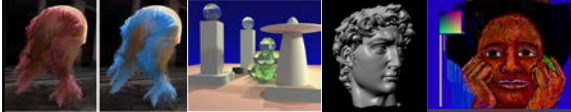


Advanced Computer Graphics

CSE 163 [Spring 2018], Lecture 14

Ravi Ramamoorthi

<http://www.cs.ucsd.edu/~ravr>



To Do

- Assignment 2 due May 18
- Any last minute issues or questions?
- Next two lectures: Imaging, Texture Synthesis
 - Then resume rendering, animation

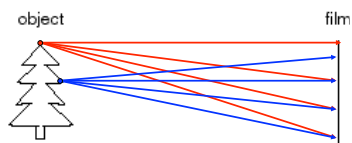
Computational Imaging

- 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: Mobile Imaging, Light Field cameras, ...

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?

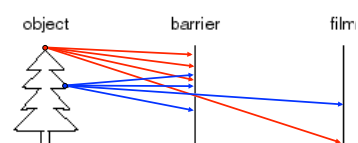


Let's design a camera

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

Slide by Steve Seitz

Pinhole camera

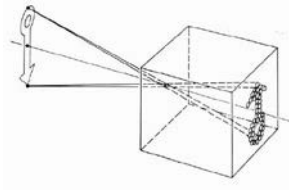


Add a barrier to block off most of the rays

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

Slide by Steve Seitz

Pinhole camera model

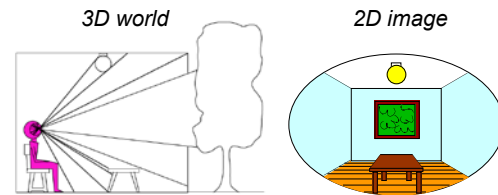


Pinhole model:

- 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)



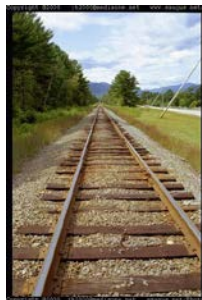
Point of observation

What have we lost?

- Angles
- Distances (lengths)

Figures © Stephen E. Palmer, 2002

Funny things happen...



Parallel lines aren't t...

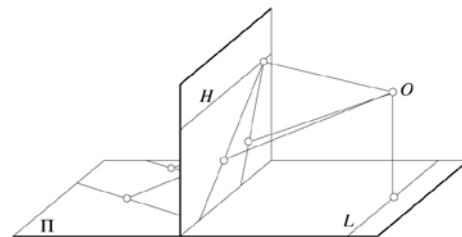


Figure by David Forsyth

Lengths can't be trusted...

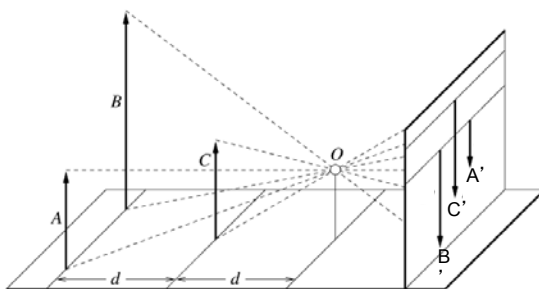
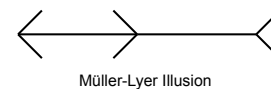
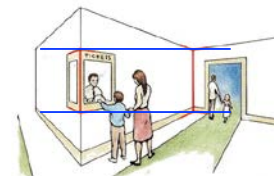


Figure by David Forsyth

...but humans adapt!



Müller-Lyer Illusion

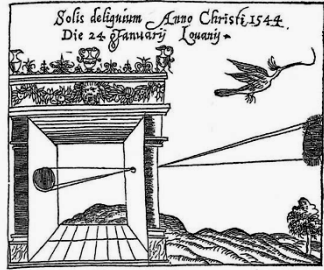


We don't make measurements in the image plane

http://www.michaelbach.de/ol/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)

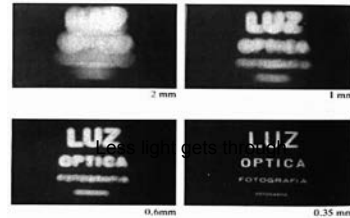
Home-made pinhole camera



Why so blurry?

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

Shrinking the aperture

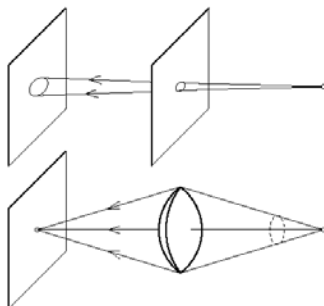


Why not make the aperture as small as possible?

- Less light gets through
- Diffraction effects...

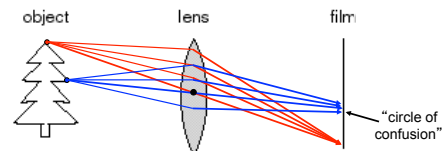
Slide by Steve Seitz

The reason for lenses



Slide by Steve Seitz

Focus and Defocus

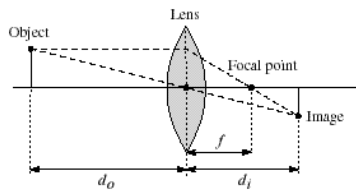


A lens focuses light onto the film

- 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.nyu.edu.tw/java/Lens/lens_e.html (by Fu-Kwun Hwang) Code by Steve Seitz

Depth of Field

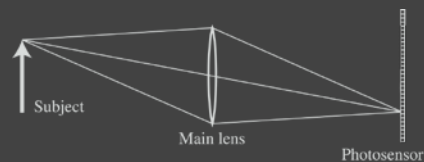


<http://www.cambridgeincolour.com/tutorials/depth-of-field.htm>

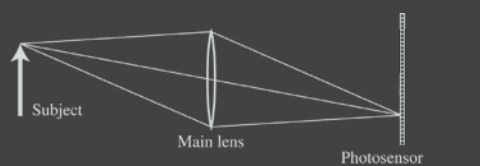
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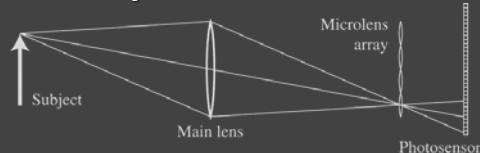
Light Field Inside a Camera



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]



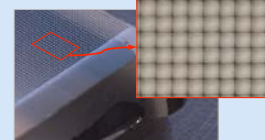
Contax medium format camera



Kodak 16-megapixel sensor



Adaptive Optics microlens array



125µ square-sided microlenses

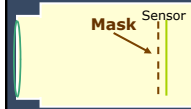
$$4000 \times 4000 \text{ pixels} \div 292 \times 292 \text{ lenses} = 14 \times 14 \text{ pixels per lens}$$

Digital Refocusing



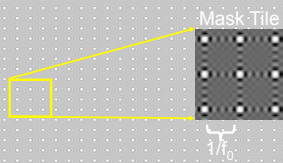
[Ng et al 2005]

Mask based Light Field Camera



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

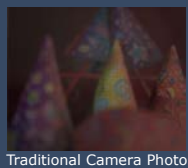
Cosine Mask Used:



Captured 2D Photo

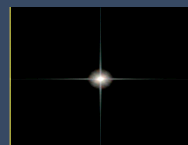


[Veeraraghavan, Raskar, Agrawal, Tumblin, Mohan, Siggraph 2007]

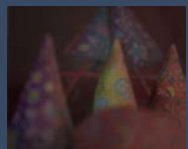


Traditional Camera Photo

2D
FFT
→



Magnitude of 2D FFT



Heterodyne Camera Photo

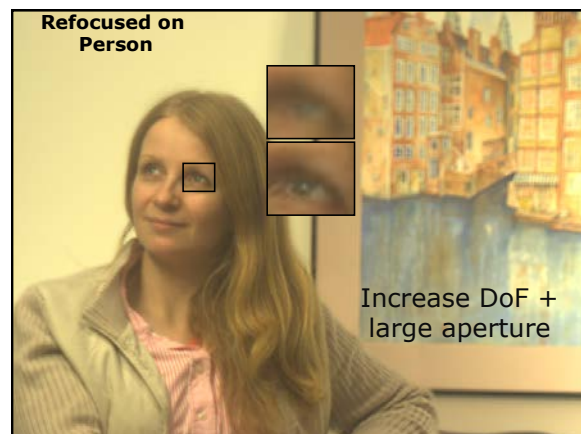
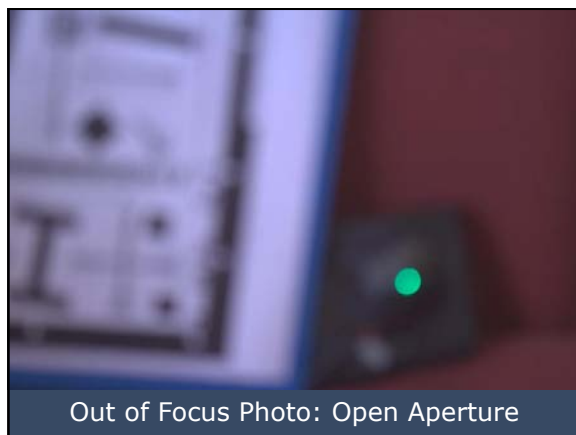
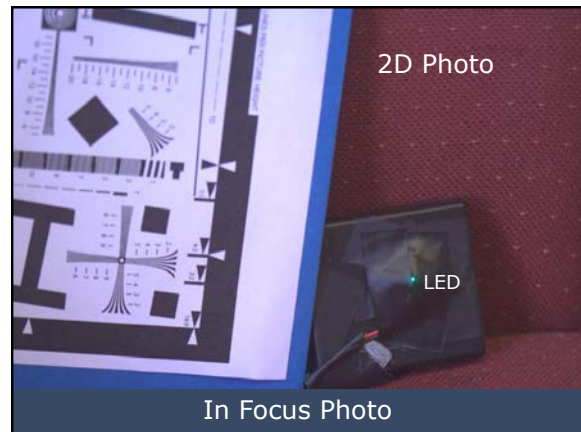
2D
FFT
→



Magnitude of 2D FFT

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