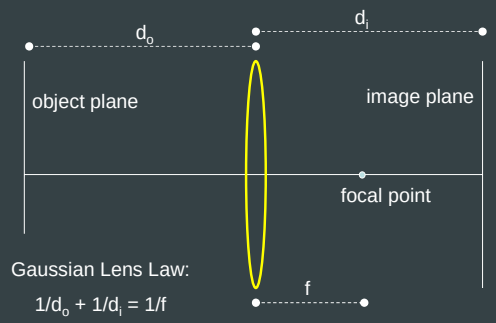
Cameras and their Problems

CS535

Daniel G. Aliaga

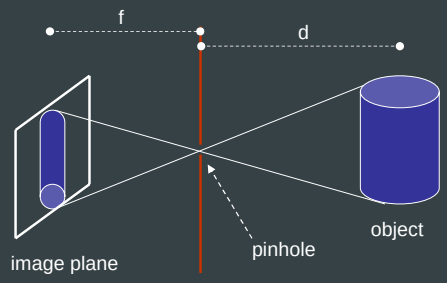
A Thin Lens System (Dioptric)



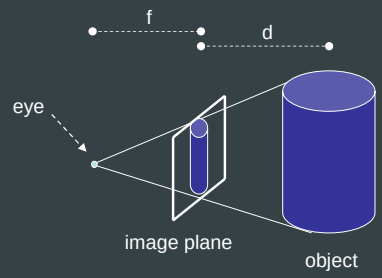
Gaussian Lens Law:

$1/d_o + 1/d_i = 1/f$

"Classic" Pinhole Camera



"Computer Graphics" Pinhole Camera



Aberrations

- A "real" lens system does not produce a perfect image
- Aberrations are caused by imperfect manufacturing and by our approximate models
  - Lenses typically have a spherical surface
    - Aspherical lenses would better compensate for refraction but are more difficult to manufacture
  - Typically 1st order approximations are used
    - Remember $\sin \Omega = \Omega - \Omega^3/3! + \Omega^5/5! - \ldots$
    - Thus, thin-lens equations only valid iff $\sin \Omega \approx \Omega$

Aberrations

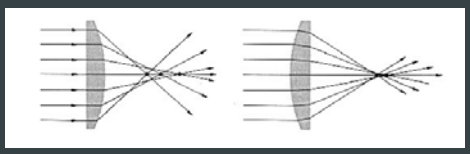
- Most common aberrations:
  - Spherical aberration
  - Coma
  - Astigmatism
  - Curvature of field
  - Chromatic aberration
  - Distortion

Spherical Aberration

- Deteriorates the axial-image

Spherical Aberration

- Deteriorates the axial-image

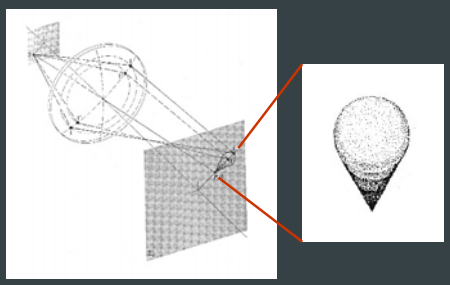


Coma

- Deteriorates off-axial bundles of rays

Coma

- Deteriorates off-axial bundles of rays

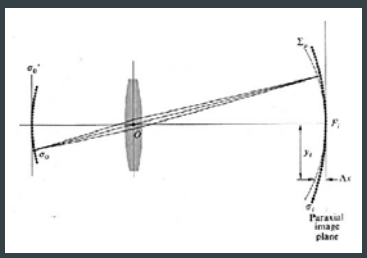


Astigmatism and Curvature of Field

- Produces multiple (two) images of a single object point

Astigmatism and Curvature of Field

- Produces multiple (two) images of a single object point



Chromatic Aberration

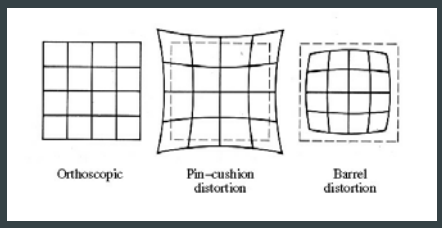
- Caused by wavelength dependent refraction
  - Apochromatic lenses (e.g., RGB) can help

Distortion

- Radial and tangential image distortions

Distortion

- Radial (and tangential) image distortions



Example radial distortions

Radial Distortion

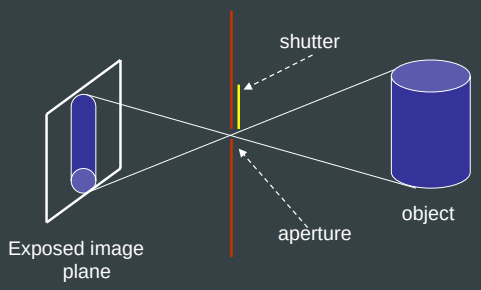
- (x, y) pixel before distortion correction
- (x', y') pixel after distortion correction
- Let $r = (x^2 + y^2)^{-1}$
- Then
  - $x' = x(1 - \Delta r/r)$
  - $y' = y(1 - \Delta r/r)$
  - where $\Delta r = k_0 r + k_1 r^3 + k_2 r^5 + \ldots$
- Finally,
  - $x' = x(1 - k_0 - k_1 r^2 - k_2 r^4 - \ldots)$
  - $y' = y(1 - k_0 - k_1 r^2 - k_2 r^4 - \ldots)$

Taking a picture…

Exposures

- An "exposure" is when the CCD is exposed to the scene, typically for a brief amount of time and with a particular set of camera parameters
- The characteristics of an "exposure" are determined by multiple factors, in particular:
  - Camera aperture
    - Determines amount of light that shines onto CCD
  - Camera shutter speed
    - Determines time during which aperture is "open" and light is shined onto CCD

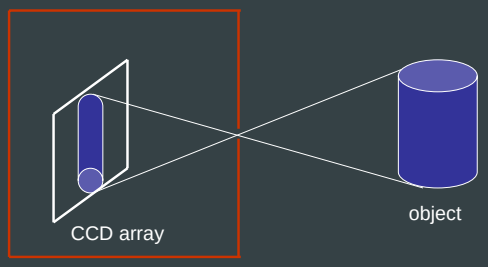
Exposures



Digital Camera vs. "Film" Camera

- Charge-Coupled Device (CCD)
  - Image plane is a CCD array instead of film
  - CCD arrays are typically ¼ or ½ inch in size
  - CCD arrays have a pixel resolution (e.g., 640x480, 1024x1024)
  - CCD Cameras have a maximum "frame rate", usually determined by the hardware and bandwidth
- Number of CCDs
  - 3: each CCD captures only R, G, or B wavelengths
  - 1: the single CCD captures RGB simultaneously, reducing the resolution by 1/3 (kinda)
- Video
  - Interlaced: only "half" of the horizontal lines of pixels are present in each frame
  - Progressive scan: each frame has a full-set of pixels

The simplest 1-CCD camera in town

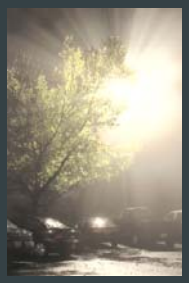


Dynamic Range

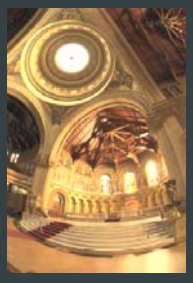
- The dynamic range of an image is the maximum difference between the darkest and brightest spot of an image
- Typical images have very limited dynamic range
  - A typical JPEG, TIFF, BMP image has 8 bits per color or a maximum dynamic range of 256 per color channel (256:1)
- The real-world has much higher dynamic range
  - A typical scene can have 100,000:1 dynamic range

Dynamic Range

- Example images



100,000:1



250,000:1

Dynamic Range

- To compensate for this, researchers either
  - Ignore the problem
  - Use more bits per color channel (the camera must support this!)
  - Use images with multiple exposures and combine them; the "combined image" can then by tone-mapped back to an 8-bit image

High Dynamic Range Images

Short exposure

Tone-mapped image

Long exposure

Aperture vs. Shutter Speed

- How do you deal with low-light scenes?
- How do you deal with fast moving objects?
- How do you produce crisp/focused images?

- Small aperture
  - Crisp images, requires lots of light
- Fast shutter speed
  - Crisp images for moving objects, requires lots of light
- Large aperture
  - Low-light ok, images can be blurry
- Slow shutter speed
  - Can produce crisp images in low light but camera/objects cannot move