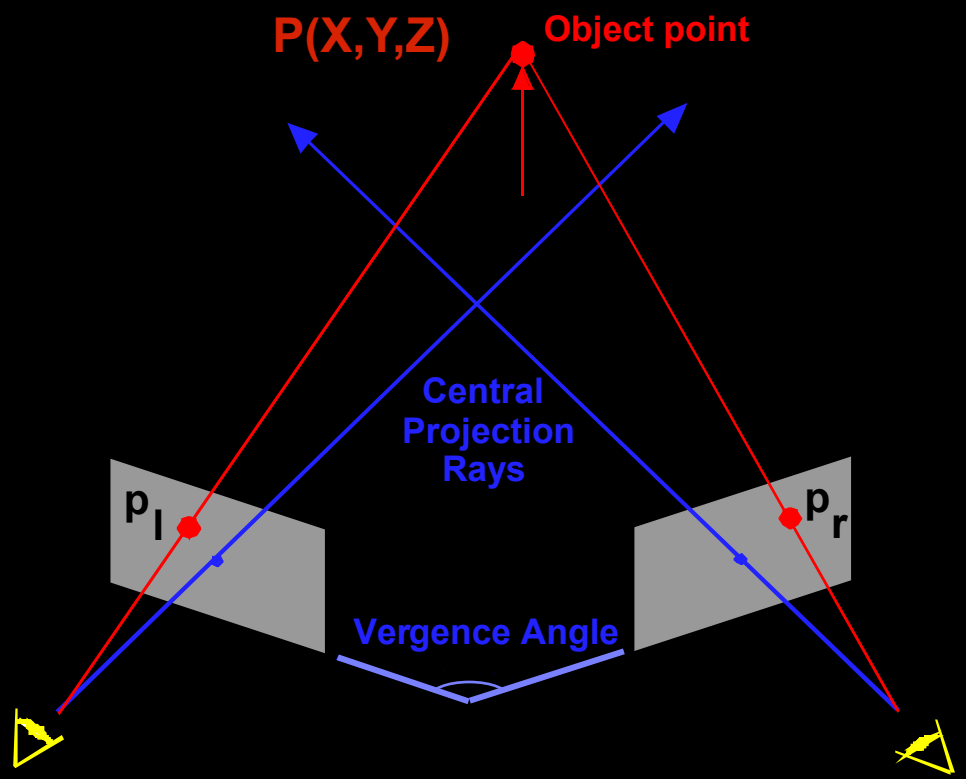
Reverse Projection

- Given a center of projection and image coordinates of a point, it is not possible to recover the 3D depth of the point from a single image.



In general, at least two images of the same point taken from two different locations are required to recover depth.

Stereo Geometry



- Depth obtained by triangulation
- Correspondence problem: p_l and p_r must correspond to the left and right projections of P, respectively.

Variability in appearance

- Consequences of image formation geometry for computer vision
  - What set of shapes can an object take on?
    - rigid
    - non-rigid
    - planar
    - non-planar
  - SIFT features
- Sensitivity to errors.

Lenses

- How can we improve on pinhole cameras?
- What are their problems?
- What are their advantages?

Lenses

- How can we improve on pinhole cameras?
- What are their problems?
  - Not enough light to stimulate receptors.
- What are their advantages?
  - Everything is in focus.

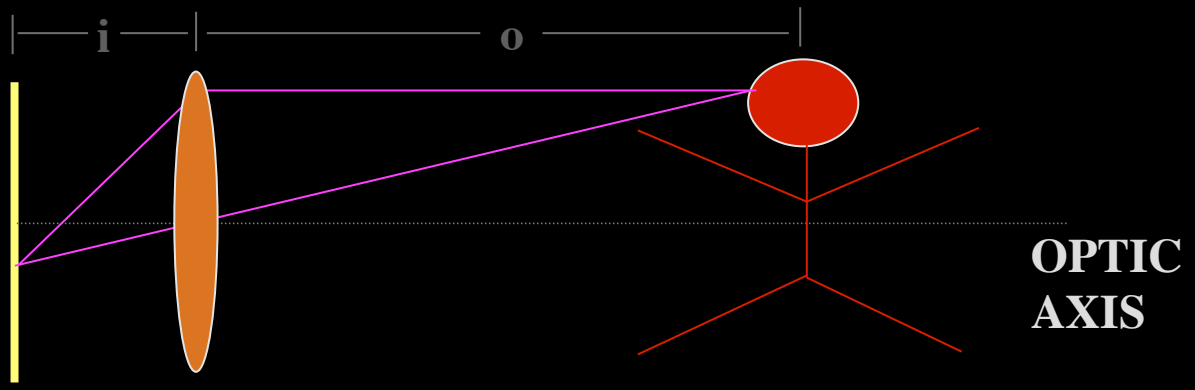
Lenses

- Allow the collection of much greater amount of light.
  - In general, proportion to the cross section of the lens area.
    - Why not just make the pinhole bigger?
- Much choose a focal distance. Not everything can be in focus.

Thin Lens Model

- Rays entering parallel on one side converge at focal point.
- Rays diverging from the focal point become parallel.

PARALLEL RAYS converge at f.



NON-PARALLEL RAYS converge at i.

OPTIC AXIS

IMAGE PLANE

LENS

$$\frac{1}{f} = \frac{1}{i} + \frac{1}{o}$$ **'THIN LENS LAW'**

Lenses: practice

- Calculate “i” for objects at a certain distance.
- How much faster can we take a picture with a lens of diameter 2cm compared to a 1mm pinhole?