Advanced Computer Graphics
CSE 190 [Winter 2016], Lecture 14
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To Do
- Assignment 2 due Feb 19
- Any last minute issues or questions?
- Next two lectures: Imaging, Texture Synthesis
- Then resume rendering, animation

Computational Imaging
- Digital cameras now commonplace
- Can we use computation for better images
  - Many novel capabilities relative to film
- And new ways of processing images
- Is this computer graphics, optics, or image proc?
  - All of the above; many rendering ideas apply
  - Application shift. Computer aided design to movies/games to photography (big market)
- Brief lecture. Subject of whole conference ICCP
  - Industry: Light Field cameras, Google glass, ...

Outline
- Image formation, basic lens-based camera
- Light Field camera
- Coded aperture depth of field
- Flutter shutter (coded aperture shutter)
- Many many more old, new innovations

How do we see the world?

Let’s design a camera
- Idea 1: put a piece of film in front of an object
- Do we get a reasonable image?

Pinhole camera

Add a barrier to block off most of the rays
- This reduces blurring
- The opening known as the aperture
- How does this transform the image?
**Pinhole camera model**

Pinhole model:
- Captures pencil of rays – all rays through a single point
- The point is called Center of Projection (COP)
- The image is formed on the Image Plane
- Effective focal length $f$ is distance from COP to Image Plane

**Dimensionality Reduction Machine (3D to 2D)**

3D world

2D image

Point of observation

What have we lost?
- Angles
- Distances (lengths)

**Funny things happen…**

**Parallel lines aren’t…**

**Lengths can’t be trusted…**

**…but humans adapt!**

Müller-Lyer Illusion

We don’t make measurements in the image plane

http://www.michaelbach.de/ot/sze_muelue/index.html
Camera Obscura

The first camera
- Known to Aristotle
- Depth of the room is the effective focal length

From Pinhole to Lenses

Computer graphics assumes pinhole model
But making aperture narrow limits light
Making aperture large causes blurriness
Real cameras have lenses to collect more light, and focus it on the image plane (Kolb et al. 95 simulates lens effects rendering)

Home-made pinhole camera

Why so blurry?

http://www.debevec.org/Pinhole/

Shrinking the aperture

Why not make the aperture as small as possible?
- Less light gets through
- Diffraction effects...

The reason for lenses

A lens focuses light onto the film
- There is a specific distance at which objects are “in focus”
  - other points project to a “circle of confusion” in the image
- Changing the shape/separation of lens changes this distance

Focus and Defocus
Thin lenses

Thin lens equation:
\[
\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}
\]

- Any object point satisfying this equation is in focus
- What is the shape of the focus region?
- How can we change the focus region?

Depth of Field

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Light Field Inside a Camera

[Adelson and Wang, 1992; Ng et al. 2005]

Stanford Plenoptic Camera [Ng et al. 2005]

Contax medium format camera
Kodak 16-megapixel sensor
Adaptive Optics microlens array
125µ square-sided microlenses

4000 × 4000 pixels ÷ 292 × 292 lenses = 14 × 14 pixels per lens
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Out of Focus Photo: Coded Aperture

Out of Focus Photo: Open Aperture

Captured Blurred Photo

Refocused on Person

Engineering the PSF when you cannot capture Lightfield

2D Photo

In Focus Photo

[Veeraraghavan, Raskar, Agrawal, Tumblin, Mohan, Siggraph 2007 ]

Increase DoF + large aperture
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Traditional Camera

Shutter is OPEN

Our Camera

Flutter Shutter

Shutter is OPEN and CLOSED

Lab Setup

Sync Function

Blurring

Convolution

Traditional Camera: Box Filter
Flutter Shutter: Coded Filter

Preserves High Frequencies!!!

Comparison

Inverse Filter Unstable

Inverse Filter stable

Input Image

Rectified Crop

Deblurred Result