Advanced Computer Graphics (Fall 2009)

CS 294, Rendering Lecture 12

Computational Imaging and Photography

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http://inst.eecs.berkeley.edu/~cs294-13/fa09

Many slides courtesy Ramesh Raskar, SIGGRAPH 2008 course

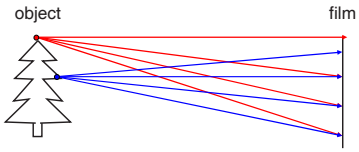
Computational Imaging

- 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. Some more on image processing by Prof. Agrawala in 2 weeks

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?

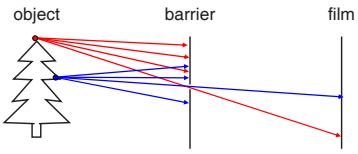


Let's design a camera

- Idea 1: put a piece of film in front of an object
- Do we get a reasonable image?

Slide by Steve Seitz

Pinhole camera

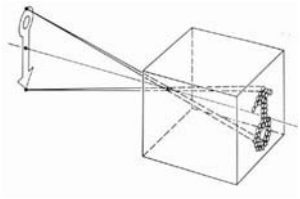


Add a barrier to block off most of the rays

- This reduces blurring
- The opening known as the **aperture**
- How does this transform the image?

Slide by Steve Seitz

Pinhole camera model



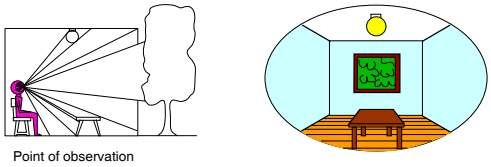
Pinhole model:

- 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

Slide by Steve Seitz

Dimensionality Reduction Machine (3D to 2D)

3D world *2D image*



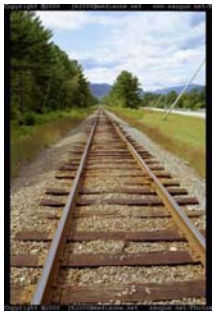
Point of observation

What have we lost?

- Angles
- Distances (lengths)

Figures © Stephen E. Palmer, 2002

Funny things happen…



Parallel lines aren't…

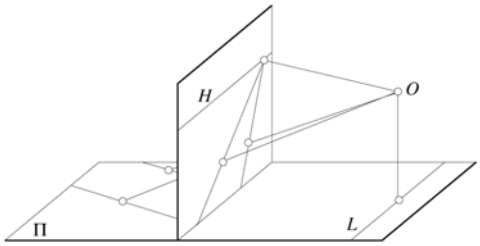


Figure by David Forsyth

Lengths can't be trusted...

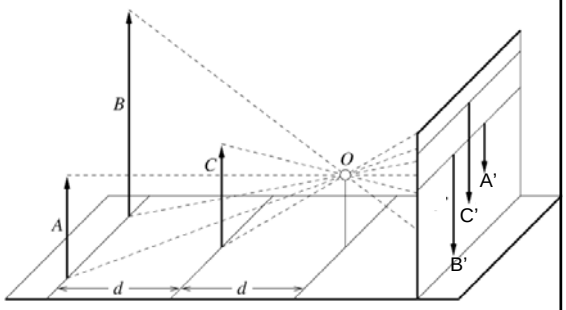
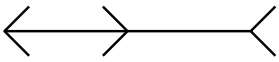
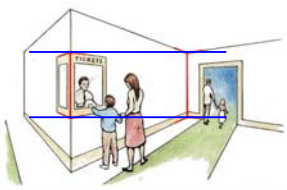


Figure by David Forsyth

…but humans adopt!



Müller-Lyer Illusion

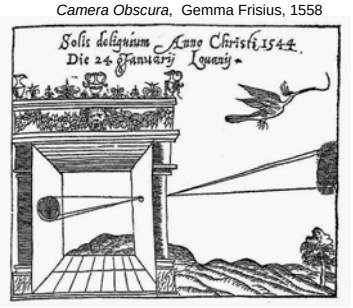


We don't make measurements in the image plane

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

Camera Obscura

Camera Obscura, Gemma Frisius, 1558



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

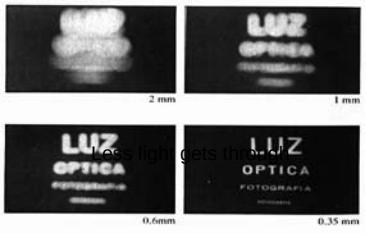
(Kolb et al. 95 simulates lens effects rendering)

Home-made pinhole camera

Why so blurry?

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

Shrinking the aperture



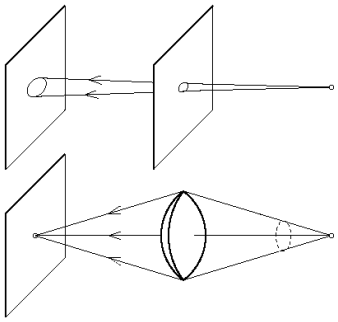
Less light gets through

Why not make the aperture as small as possible?

- Less light gets through
- Diffraction effects…

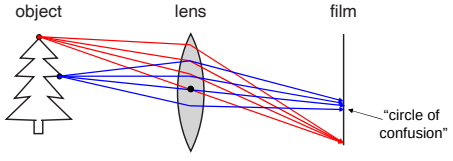
Slide by Steve Seitz

The reason for lenses



Slide by Steve Seitz

Focus and Defocus

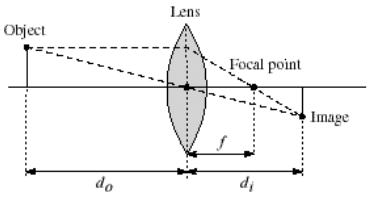


A lens focuses light onto the film

- 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

Slide by Steve Seitz

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?
- Thin lens applet: http://www.phy.ntnu.edu.tw/java/Lens/lens_e.html (by Fu-Kwun Hwang)

Slide by Steve Seitz

Depth of Field

http://www.cambridgeincolour.com/tutorials/depth-of-field.htm

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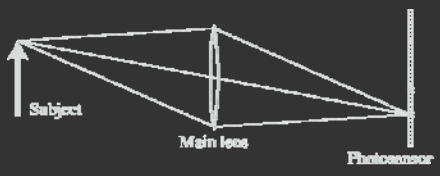
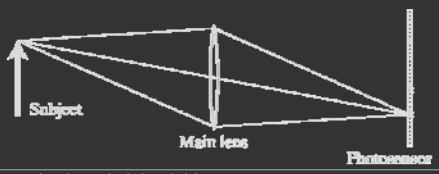
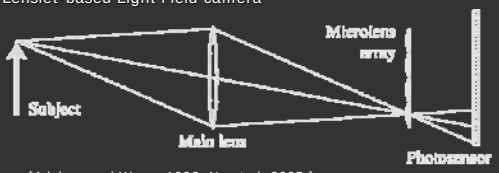
Light Field Inside a Camera



Light Field Inside a Camera



Lenslet-based Light Field camera



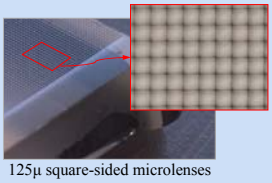
[Adelson and Wang, 1992, Ng et al. 2005]

Stanford Plenoptic Camera [Ng et al 2005]

Contax medium format camera

Kodak 16-megapixel sensor

Adaptive Optics microlens array



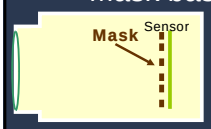
125μ square-sided microlenses

4000 × 4000 pixels ÷ 292 × 292 lenses = 14 × 14 pixels per lens

Digital Refocusing

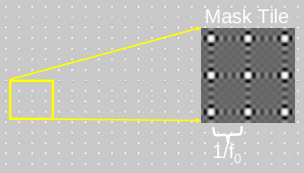
[Ng et al 2005]

Mask based Light Field Camera



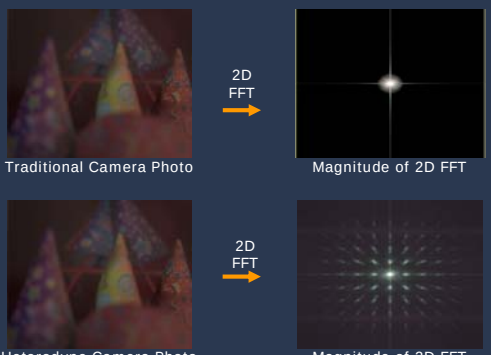
[Veeraraghavan, Raskar, Agrawal, Tumblin, Mohan, Siggraph 2007]

Cosine Mask Used



Captured 2D Photo

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



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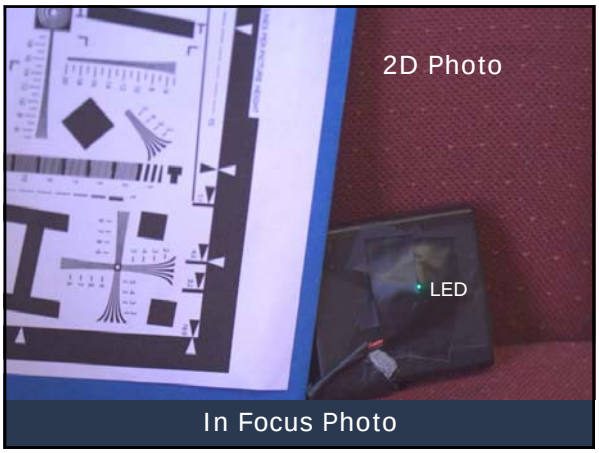
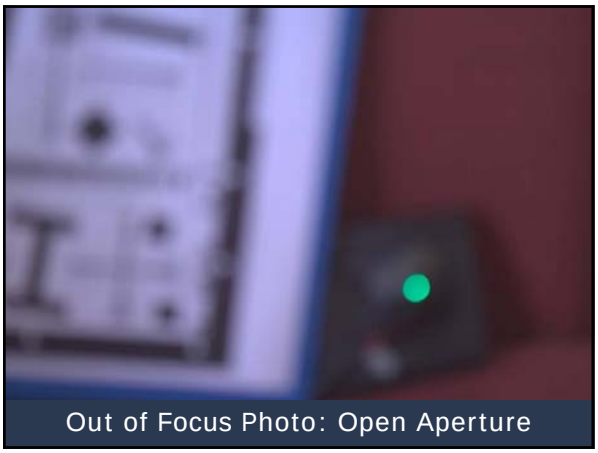
Engineering the PSF when you cannot capture Lightfield

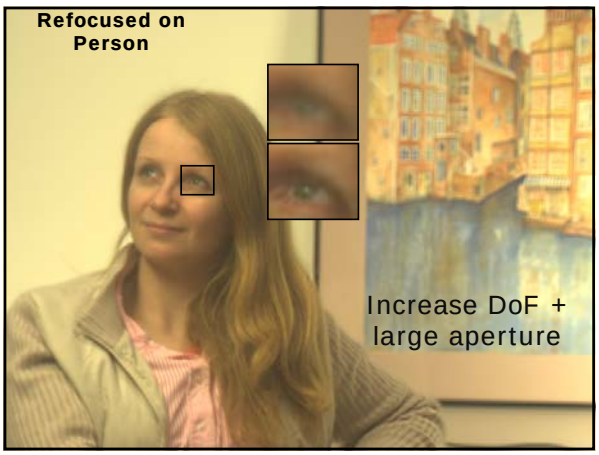
Out of Focus Photo: Coded Aperture



In Focus Photo


Out of Focus Photo: Open Aperture


Out of Focus Photo: Coded Aperture



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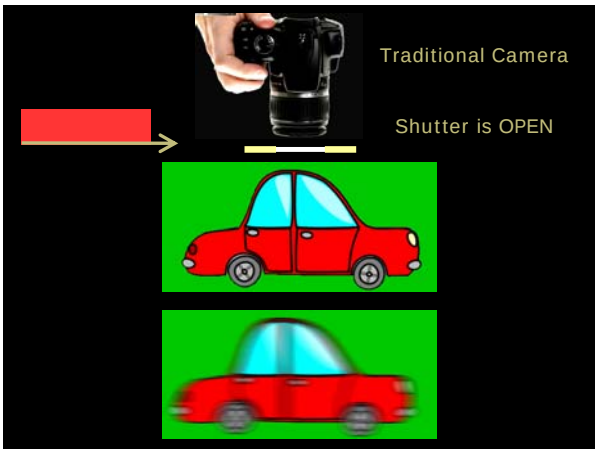
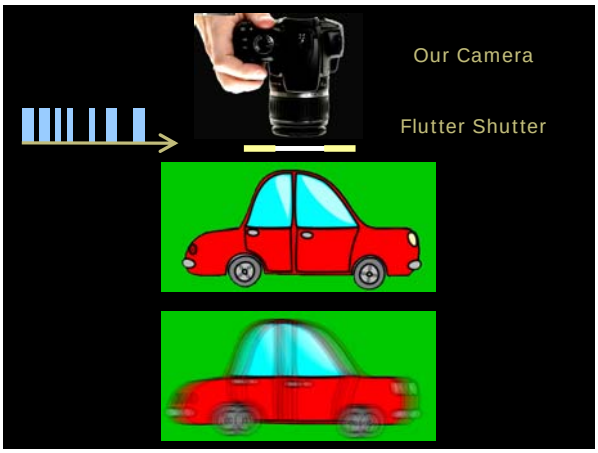
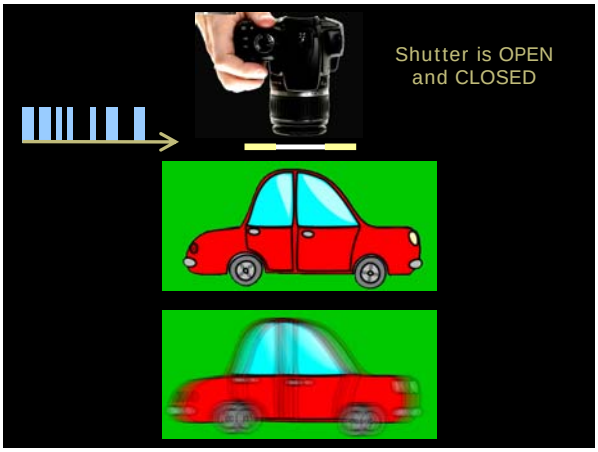
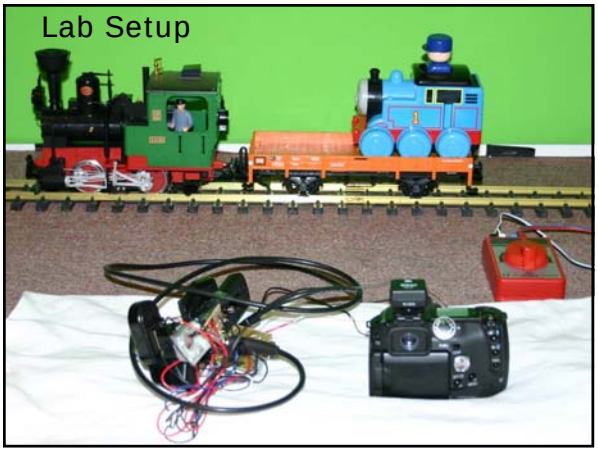
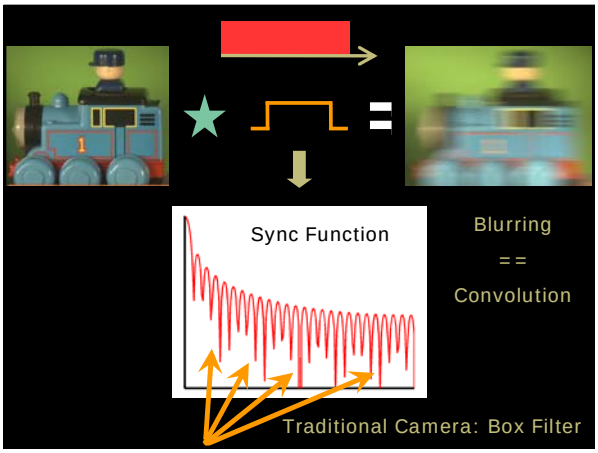
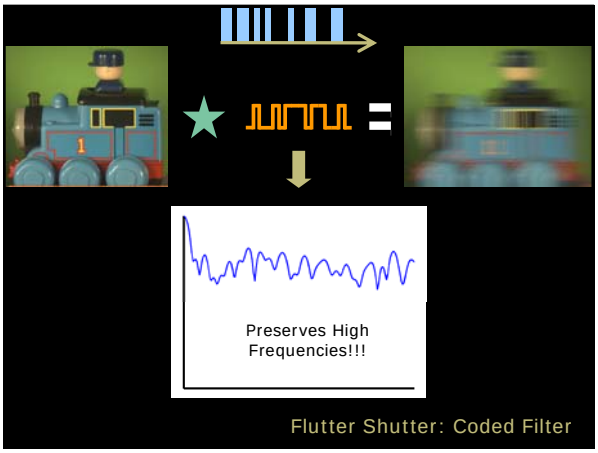

Traditional Camera
Shutter is OPEN

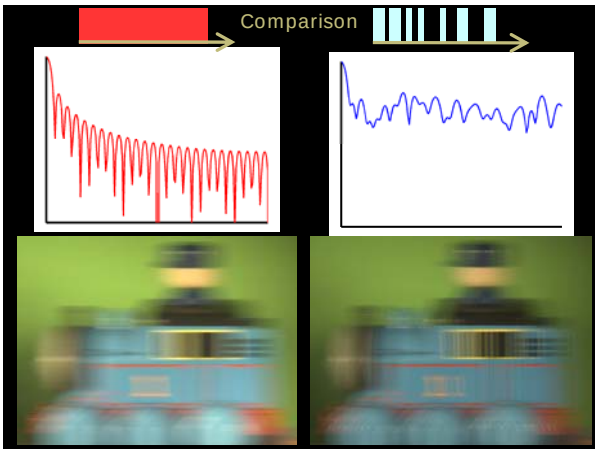

Our Camera
Flutter Shutter

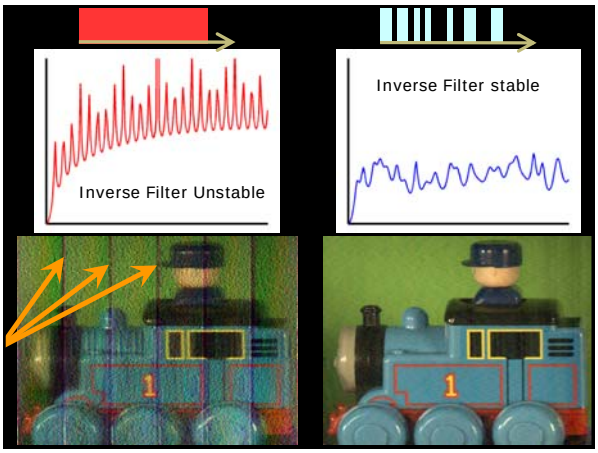

Shutter is OPEN
and CLOSED

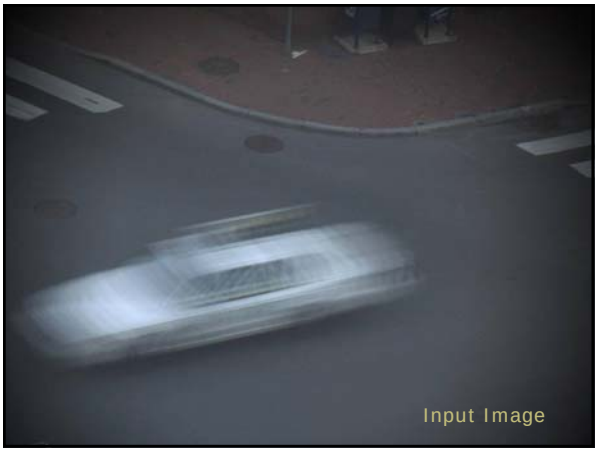

Lab Setup

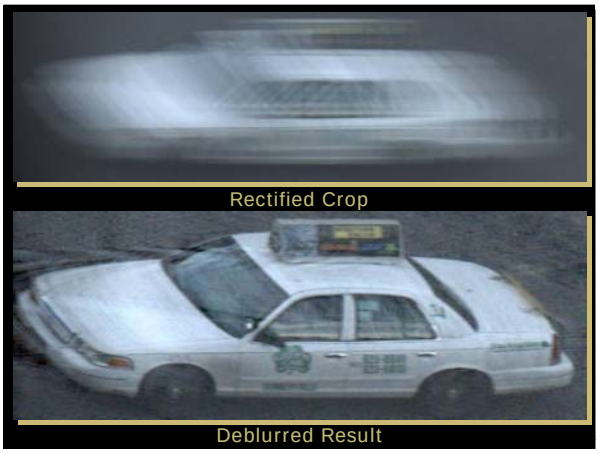

Sync Function
Blurring
= =
Convolution
Traditional Camera: Box Filter


Preserves High
Frequencies!!!
Flutter Shutter: Coded Filter


Comparison


Inverse Filter stable
Inverse Filter Unstable


Input Image


Rectified Crop
Deblurred Result