Today’s Agenda

Image Formation

Image Formation at a Glance

Exposure

Reflection

Illumination

This is light transport.

Illumination is generated at light sources, propagates thru world.

Interacts with objects in scene.

Elements of image formation:

- Illumination sources
- Objects
- Viewer (e.g., camera and eye)
- Attributes of materials

Absorption

The Response of Cones to Color

Three kinds of cones: S, L, and M

- S cones respond to blue
- M cones respond to green
- L cones respond to red

Response levels to illumination are

$$s = \int S(\lambda)P(\lambda)d\lambda$$

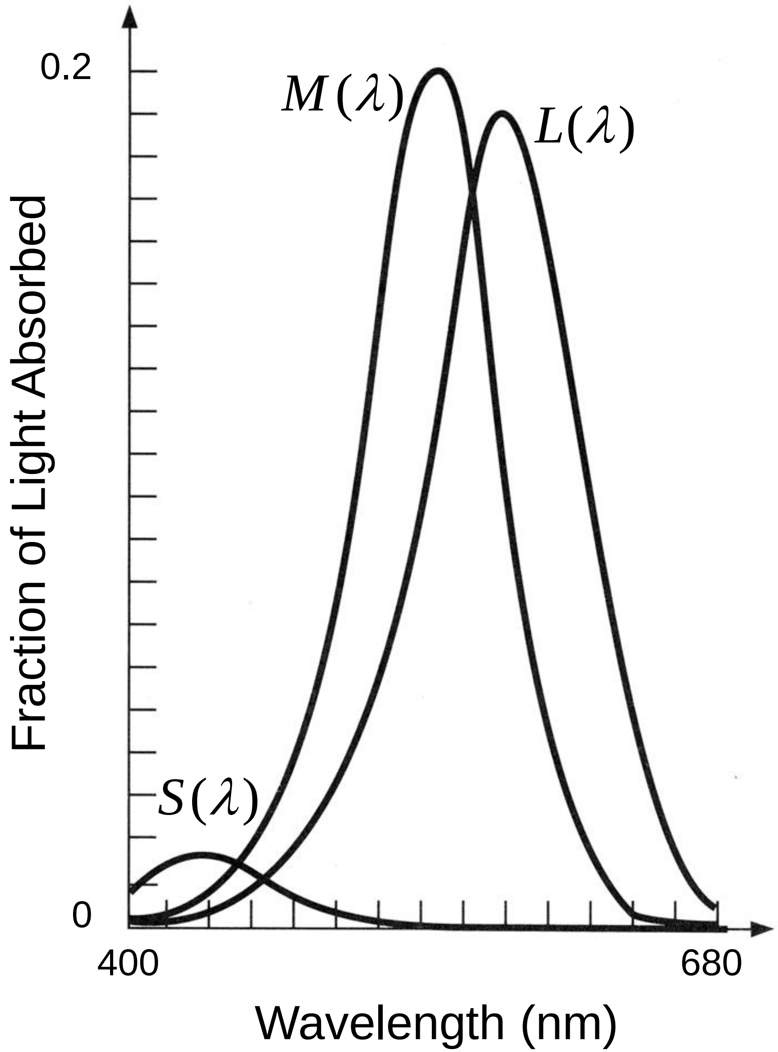
$$m = \int M(\lambda)P(\lambda)d\lambda$$

$$l = \int L(\lambda)P(\lambda)d\lambda$$

- where s, m, l are scalars
- this implies that we humans perceive light as a 3-D space

And this 3D space is very complex

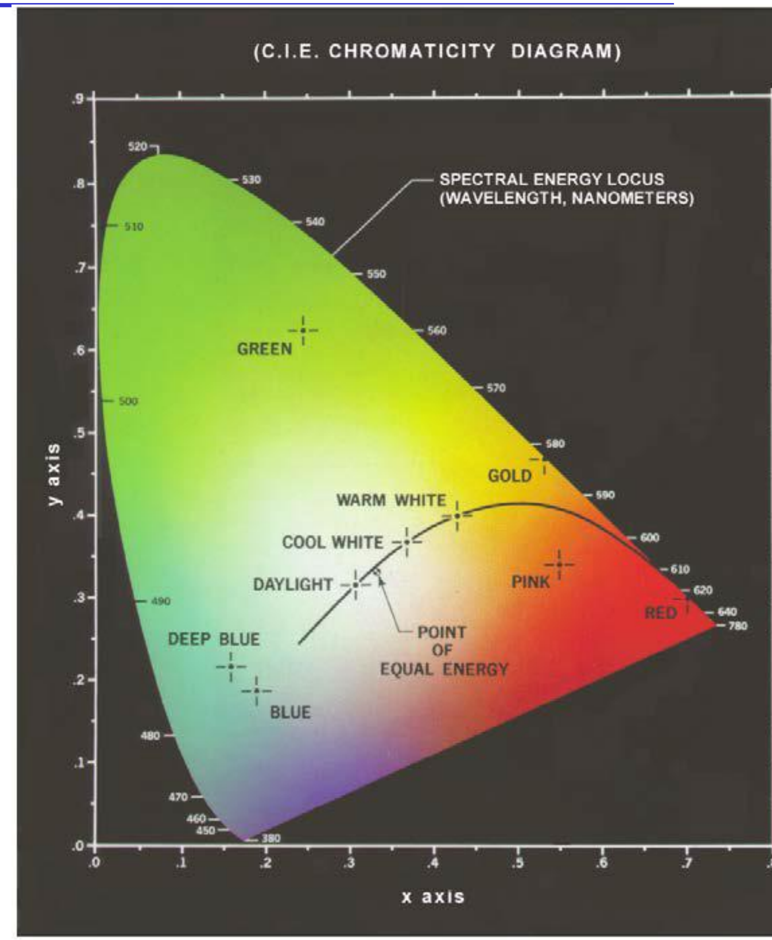
- for instance, it's not Euclidean



Humans Perceive a 3D Color Space

We can't distinguish all distributions

- metamers: two colors with different spectral distributions but identical s, m, l values
- these would look identical

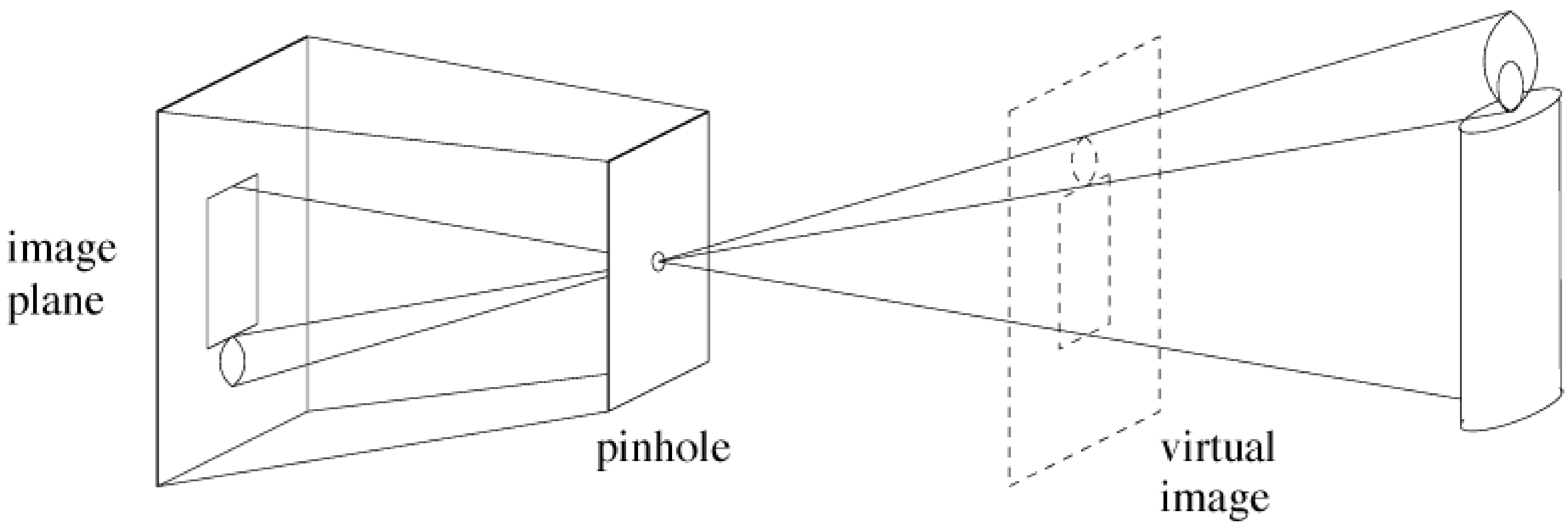


The Simplest Camera: Pinhole Camera

Mount a piece of film in a lightproof box with a single pinhole in it

Pinhole focuses light on the film

- Lens degenerates to a point – no distortion
- One-to-one correspondence between 3D object point and 2D image point
- only select light ray can go through the hole (the hole is reduced to a point)
- note that image on film is flipped upside down

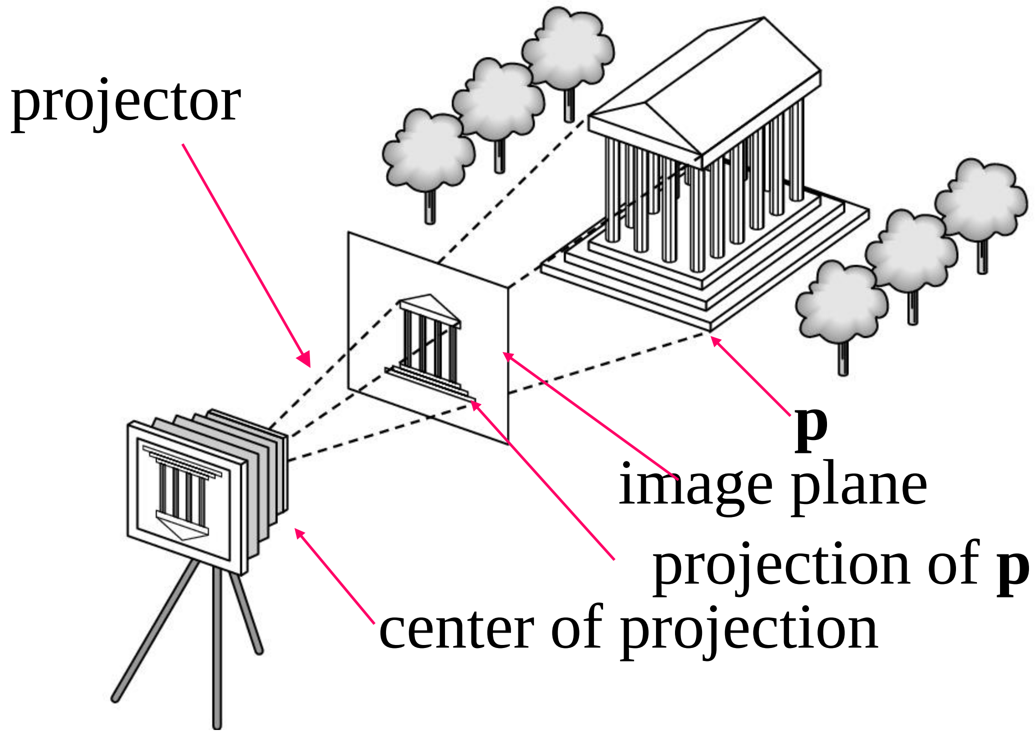


Picture Taken by Pinhole Camera

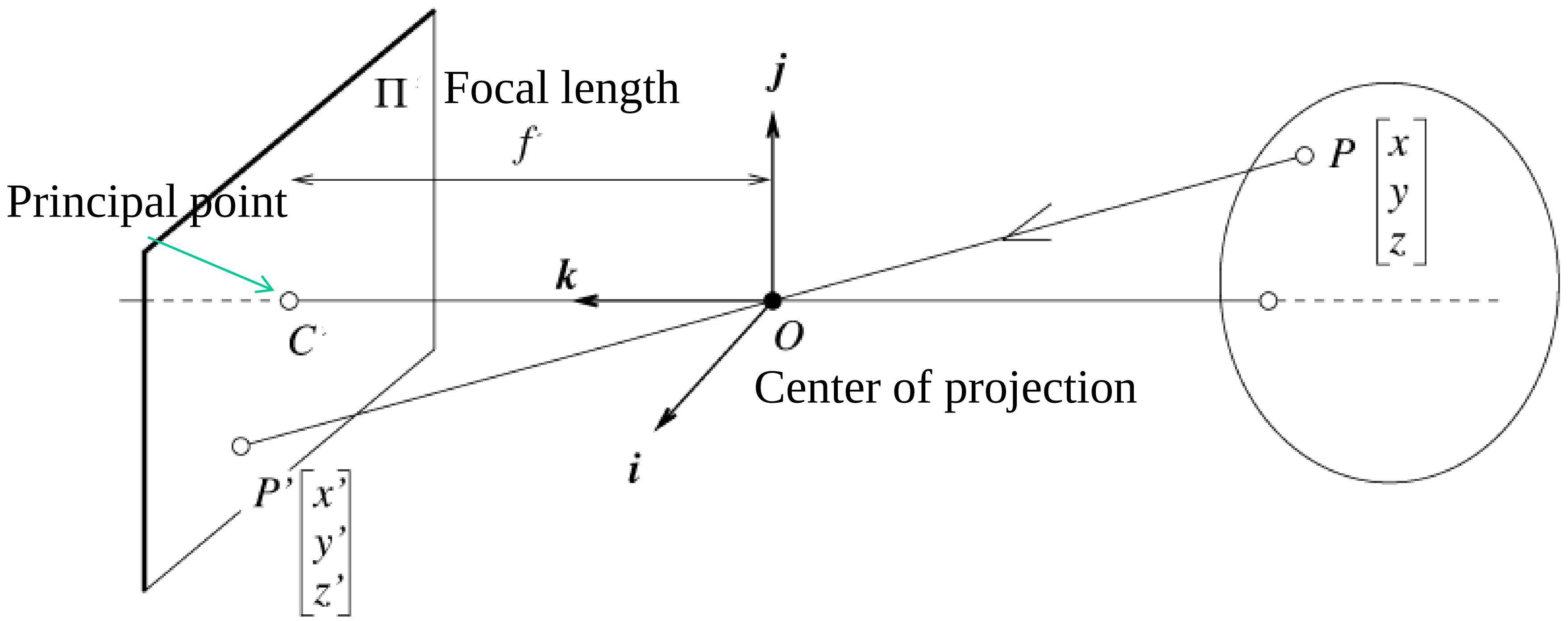
How to make pinhole camera?

- http://www.exploratorium.edu/light_walk/camera_todo.html

Synthetic Camera Model



The Equation of Projection



Only one coordinate system – camera coordinate system

The Equation of Perspective Projection

Cartesian coordinates:

- We have, by similar triangles, that

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

- Ignore the third coordinate, and assume the image plane is before the camera, we get

$$(x, y, z) \rightarrow (u, v) = (\frac{f}{z}x, \boxed{\frac{f}{z}}y)$$

Isotropic scaling

3D object point → 2D image point

The perspective projection is non-linear!

Properties of Perspective Projection

Points project to points

Lines project to lines

Planes project to the whole or half image

- A plane may only has half of its area in the projection side

Scaling and foreshortening

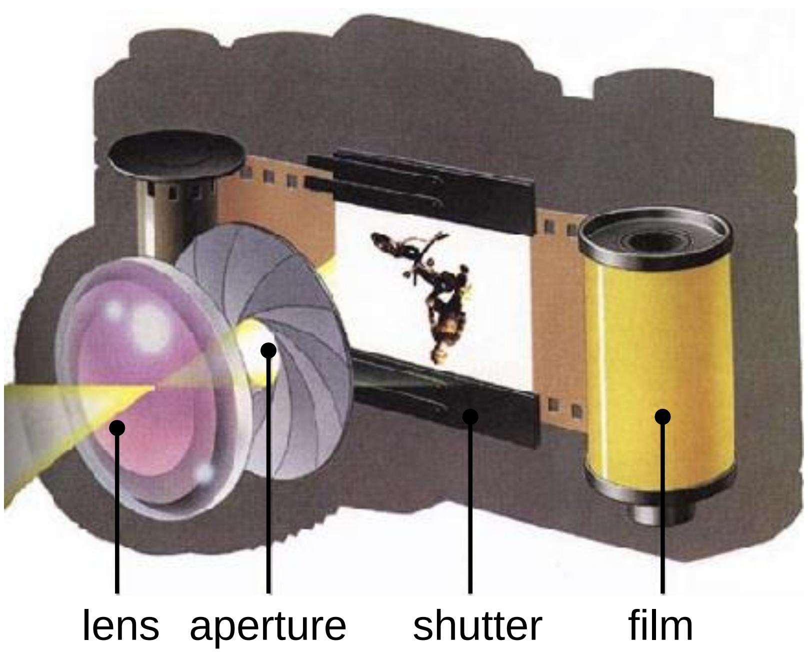
Angles are not preserved

- Parallel lines may be not projected to parallel lines unless they are parallel to the image plane

Degenerate cases

- Line through focal point projects to a point.
- Plane through focal point projects to line

The Structure of a Typical Camera



Film is light sensitive material

Lens focuses light on film

Aperture is the opening of lens
- opening may vary in size
- controls the total energy of incoming lights

Shutter restricts access to film
- can open for variable periods
- controls total energy that hits the film

Film is replaced by Charged Couple Device (CCD) in a digital camera

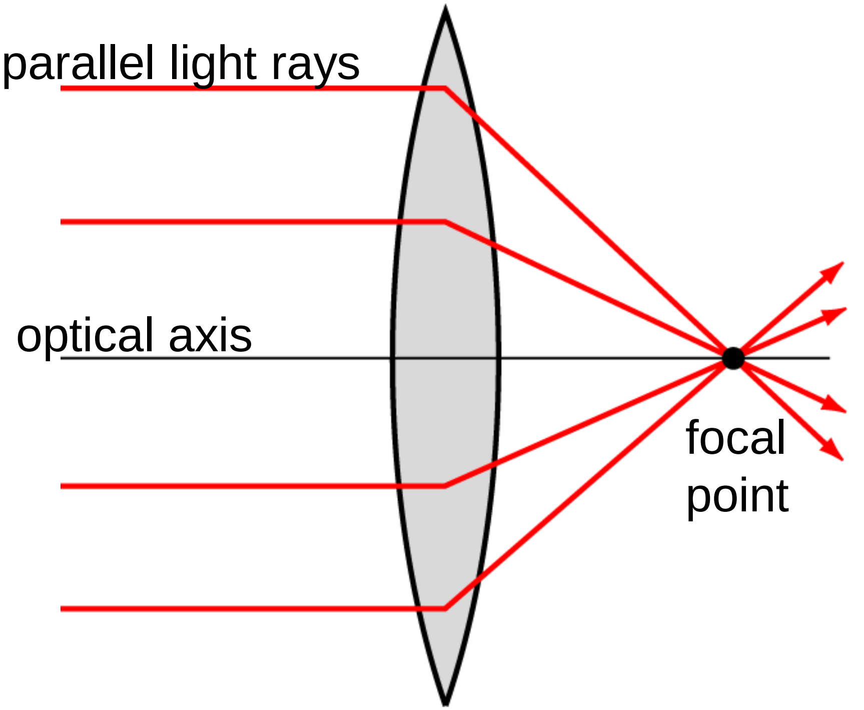
Refractive Lenses

Refraction happens when light rays travel between materials

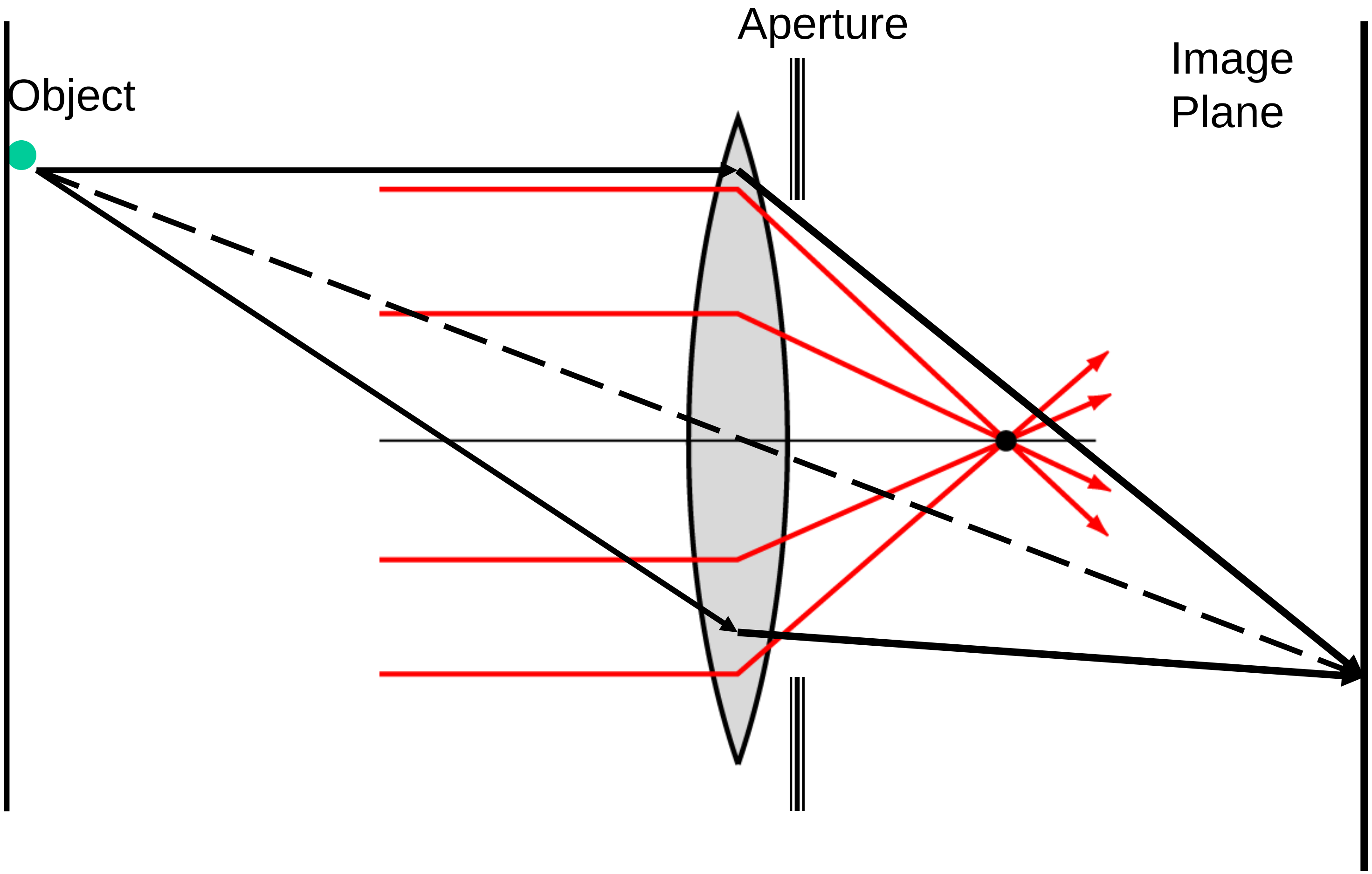
- results from dependence of the speed of light on the material

Real cameras use refractive lenses

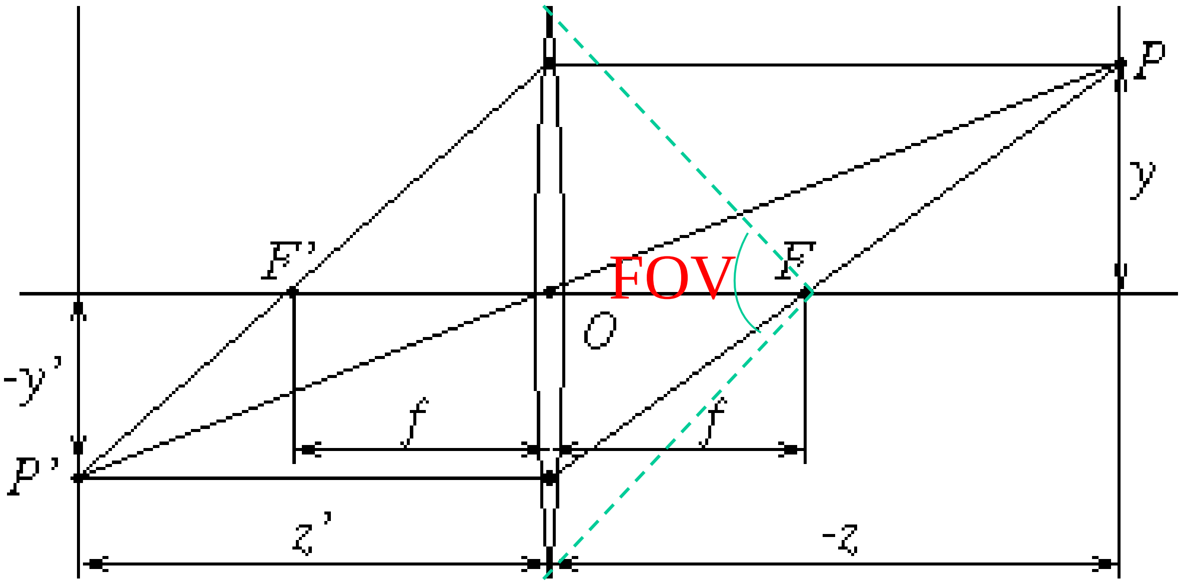
- typically made of glass or plastic
- bend incoming light rays
- parallel incoming rays converge on the focal point



Refractive Lenses



Basic Optics: Thin Lens



$$\text{Field of View:}\,\omega = 2arctan\frac{d}{f}$$

Depth of view (DOF) is inversely proportional to the focus length (f) and inversely proportional to the aperture (d)

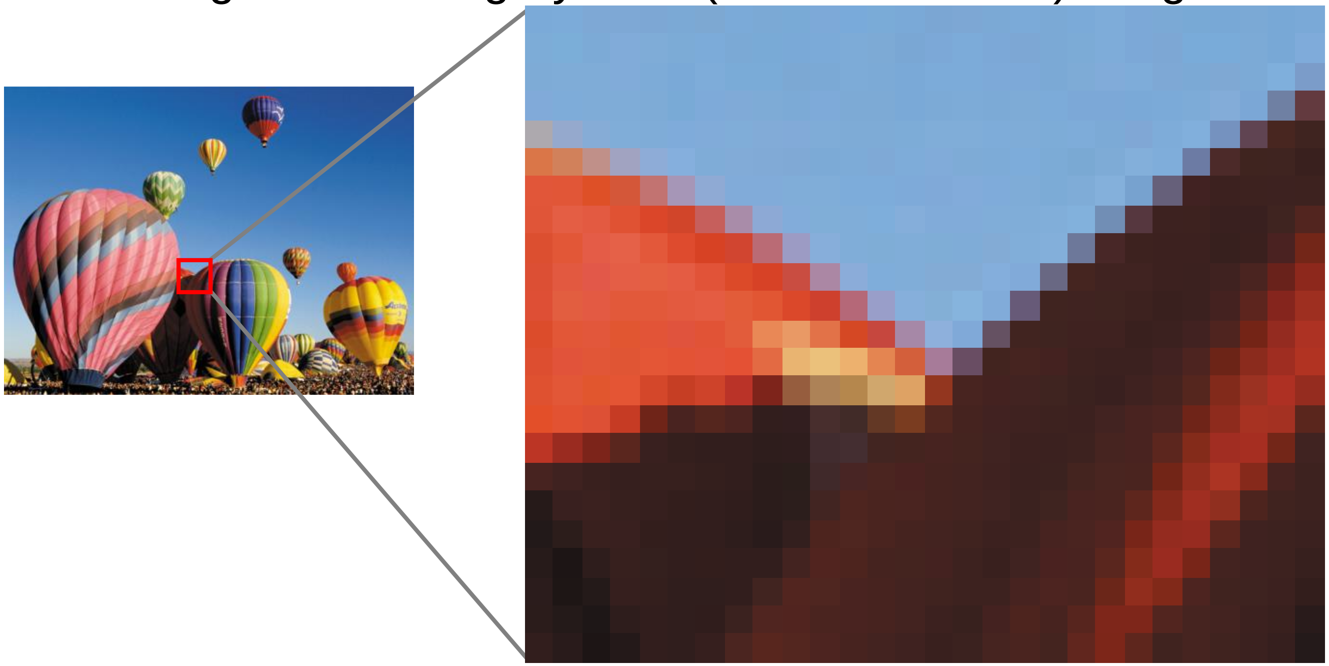
Raster Image Representation

Continuous representation needs to be sampled and quantized to generate a discrete representation

Each image is represented by a rectangular grid of pixels $P[x,y]$

each pixel p will store a color value

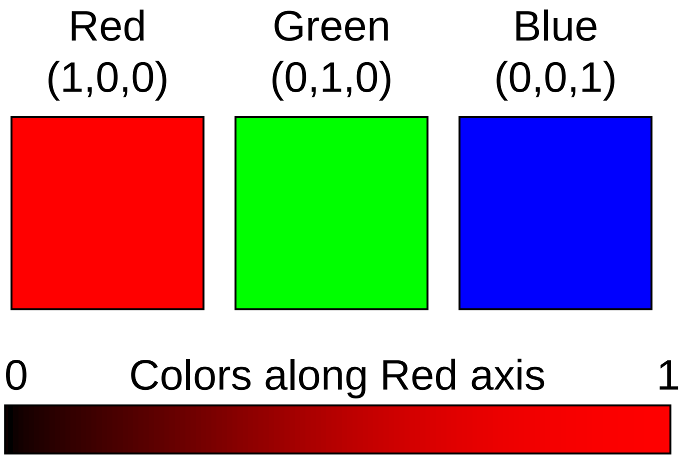
- RGB triple for color images
- single value for grayscale (or monochrome) images

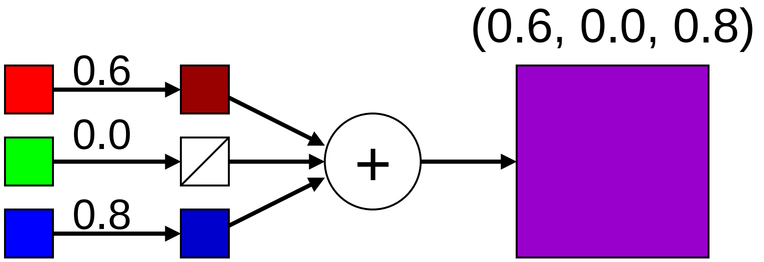


Basic Color Representation in Graphics

For each pixel, we will treat colors as a 3-D space of (r, g, b) triples

- all colors will be composed from three primary colors: red, green, blue
- the value of each (r, g, b) is between 0 and 1
- coefficients represent relative contribution of each primary





Raster Image Representation

Can separate RGB color image into 3 distinct color channels

- each by itself is a monochrome image

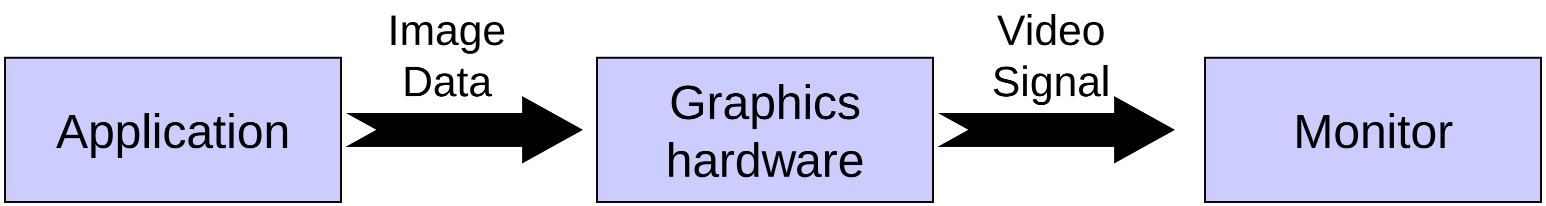
Question

What are those colors?

(r g b) = (0 0 0)

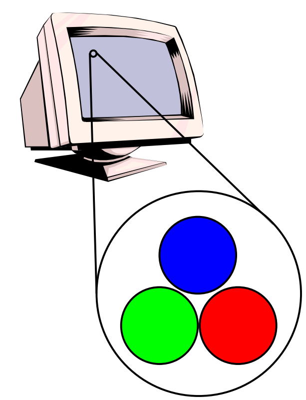
(r g b) = (1 1 1)

Generic Raster Display Systems



Graphics hardware maintains a 2-D array of pixels: the frame buffer

- values in the frame buffer control intensity of electron beams in CRT
- raster scan process is typically performed at 60–100 Hz

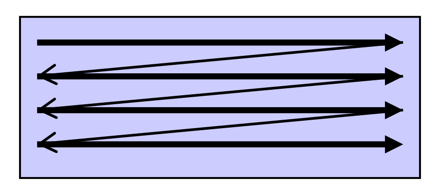


Frame buffers are characterized by

- resolution: dimensions in pixels (eg. 1024 x 768)
- bit depth: # of bits per pixel (typically 8–24)

Color image and gray-scale image

- r=g=b → gray-scale image
- pixel intensity is used instead of RGB channels



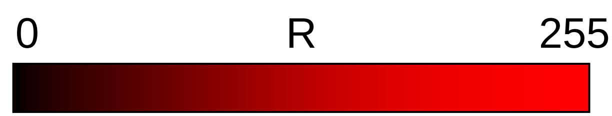
Full-Color Displays

Each pixel contains 3 values, one for each of R, G, and B

- typically 24 bits/pixel = 8 bits/channel = values of 0–255
- integer values 0–255 correspond to floating points values **0–1**
- integers are just more convenient in hardware implementation

Pixel values directly control intensity of electron beams

- R=0 implies red beam is off
- R=255 implies red beam at full intensity



24 bits/pixel generally considered "full-color"

- produces $2^{24} \approx$ 16 million different colors
- high-end systems might support 36 bits/pixel or more

Color Display Via Lookup Tables

Alternative to direct RGB values

- single value per pixel
- typically 8 or 16 bits
- pixel value is an index into a color lookup table or palette

Common when memory is scarce

- can customize set of colors to image being displayed
  - 256 colors of your choice

Also supports some handy tricks

- can recolor entire image just by changing palette
- animating palette creates interesting effects (eg. glowing)

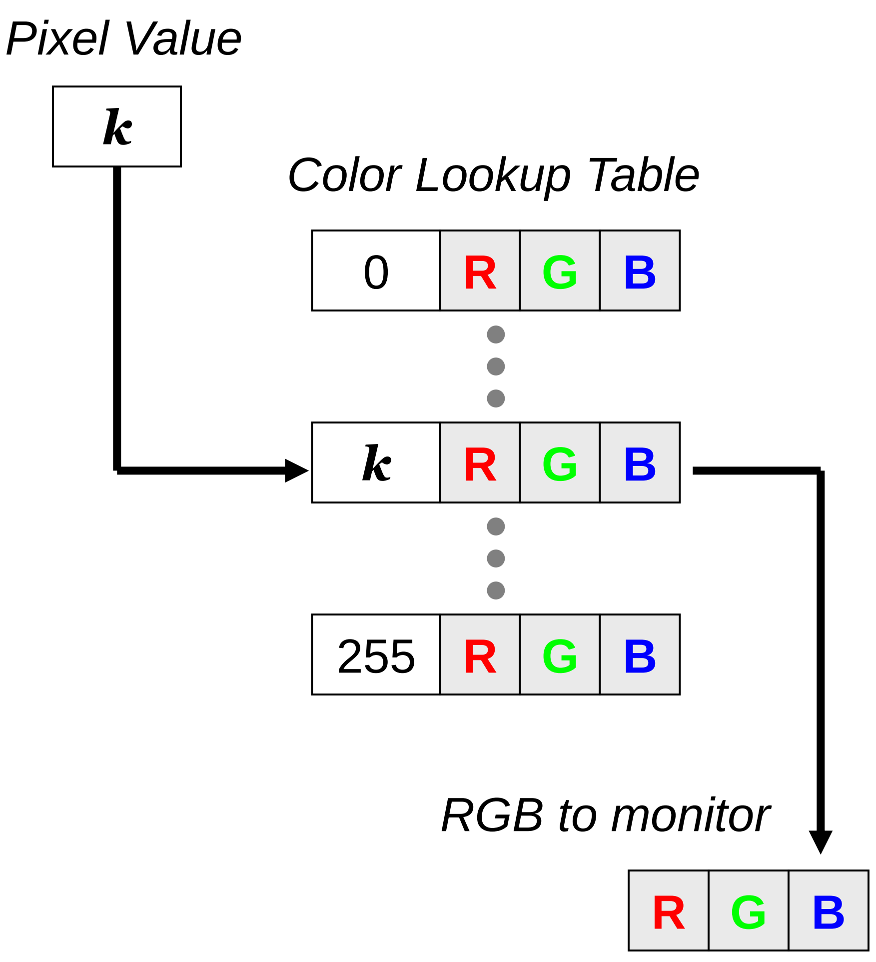
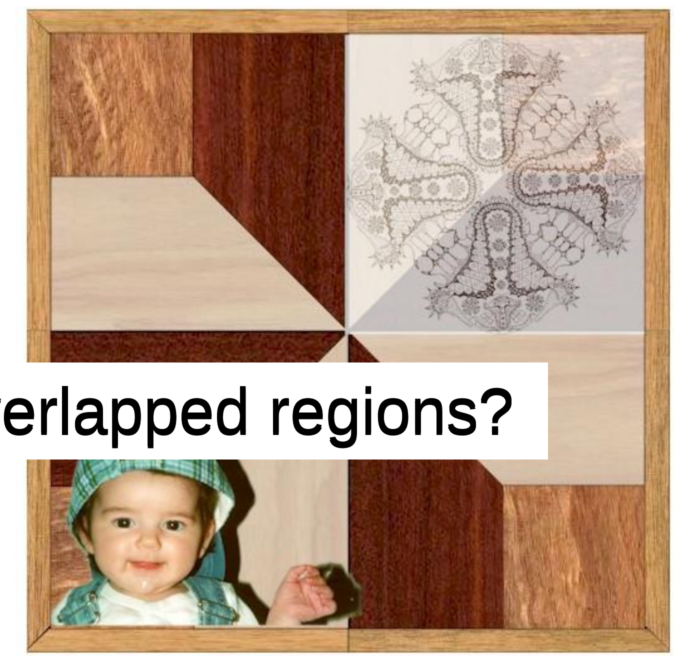


Image Compositing

Often want to combine a sequence of images together

- different parts of final image can come from different sources
- TV stations have been doing this for a long time



Question: how to handle the overlapped regions?

Image Compositing

Introduce a new alpha channel in addition to RGB channels

- the α value of a pixel indicates its transparency
  - if $\alpha=0$, pixel is totally transparent
  - if $\alpha=1$, pixel is totally opaque
- alternatively, can think of α as the fraction of the pixel actually covered by the stored color
- convenient to work with premultiplied colors

$$P = \begin{bmatrix} r_p \\ g_p \\ b_p \\ \alpha_p \end{bmatrix} \Longrightarrow P' = \begin{bmatrix} \alpha_p r_p \\ \alpha_p g_p \\ \alpha_p b_p \\ \alpha_p \end{bmatrix}$$

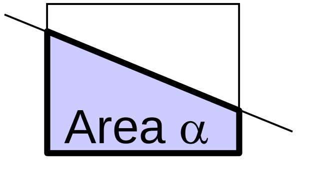


Image Compositing

Compositing one image over another is most common choice

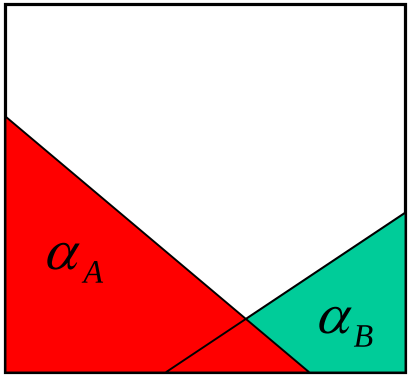
- can think of each image drawn on a transparent plastic sheet
- the final image is formed by stacking layers together

Given images $\boldsymbol{A}$ & $\boldsymbol{B}$, we can compute $\boldsymbol{C} = \boldsymbol{A}$ over $\boldsymbol{B}$

$$C_{rgb} = \alpha_A A_{rgb} + (1 - \alpha_A)\alpha_B B_{rgb}$$

- if we pre-multiply α values, this simplifies to

$$C' = A' + (1 - \alpha_A)B'$$



This is only one possible compositing operator

- there are in fact 12 possible ways of combining 2 images

Example: Image Compositing

Read RGBα values from frame buffer

Given RGB colors $A = (0.8, 0.6, 1.0)$ and $B = (1,1,1)$; $\alpha_A = 0.5$; $\alpha_B = 0.2$

Premultiply: $A' = \alpha_A A = (0.4, 0.3, 0.5)$ $B' = \alpha_B B = (0.2, 0.2, 0.2)$

$$C' = A' + (1 - \alpha_A)B' = \begin{bmatrix} 0.5 \\ 0.4 \\ 0.6 \\ 0.6 \end{bmatrix} \qquad \alpha_C = 0.6$$

De-premultiply: $C = C' / \alpha_C = (0.83, 0.67, 1.0)$

Write C (RGBα values) back into frame buffer

Next Time: Basic Geometric Primitives

We'll look at the simplest tools for representing geometry

- lines, planes, triangles, and polygons

We'll also look at some OpenGL basics

- this will help you with your projects

Reading Assignment

Chapter 1 of Angel