Ramesh Raskar
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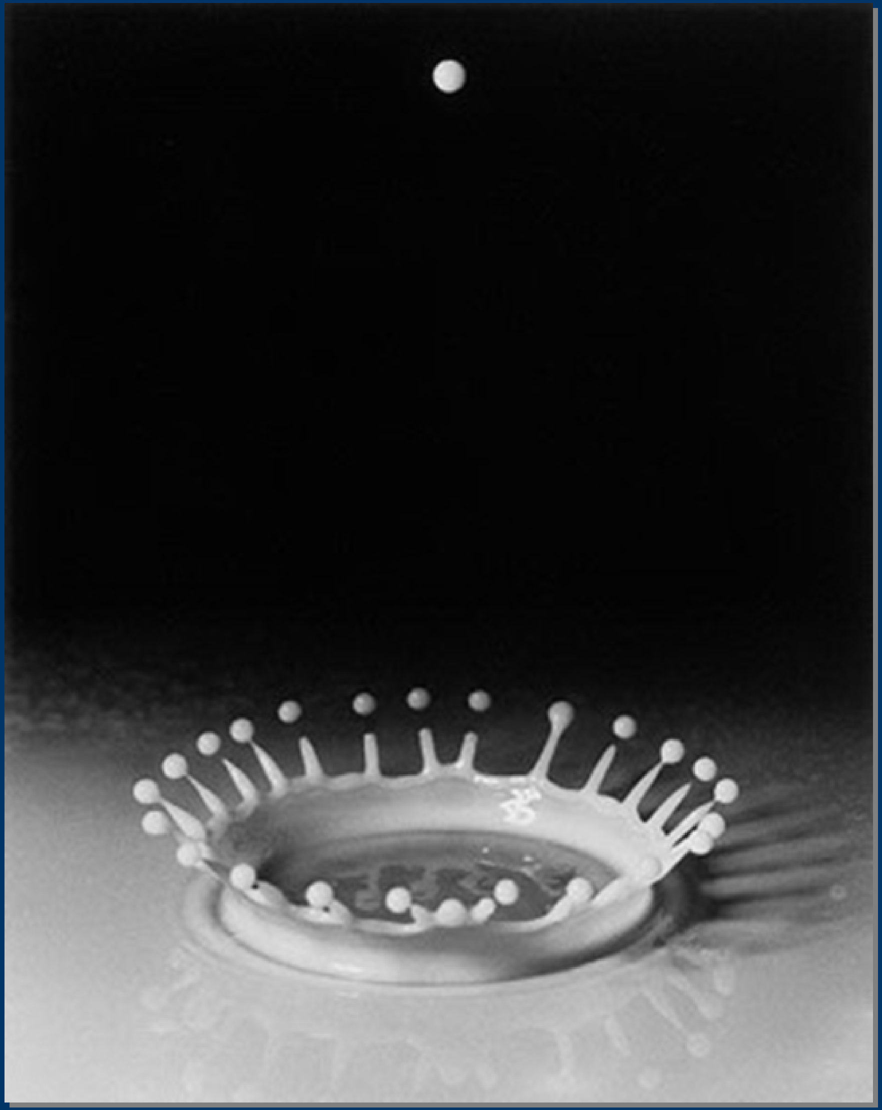
Camera Culture

Course WebPage :
http://raskar.info/course.html



Harold 'Doc' Edgerton 1936

Today's Plan

- Summary, 'Camera in 10 years'
- Next class big question:
  - 'Camera for better Image Search'
- Understanding Camera Constraints
  - Camera Parameters
  - Solutions

- Homework
  - What will a camera look like in 10 years, 20 years?
  - What will be the dominant platform and why?

Next Class

- Homework
  - How can we augment the camera to support best 'image search'?
  - Search=segment/identify/recognize/transform/compare/archive
  - How can we make the visual experience machine readable? Is this the key problem? 3D reconstruction? Hardware and software solutions? Crowdsourcing? Metadata tagging?
  - Material index/Segmentation/Repeatable view and illumination invariance/
  - Email to [raskar@media.mit..]
- Volunteer
  - Class notes
  - Select/read/present/paper
    - Visual Social Computing
    - Beyond Visible Spectrum
    - Mobile Photography
    - Emerging sensors
    - [Send me email ..]
  - (Extra Credit)

Topics

- Imaging Devices, Modern Optics and Lenses
- Emerging Sensor Technologies
- Mobile Photography
- Visual Social Computing and Citizen Journalism
- Imaging Beyond Visible Spectrum
- Computational Imaging in Sciences
- Trust in Visual Media
- Solutions for Visually Challenged
- Cameras in Developing Countries
- Future Products and Business Models

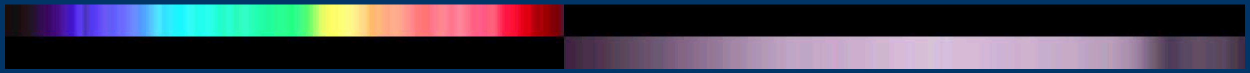
Topics

- Other courses
  - Art and Photography
  - CSAIL: Computational Photography
  - MechE: Optics
- Fall'2008
  - 'Intro to Computational Camera and Photography'
  - I will teach course in Fall
- Current course
  - More emphasis on future cameras
  - Faster review of technology and then look at impact/applications/opportunities
  - Big ideas/technologies/applications,
  - Understand rules-of-thumb and trade-offs
  - Ideal for thesis/projects/research papers/business models
  - Learn fun stuff before the nitty gritty

Jack Tumblin's Questions

- What does direct visual examination of an object give us that current photographs lack?
- What could we do to capture most of a photo's visually meaningful contents in machine-readable form?
- What is the best way to 'lash together' multiple photos of an object to form a unified visual archive?
- Museum Objects
  - How can we make a quick, low-cost, but complete archival record of a museum object?
  - Can we make such archives expandable? device-independent? View independent? Lighting-independent?
  - Can these archives help us find hidden object features? Search for similarities among large sets of objects?
  - Can they help us detect subtle long-term change & degradation of objects? Identify lost or stolen objects? Detect fakes?
  - What digital tools will help museum officials protect, share, and explore their collections with visitors?

Near Infrared Imaging



http://www.hoagieshouse.com/IR

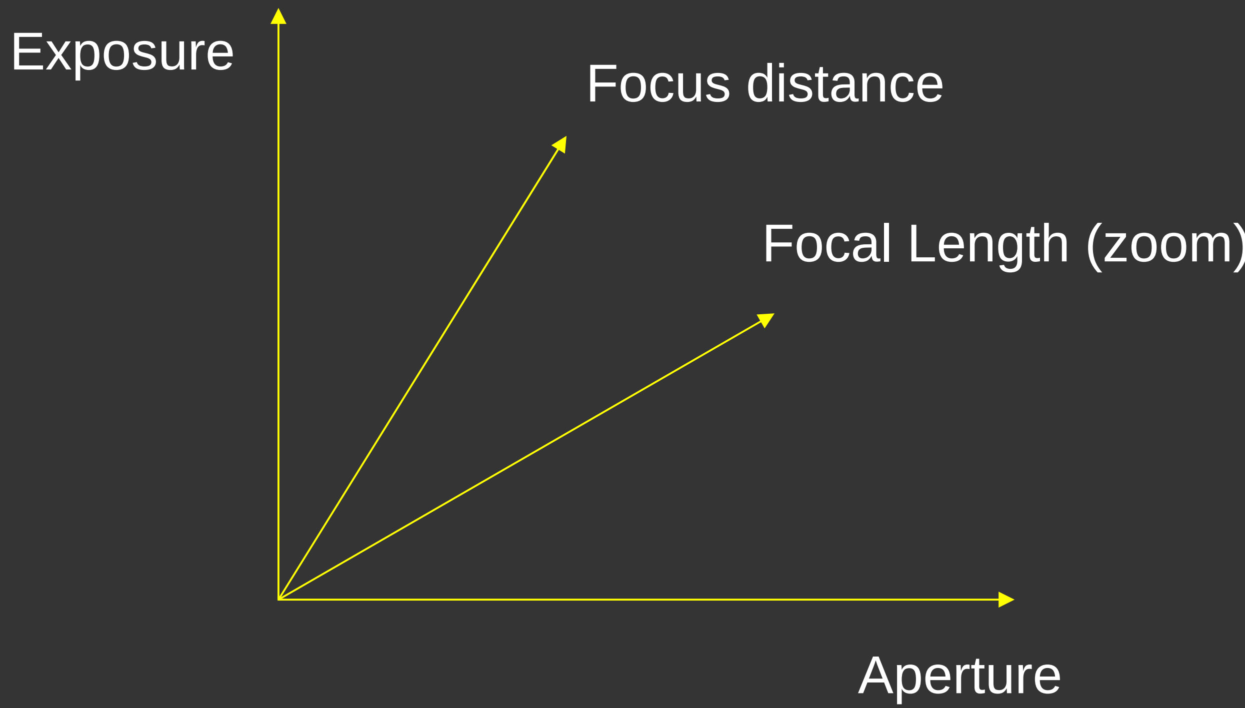
http://www.flickr.com/photos/mariusm/6333589/

Illumination for Traffic Cameras

Photography: Full of Tradeoffs...

- **Available light vs. exposure time vs. scene movement vs. field of view vs. focus depth vs. sensitivity vs. noise vs. color rendition vs. color gamut vs. contrast vs. visible detail vs. ….**

Available Light vs Parameter ‘box’



Dynamic Range

Short Exposure

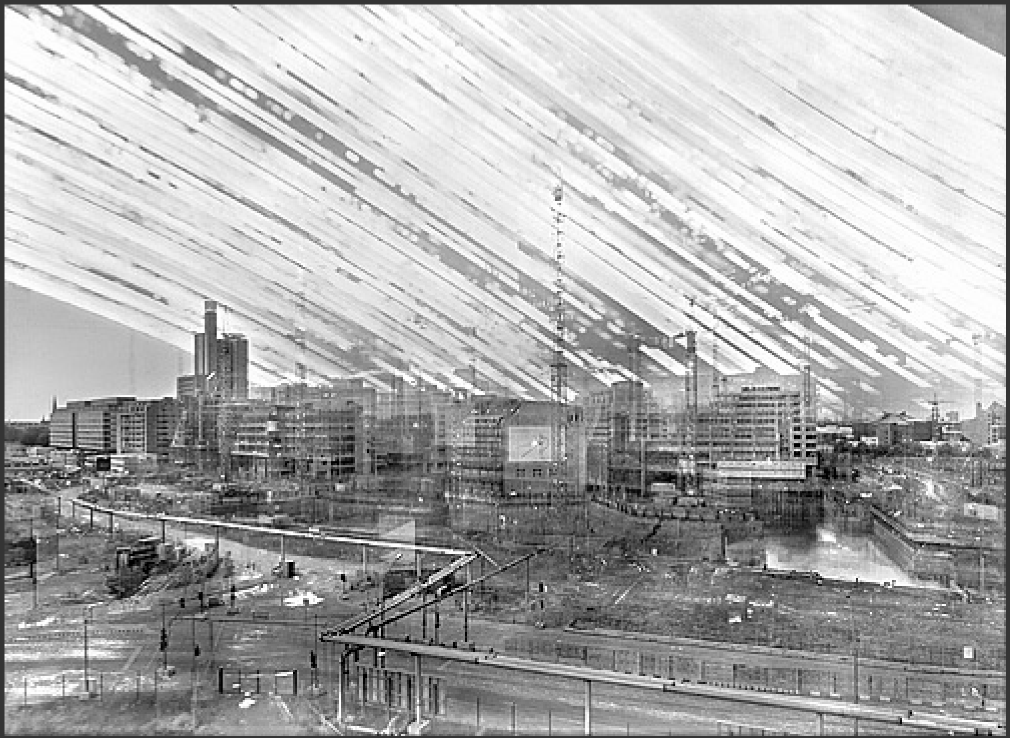
Long Exposure

Goal: High Dynamic Range

Processing: Very Long Exposure ?

Michael Wesely: Open Shutter at The Museum of Modern Art

- http://www.wesely.org/moma.php?show_page=1
- http://www.moma.org/exhibitions/2004/Michael_Wesely_11-20-04.html



Postdamer Platz, Berlin

18 month long exposure

26 Month long exposure: Notice the sun tracks

High depth-of-field

- adjacent views use different focus settings
- for each pixel, select sharpest view

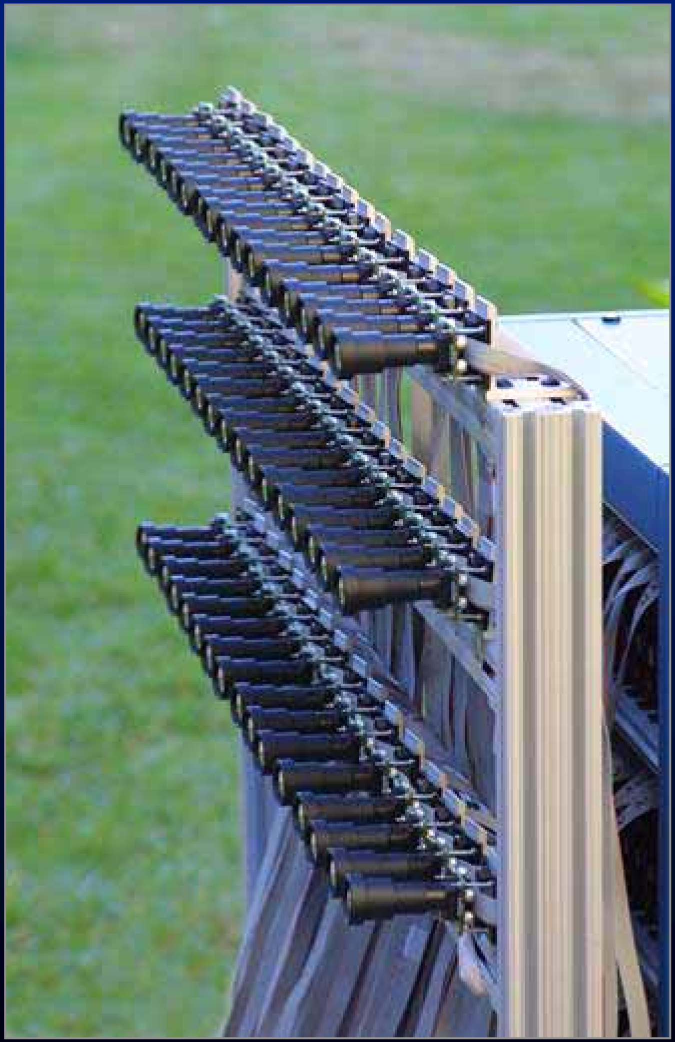
[Haeberli90]

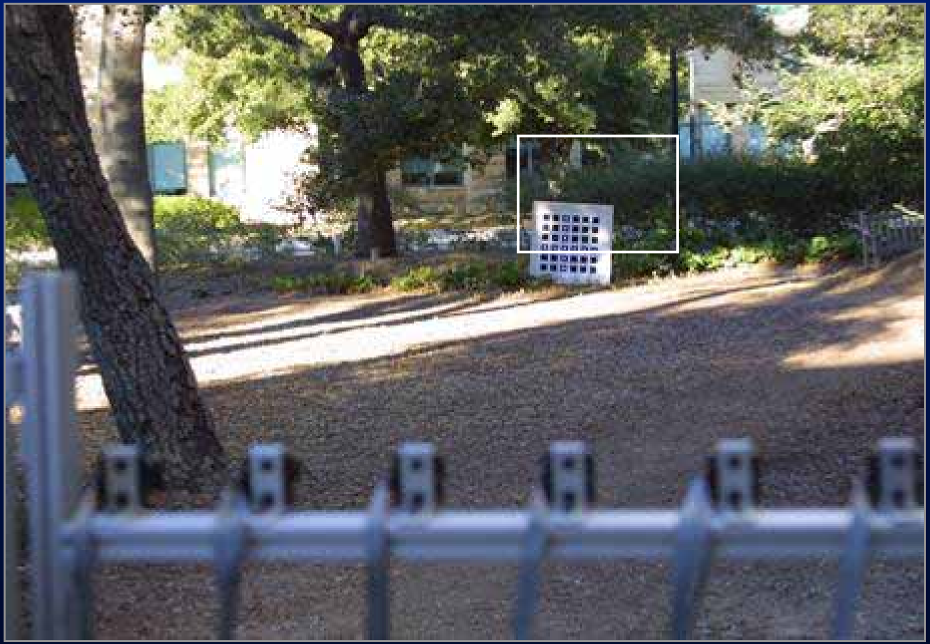
close focus

distant focus

composite

Long-range synthetic aperture photography



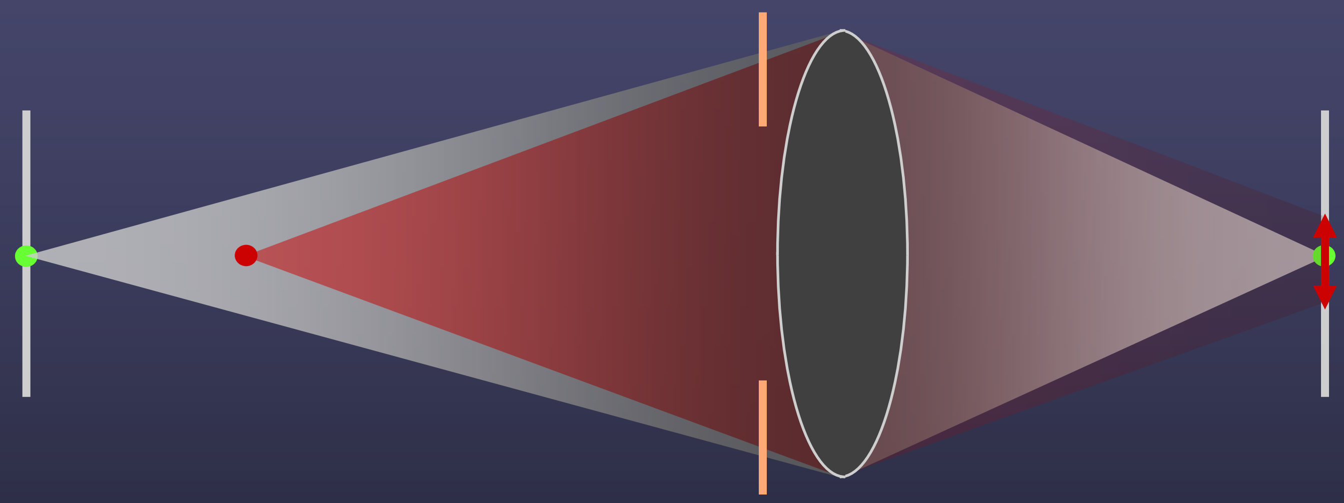


Levoy et al., SIGG2005

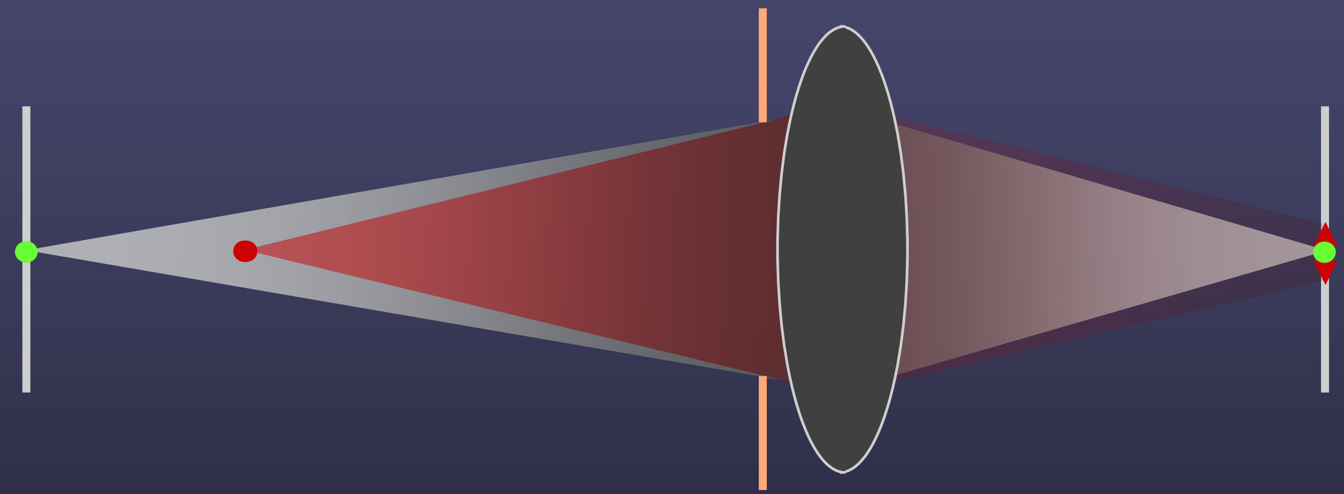
Synthetic aperture videography

Focus Adjustment: Sum of Bundles

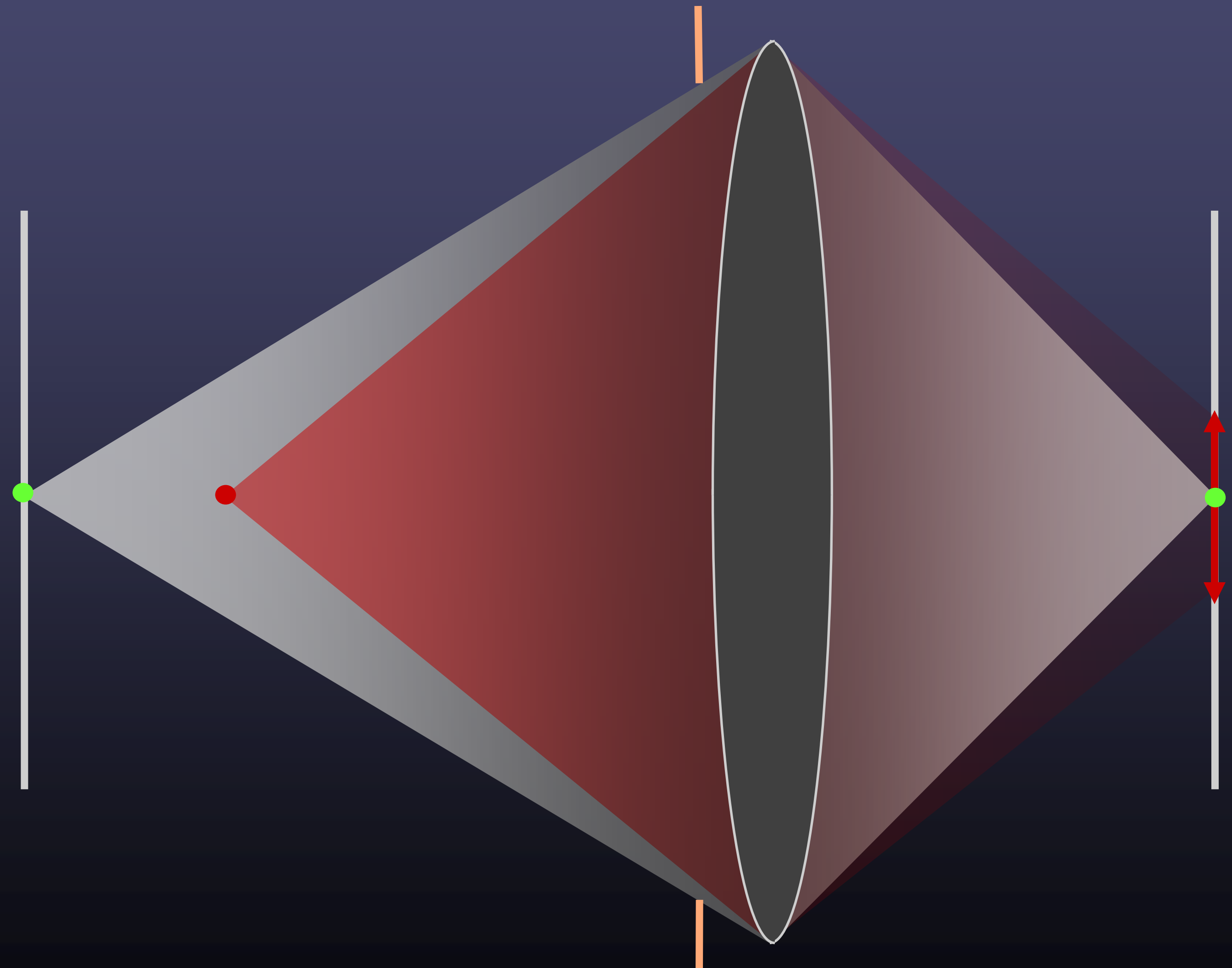
Synthetic aperture photography



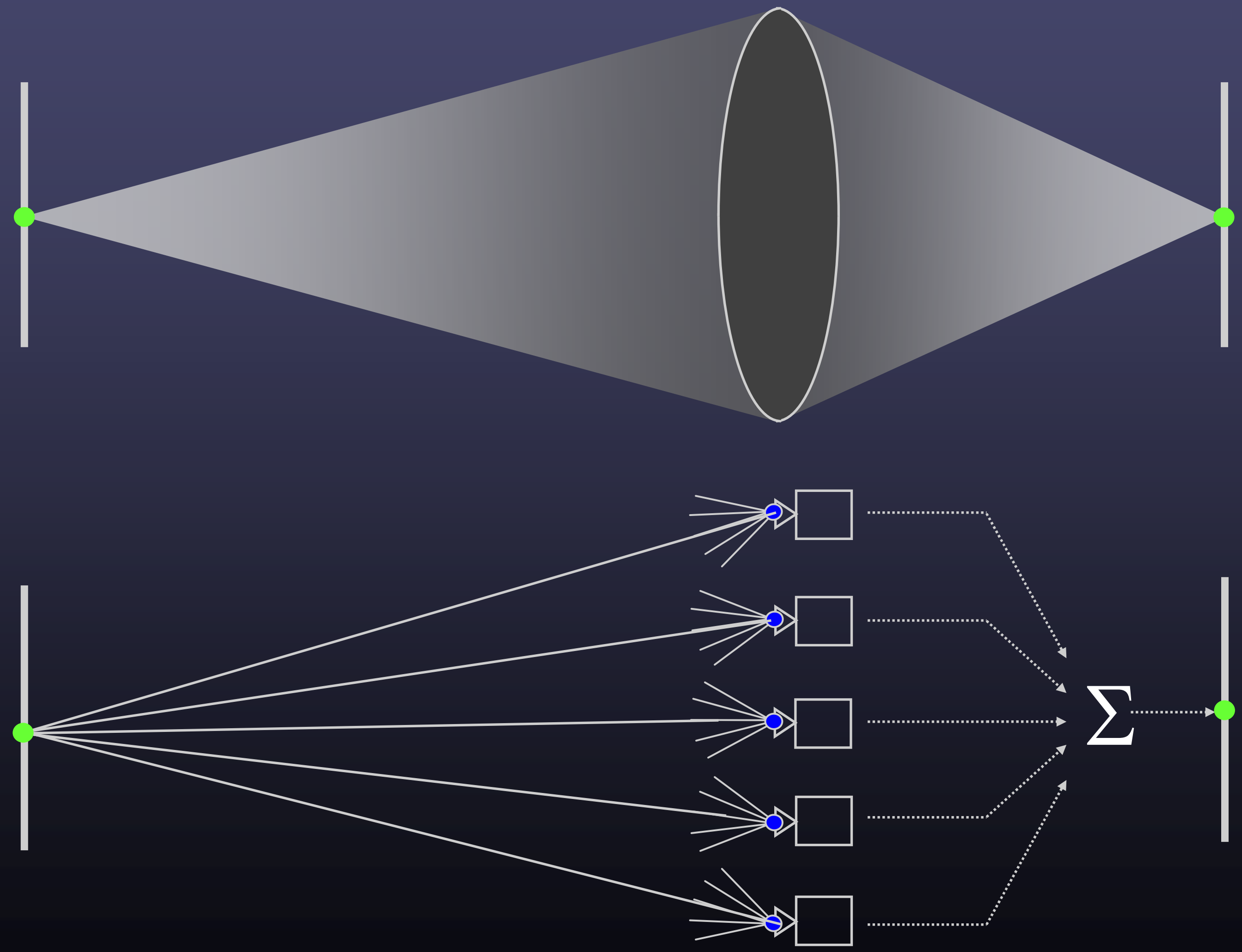
Synthetic aperture photography



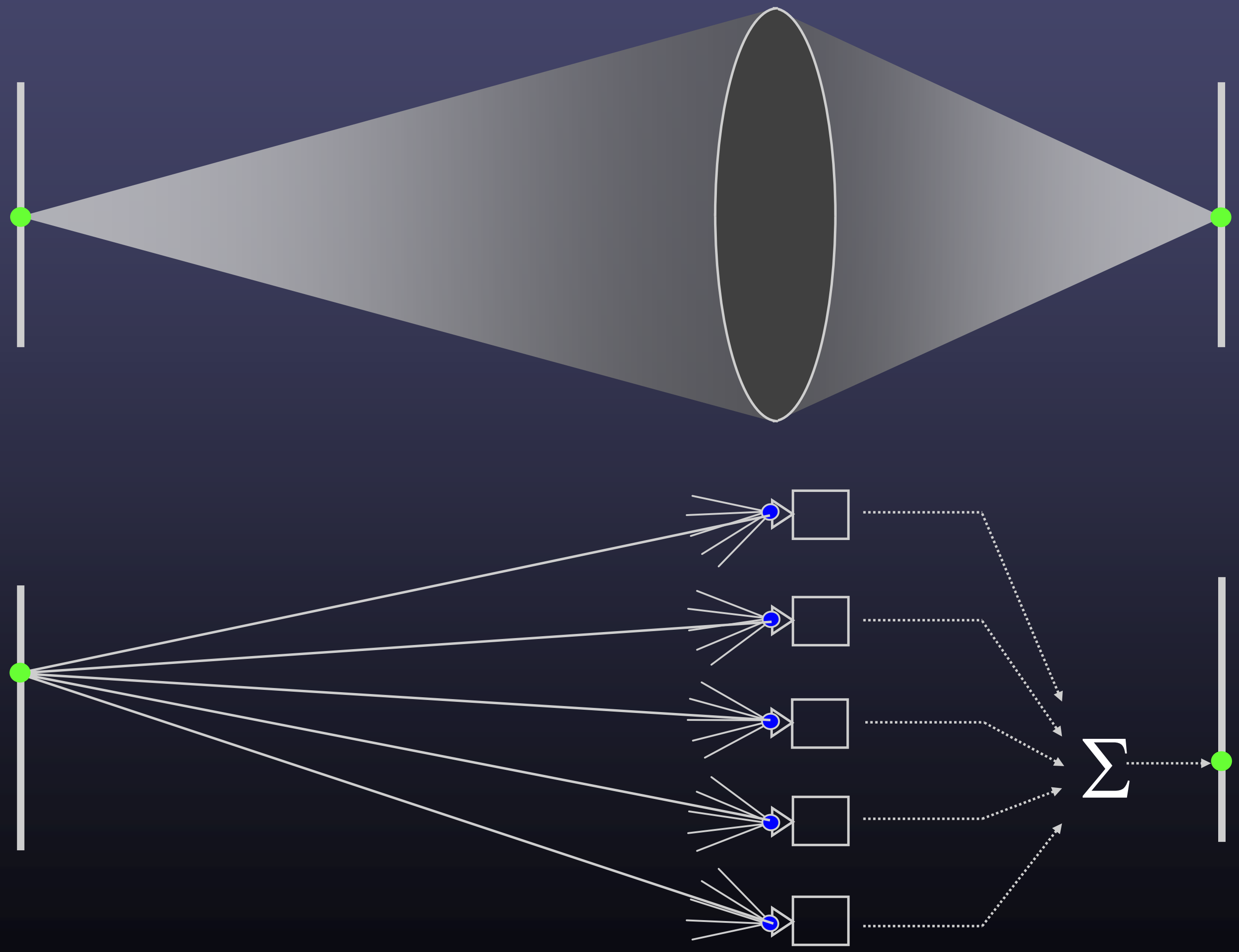
Synthetic aperture photography



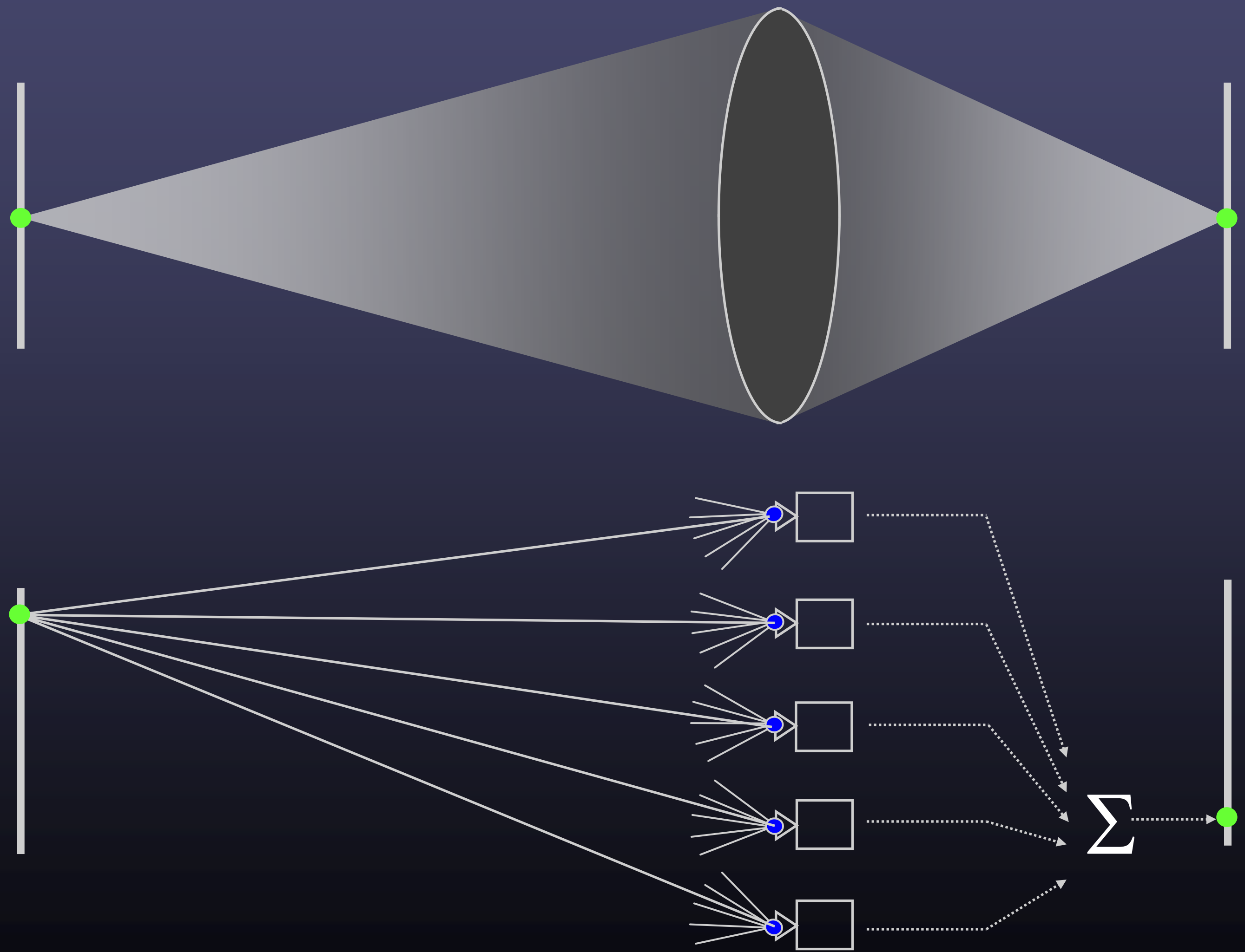
Synthetic aperture photography



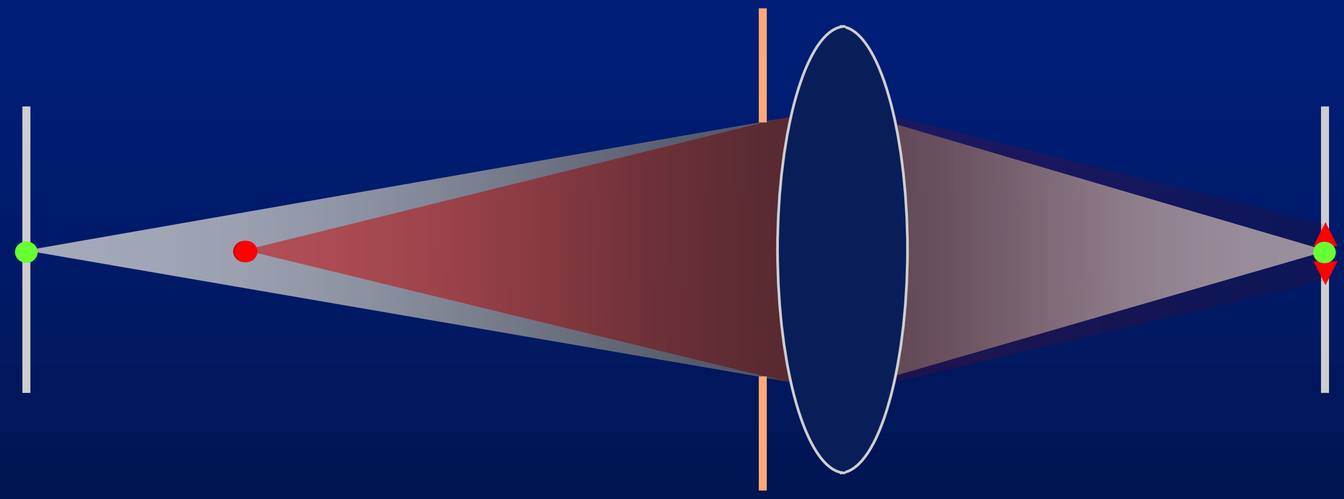
Synthetic aperture photography



Synthetic aperture photography



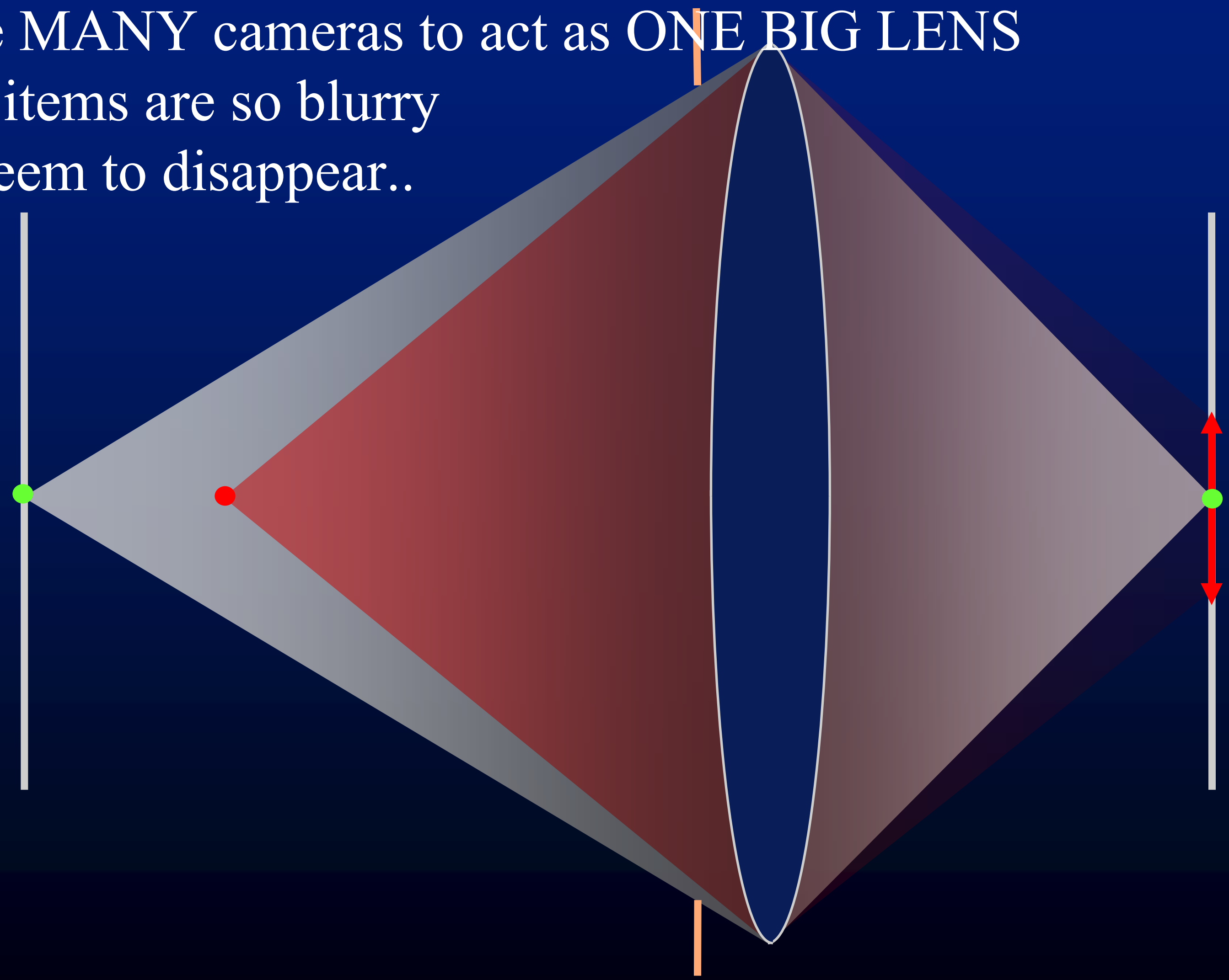
Synthetic aperture photography



Smaller aperture → → less blur, smaller circle of confusion

Synthetic aperture photography

Merge MANY cameras to act as ONE BIG LENS
Small items are so blurry
they seem to disappear..



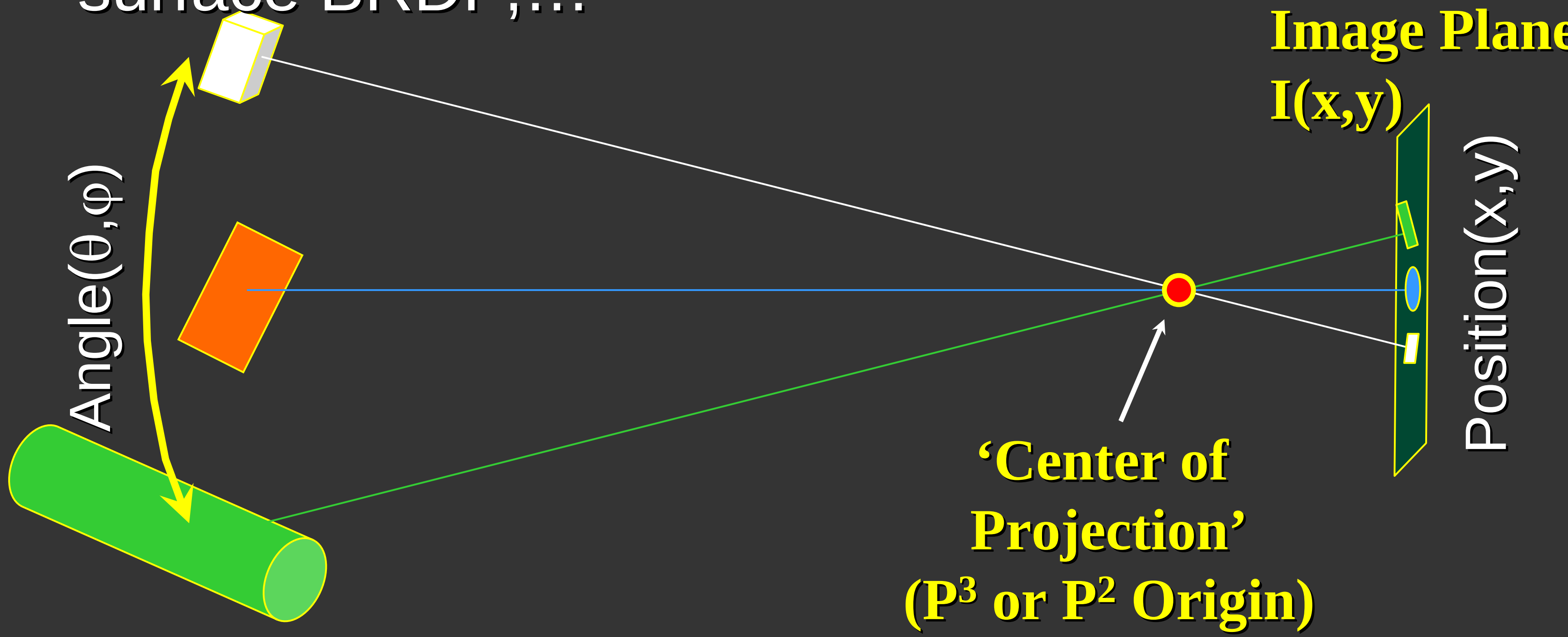
Focus Adjustment: Sum of Bundles

- Epsilon Photography
  - Vary focus, exposure polarization, illumination
  - Vary time, view
  - Better than any one photo
- Achieve effects via multi-photo fusion
- Create a Super-camera
  - Mimic human eye

‘Film-Like Photography’: Ray Model

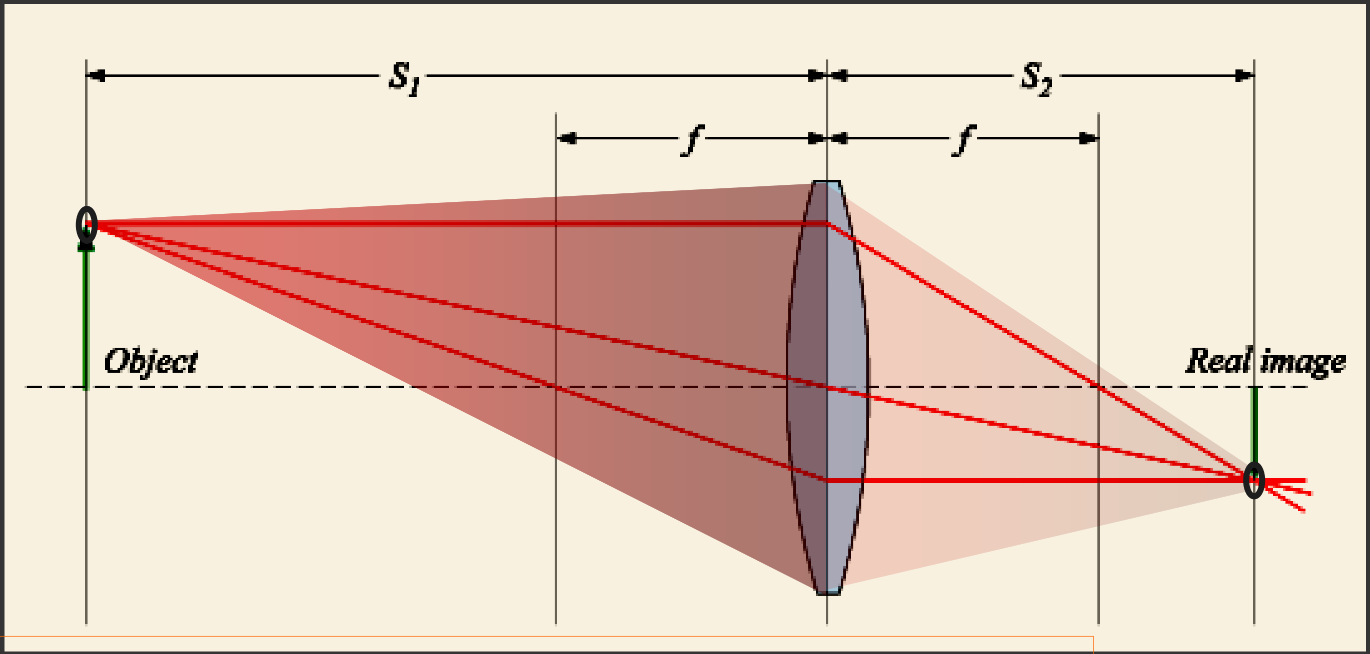
Light + 3D Scene: → **Image:**

Illumination, shape, movement, surface BRDF,… → Planar 2D map of light intensities



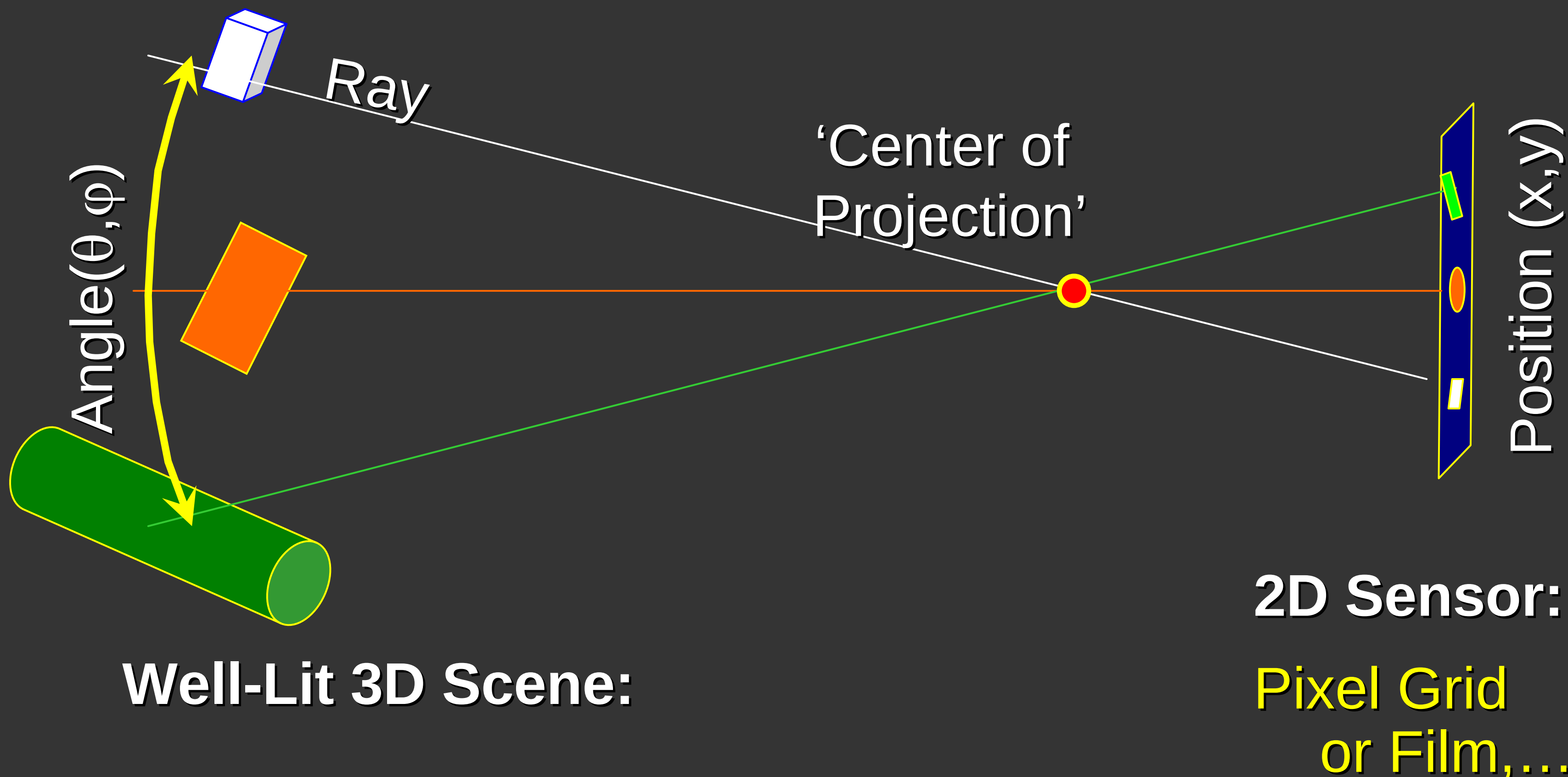
Ray BUNDLES approximate Rays

- Lens Systems:
  approximate rays with bundles
- Finite angle, not rays *(lens aperture)*
- Finite area, not points *(circle of confusion)*



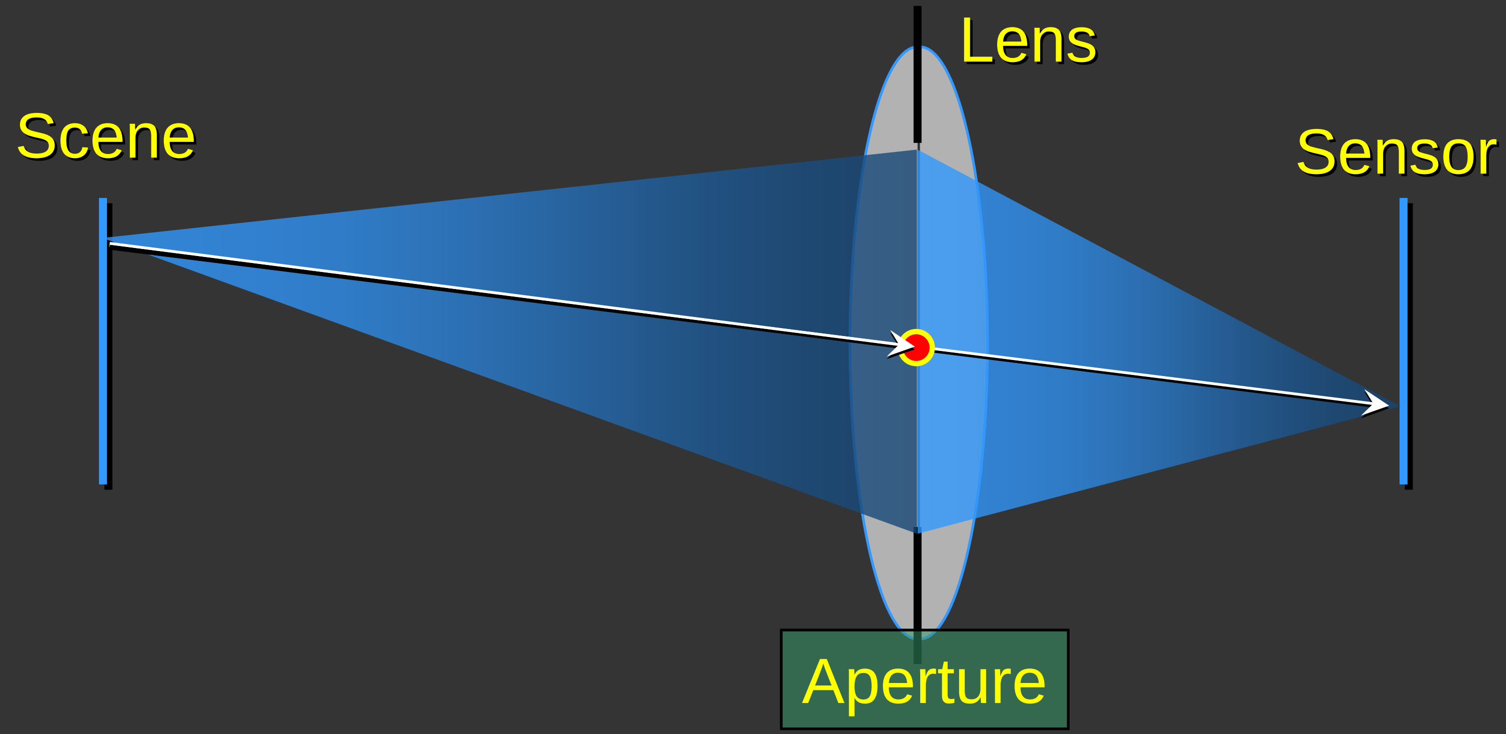
http://www.nationmaster.com/encyclopedia/Lens-(optics)

Film-like Optics: Imaging Intuition



'Pinhole' Model: Rays copy scene onto 'film'

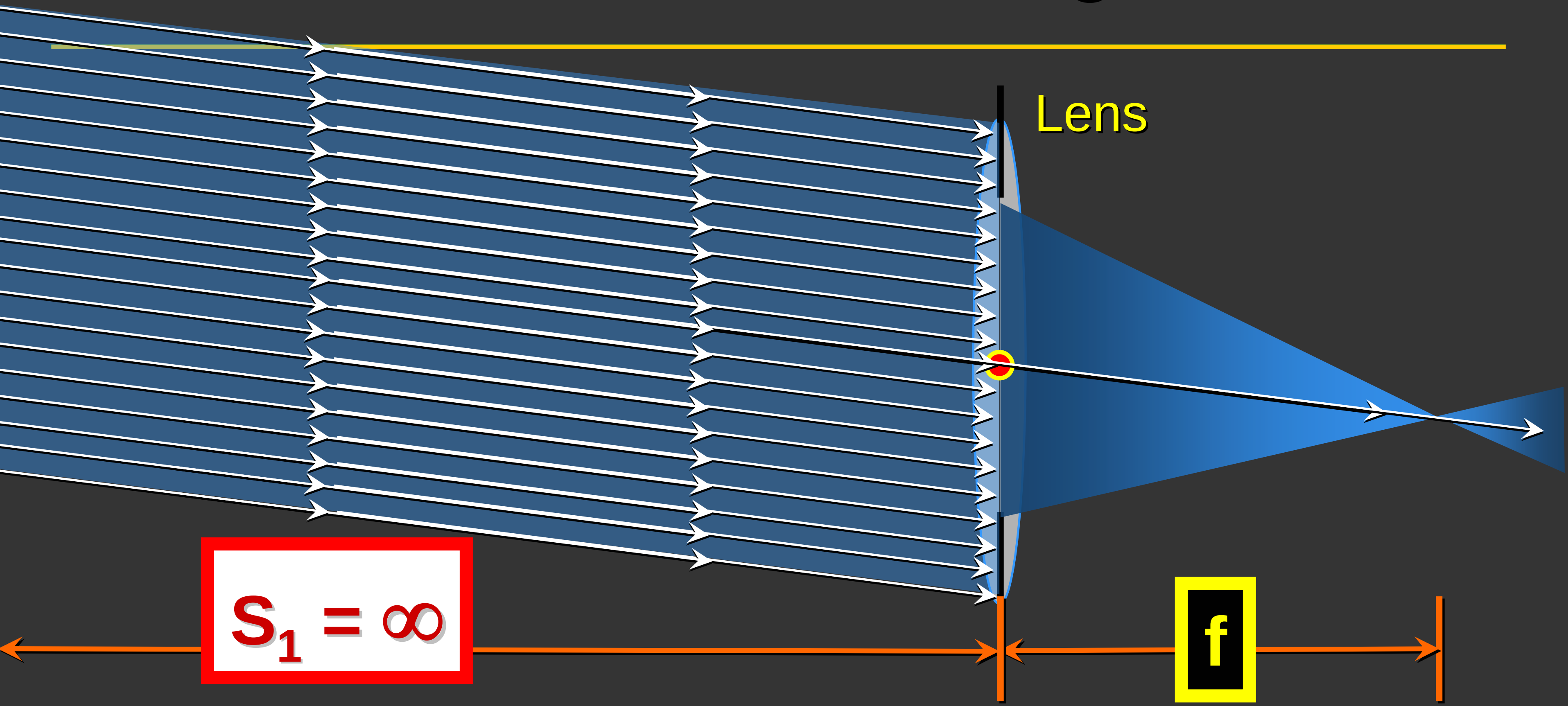
Not *One* Ray, but a *Bundle* of Rays



- (BUT Ray model *isn't perfect*: ignores diffraction)
- Lens, aperture, and diffraction sets the point-spread-function (PSF)

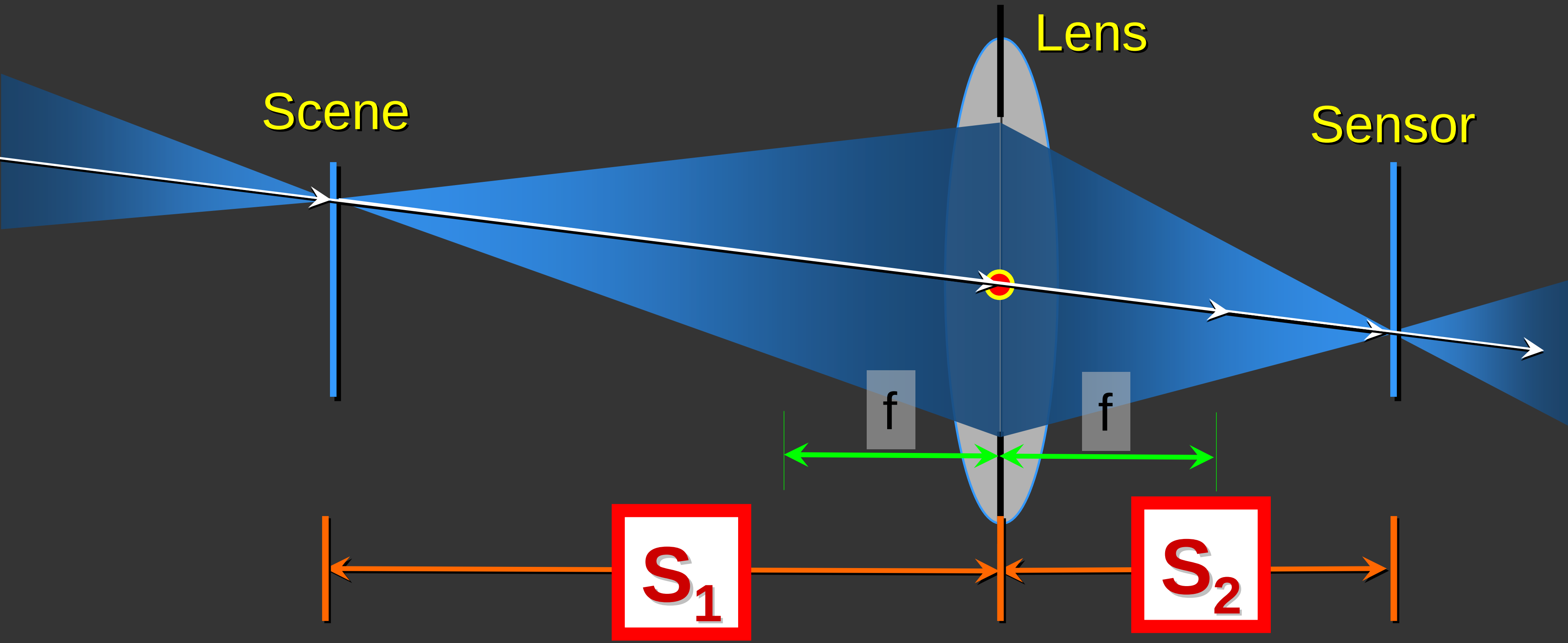
(How? See: Goodman,J.W. 'An Introduction to Fourier Optics' 1968)

Review: Focal Length f



- Lens focal length f : <u>where parallel rays converge</u>
- *<u>greater</u>* focal length: ***<u>less</u>*** ray-bending ability…
- For flat glass; for air : $f = \infty$

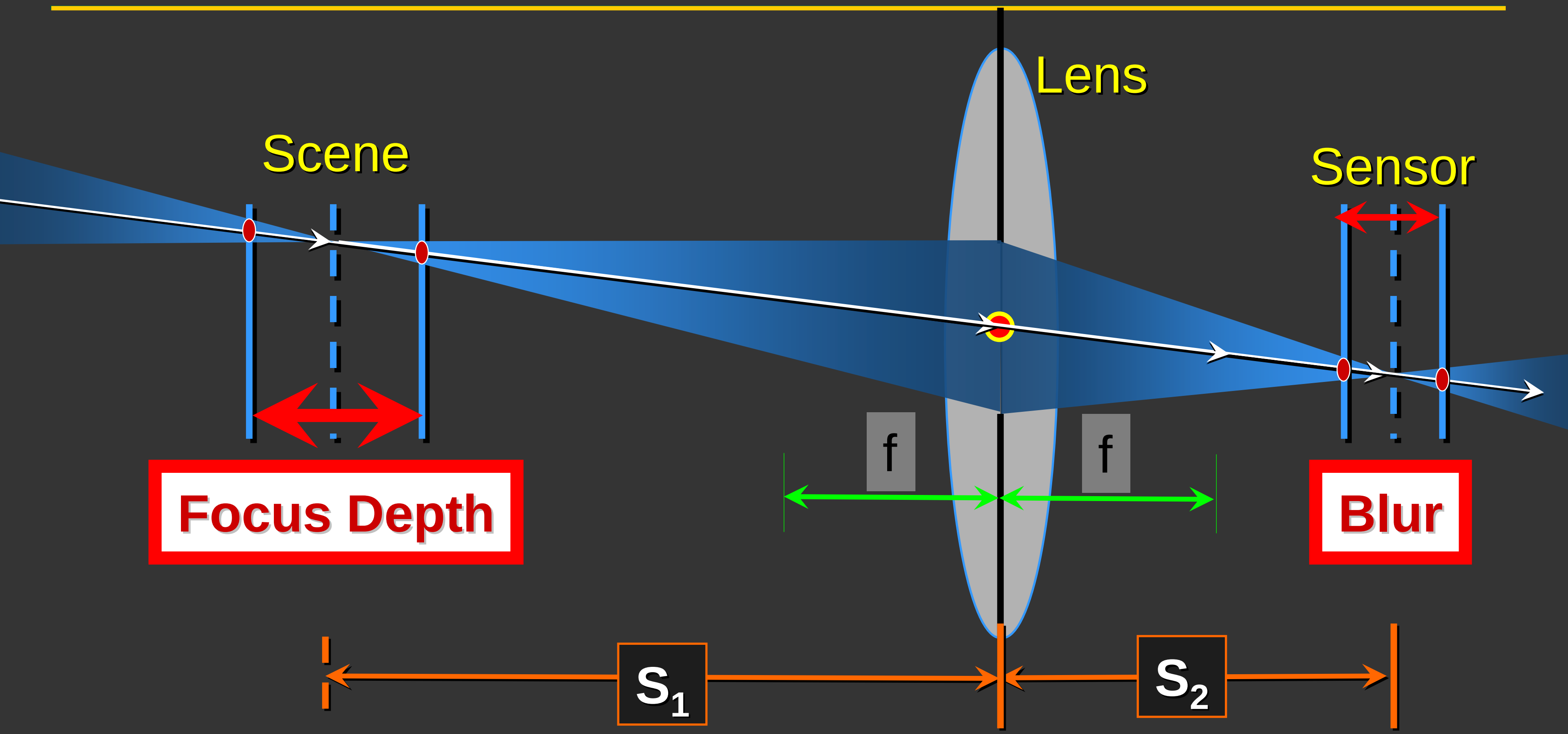
Review: Thin Lens Law



- **Thin Lens Law:** in focus when: $$\frac{1}{S_1} + \frac{1}{S_2} = \frac{1}{f}$$
- Note that $S_1 \geq f$ and $S_2 \geq f$

Try it Live! Physlets… http://webphysics.davidson.edu/Applets/Optics/intro.html

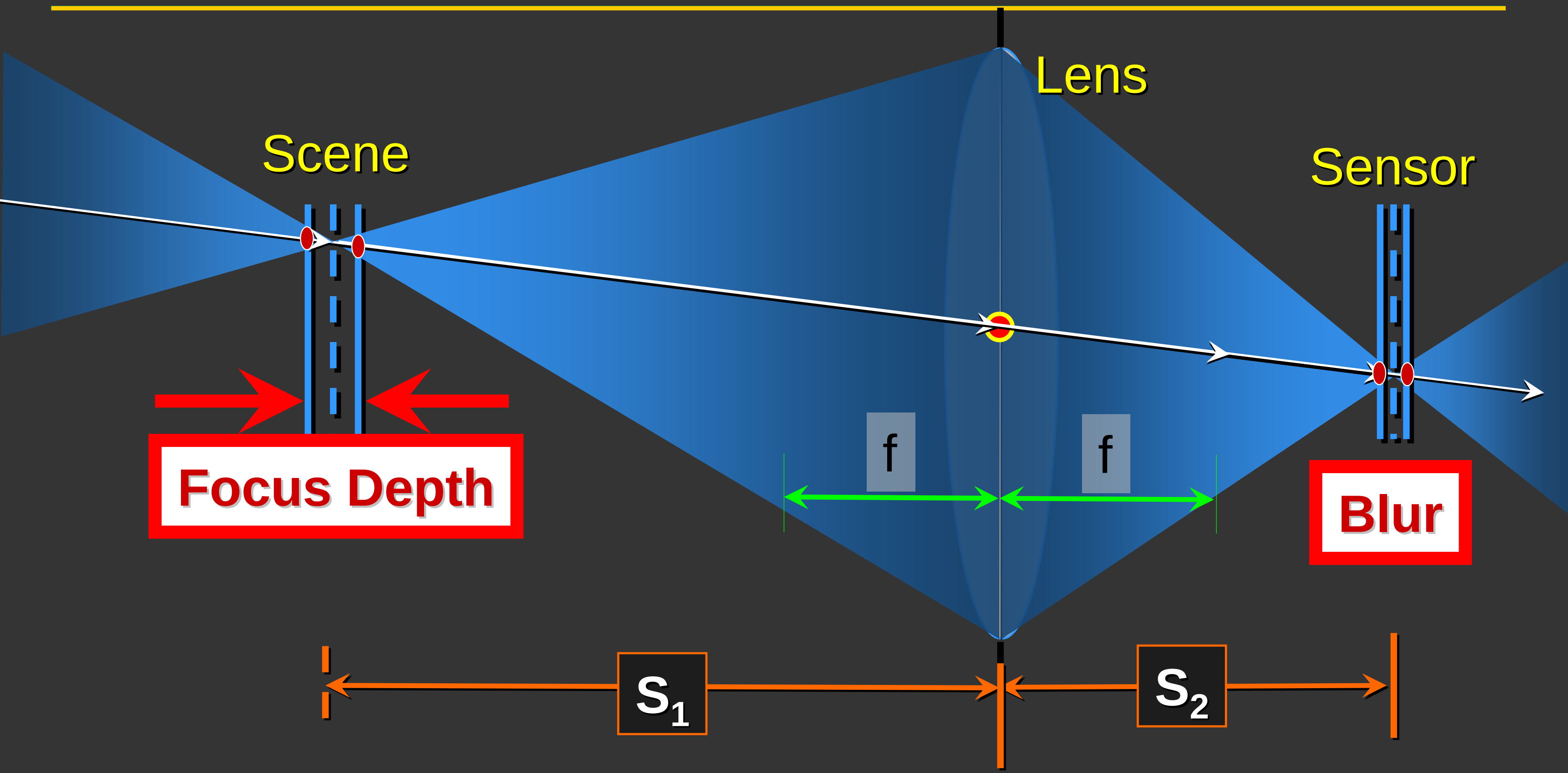
Aperture and Depth-Of-Focus:



For *same* focal length:

- Smaller Aperture → Larger focus depth, but less light

Aperture and Depth-Of-Focus:



For *same* focal length:

- **Larger Aperture → smaller focus depth, but more light**

Focal Length vs. Viewpoint vs. Focus

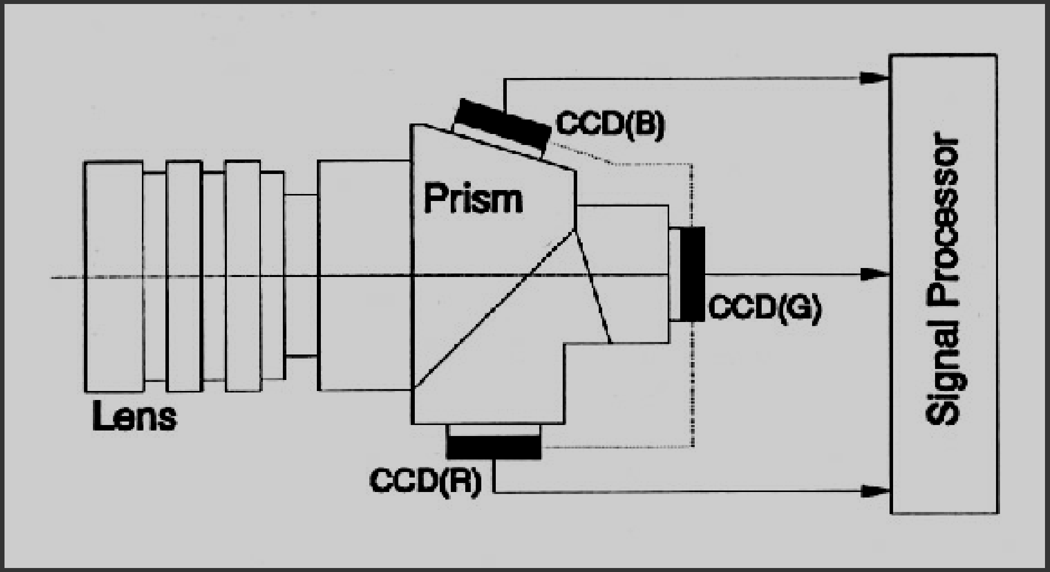
Wide angle | Standard | Telephoto

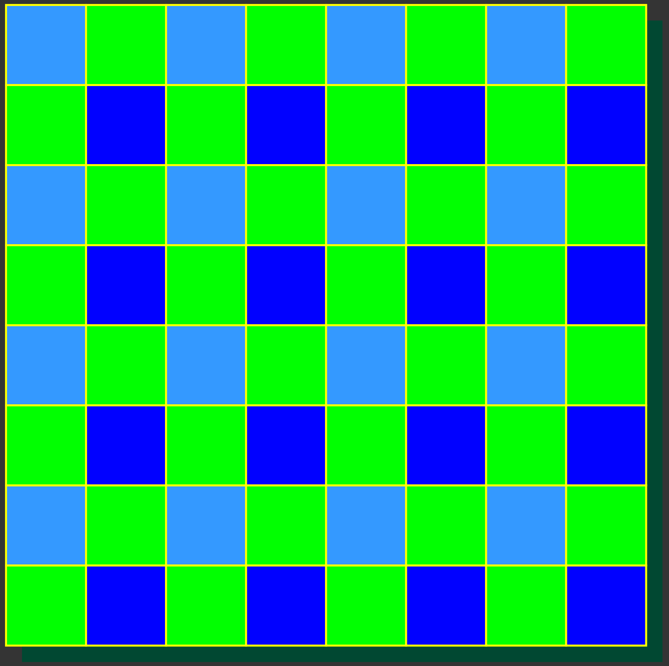
Large/Deep ← ← Depth of Focus ← ← Small/shallow

Wide angle isn’t flattering; do you know why?

Color Sensing

- 3-chip: separate R,G,B sensors, vs.
- 1-chip: interleaved R,G,B: quality vs. cost

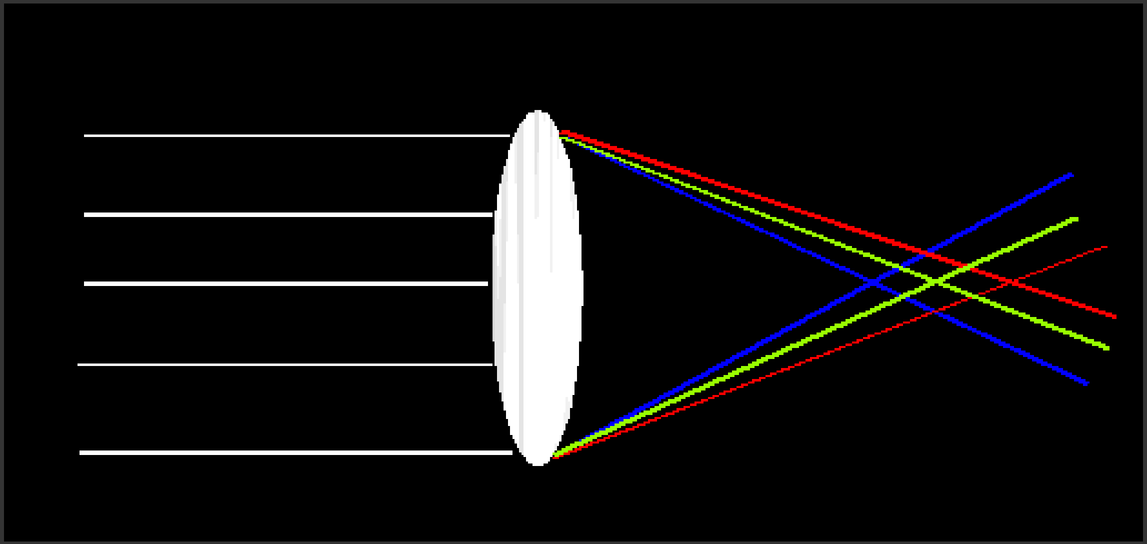




http://www.cooldictionary.com/words/Bayer-filter.wikipedia

Lens Flaws: Chromatic Aberration

- **Dispersion:** wavelength-dependent refractive index
  - (enables prism to spread white light beam into rainbow)
- Modifies ray-bending and lens focal length: f(λ)

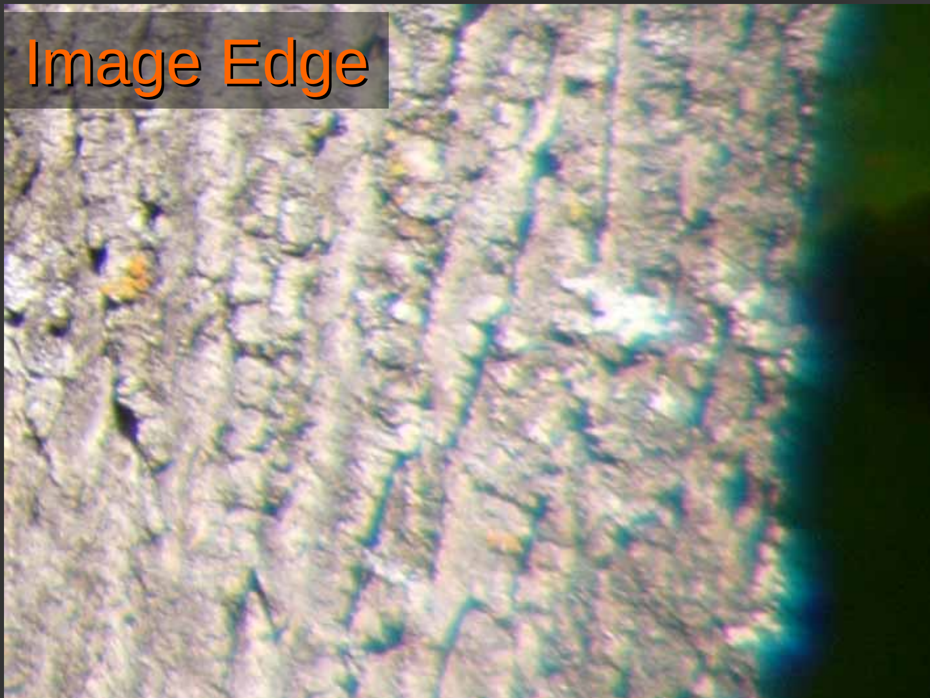


- color fringes near edges of image
- Corrections: add ‘doublet’ lens of flint glass, etc.

http://www.swgc.mun.ca/physics/physlets/opticalbench.html

Chromatic Aberration

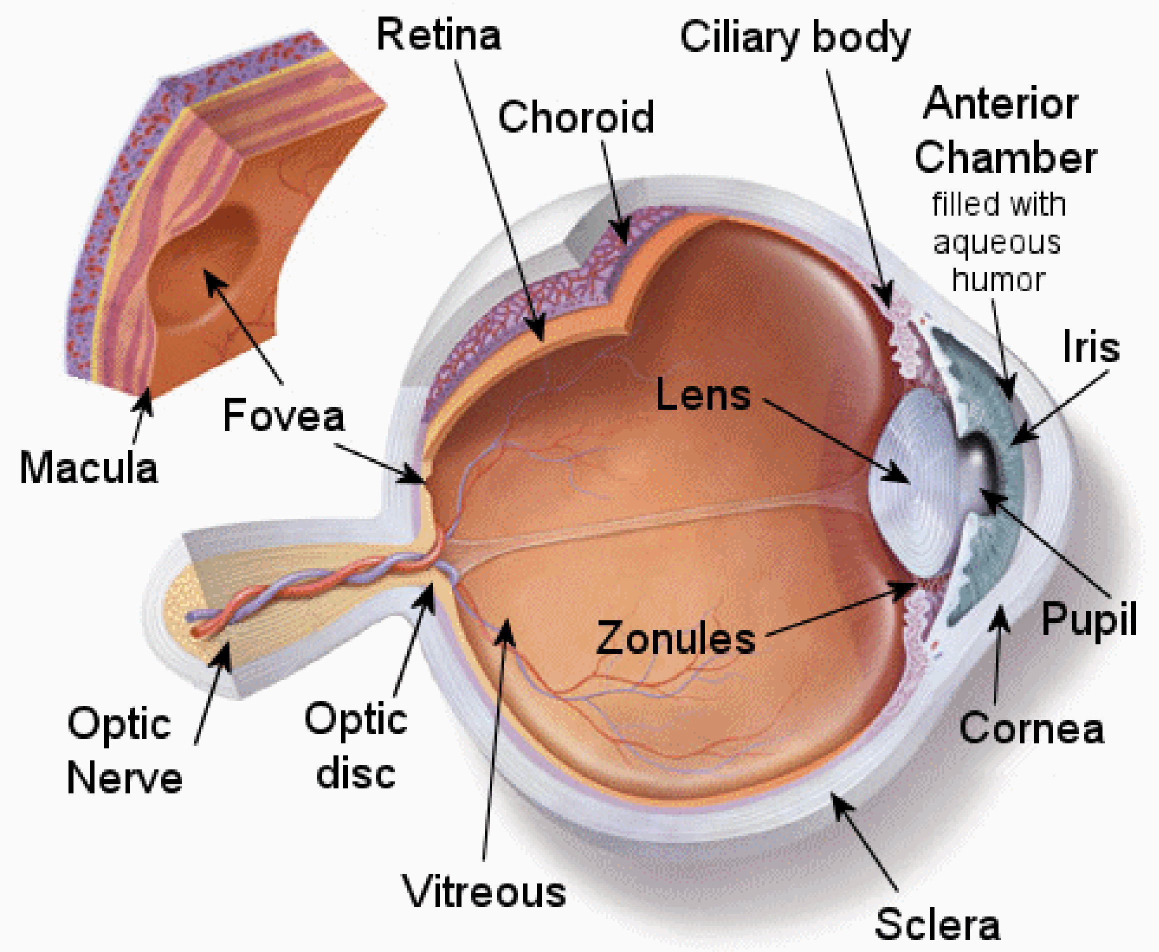
- **Lens Design Fix:** Multi-element lenses
  Complex, expensive, many tradeoffs!
- **Computed Fix:** Geometric warp for R,G,B



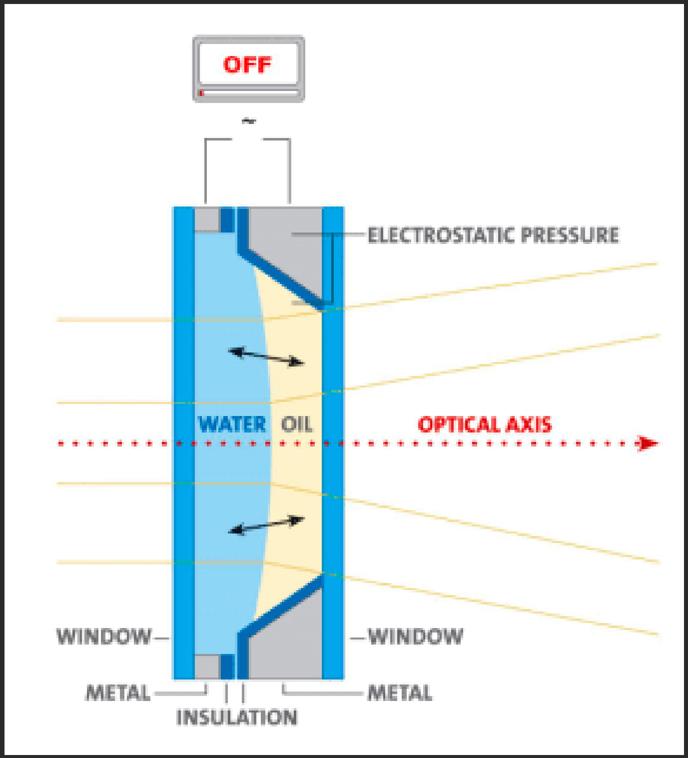
Many Limitations & Tradeoffs:
(how can computing change them?)

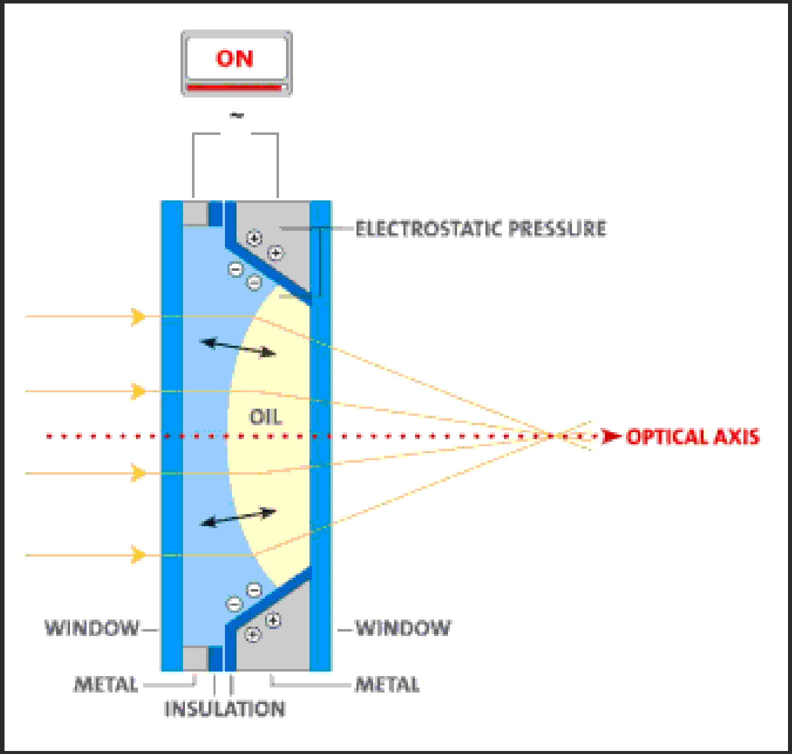
- Optics:
  Single focus distance, limited depth-of-field, limited field-of-view, internal reflections/flare/glare
- Lighting:
  Camera has no knowledge of ray source strength, position, direction; little control (e.g. flash)
- Sensor:
  Exposure setting, motion blur, noise, response time,…
- Processing:
  - Quantization/color depth, camera shake, scene movement…

The Eye's Lens



Varioptic Liquid Lens: Electrowetting





Varioptic, Inc., 2007

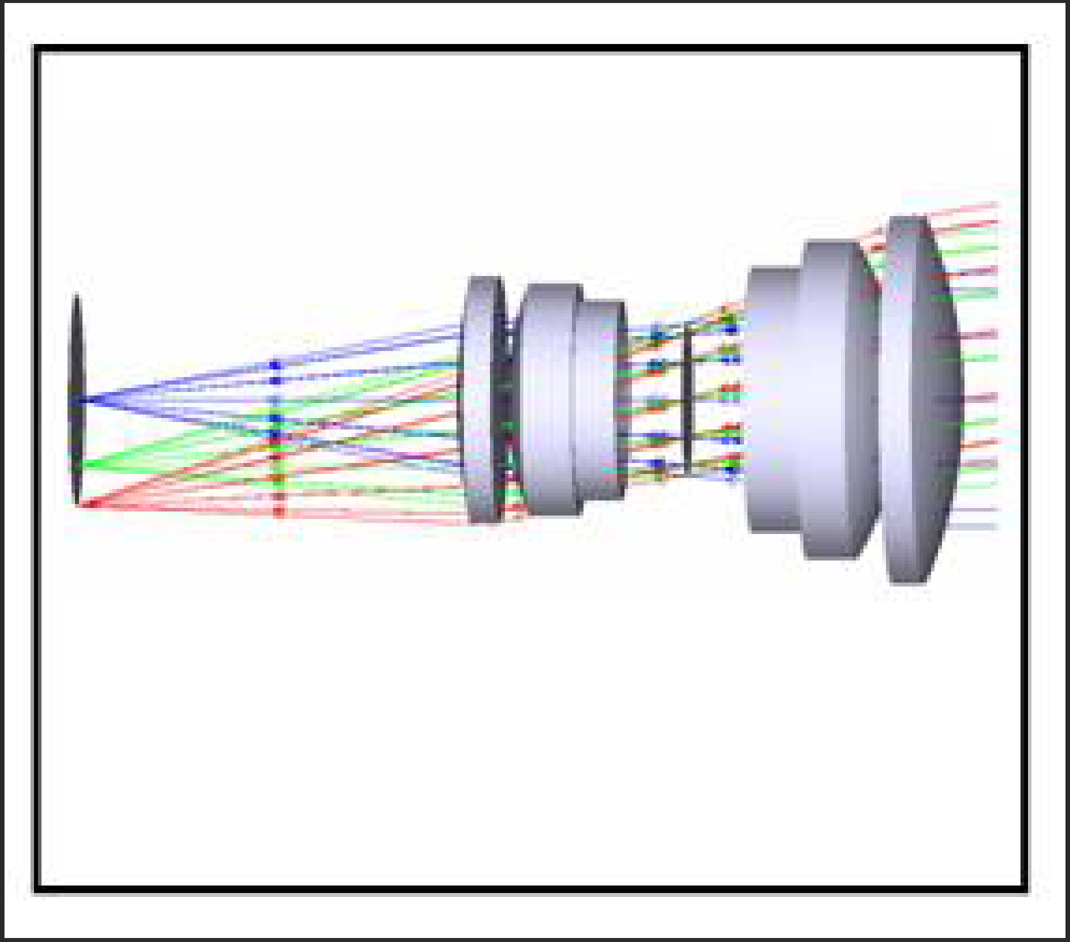
Varioptic Liquid Lens

(Courtesy Varioptic Inc.)

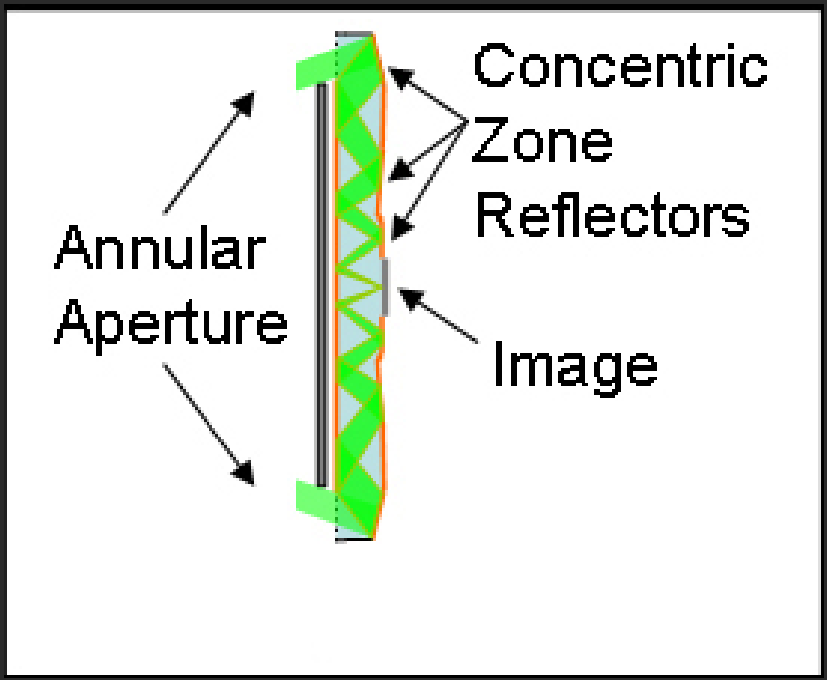
Captured Video

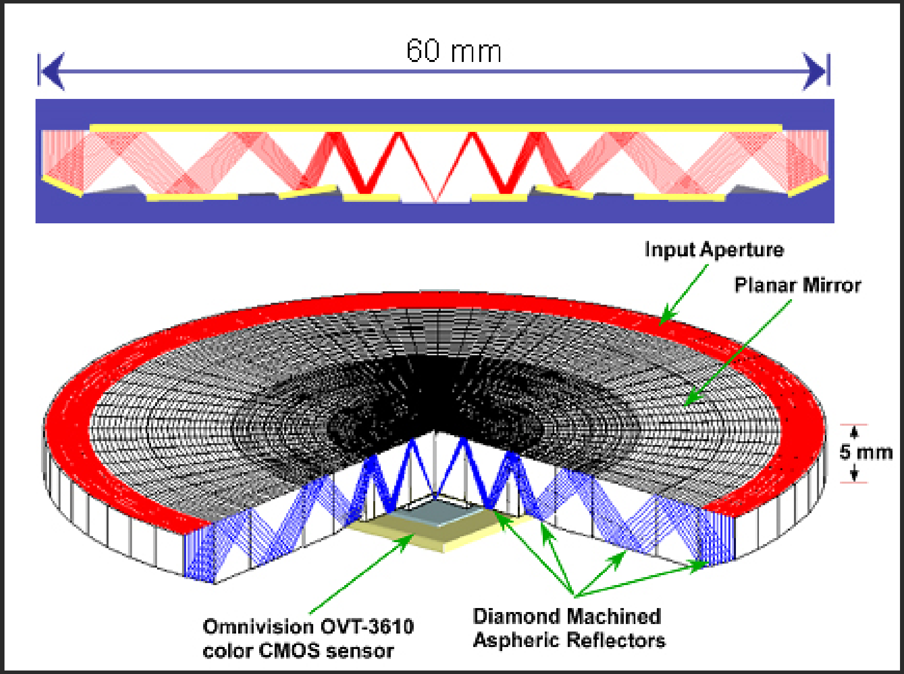
(Courtesy Varioptic Inc.)

Conventional Compound Lens



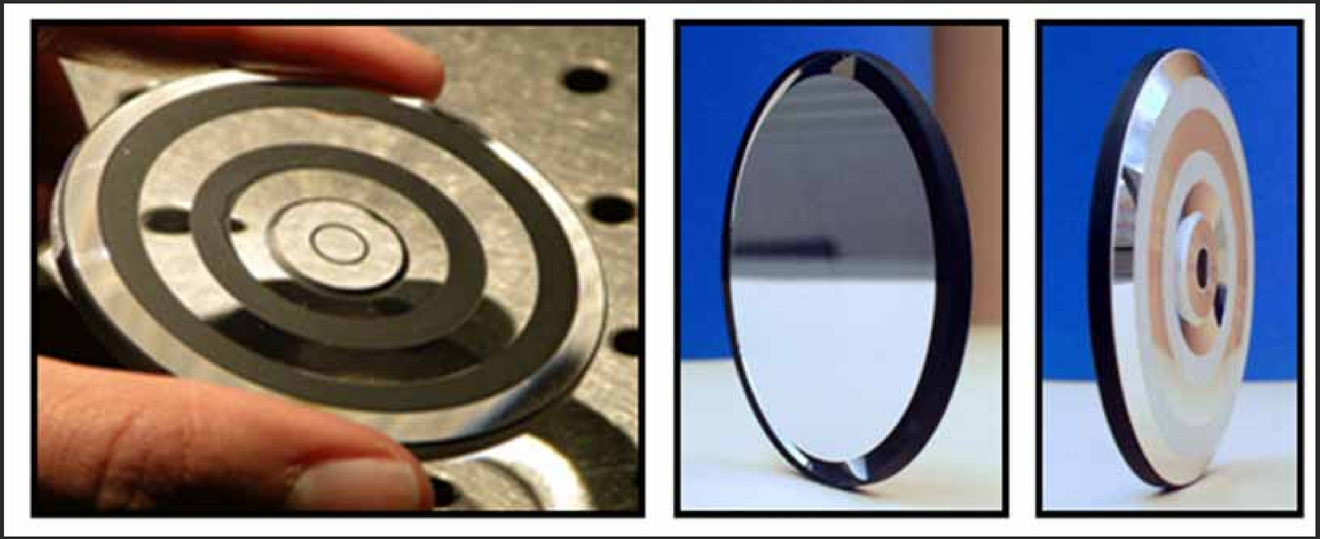
"Origami Lens": Thin Folded Optics (2007)





"Ultrathin Cameras Using Annular Folded Optics, "
E. J. **Tremblay**, R. A. Stack, R. L. Morrison, J. E. **Ford**
Applied Optics, 2007 - OSA

Origami Lens



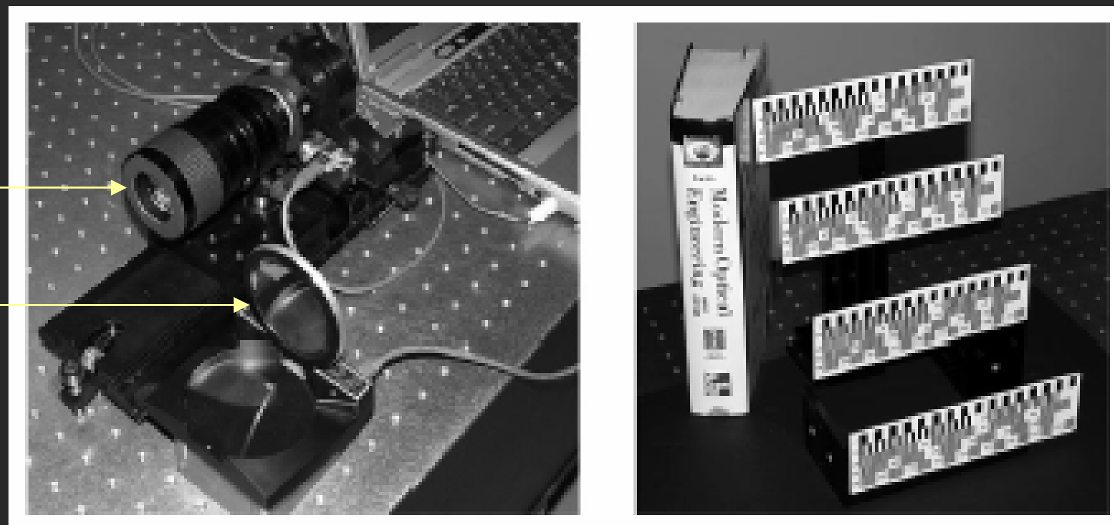
Conventional Lens

Origami Lens

Optical Performance

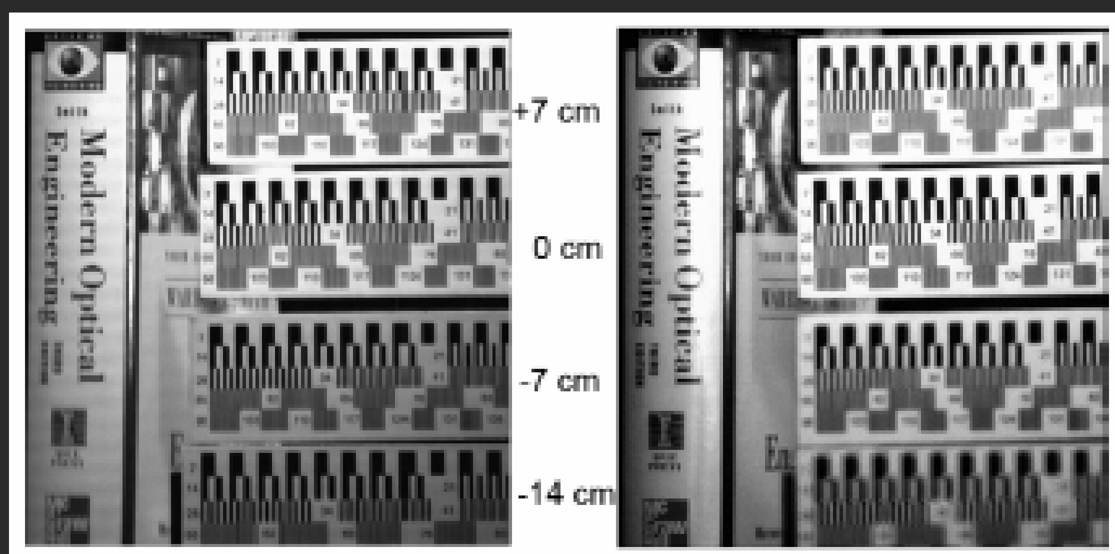
Conventional

Origami



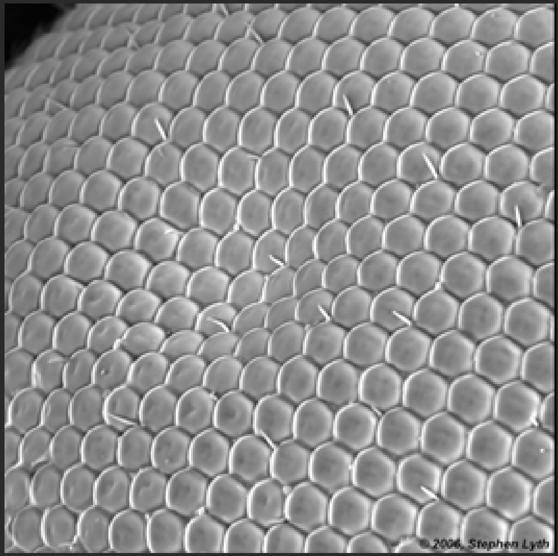
Scene

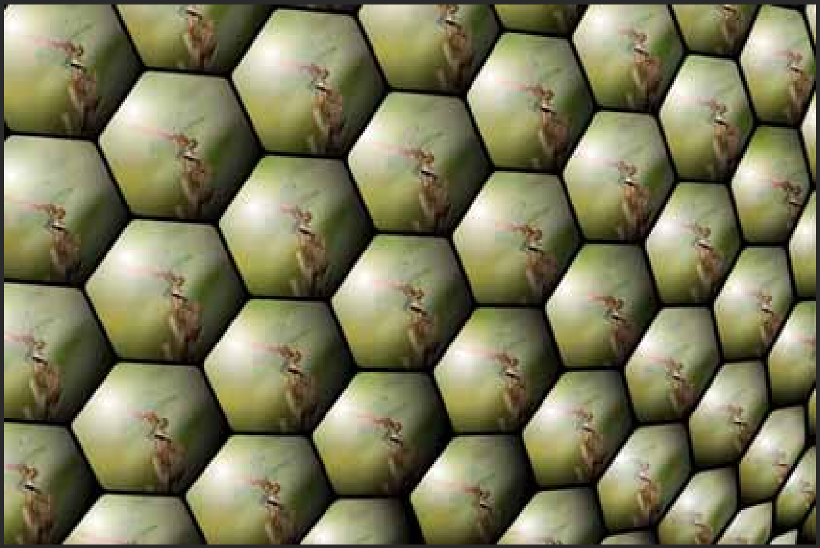
Conventional Lens Image



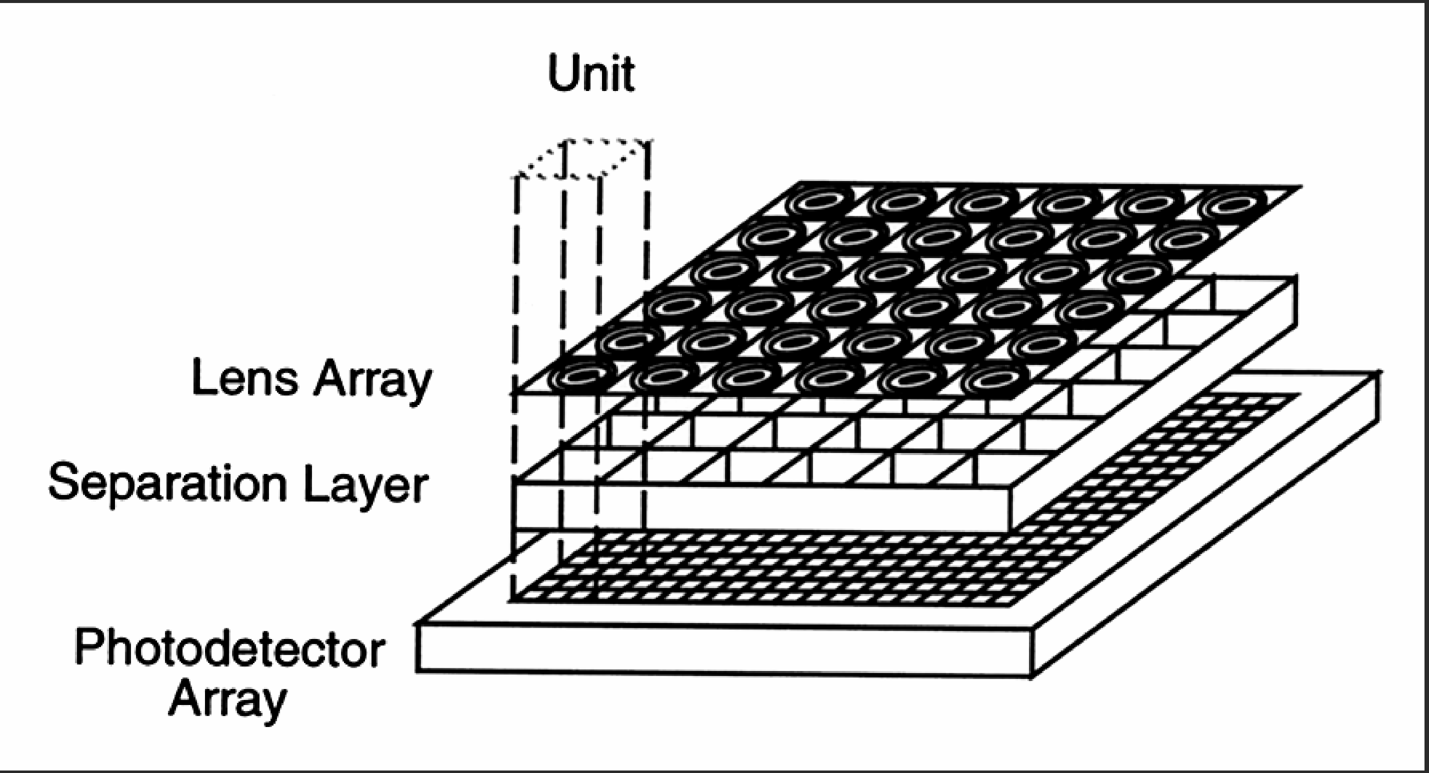
Origami Lens Image

Compound Lens of Dragonfly



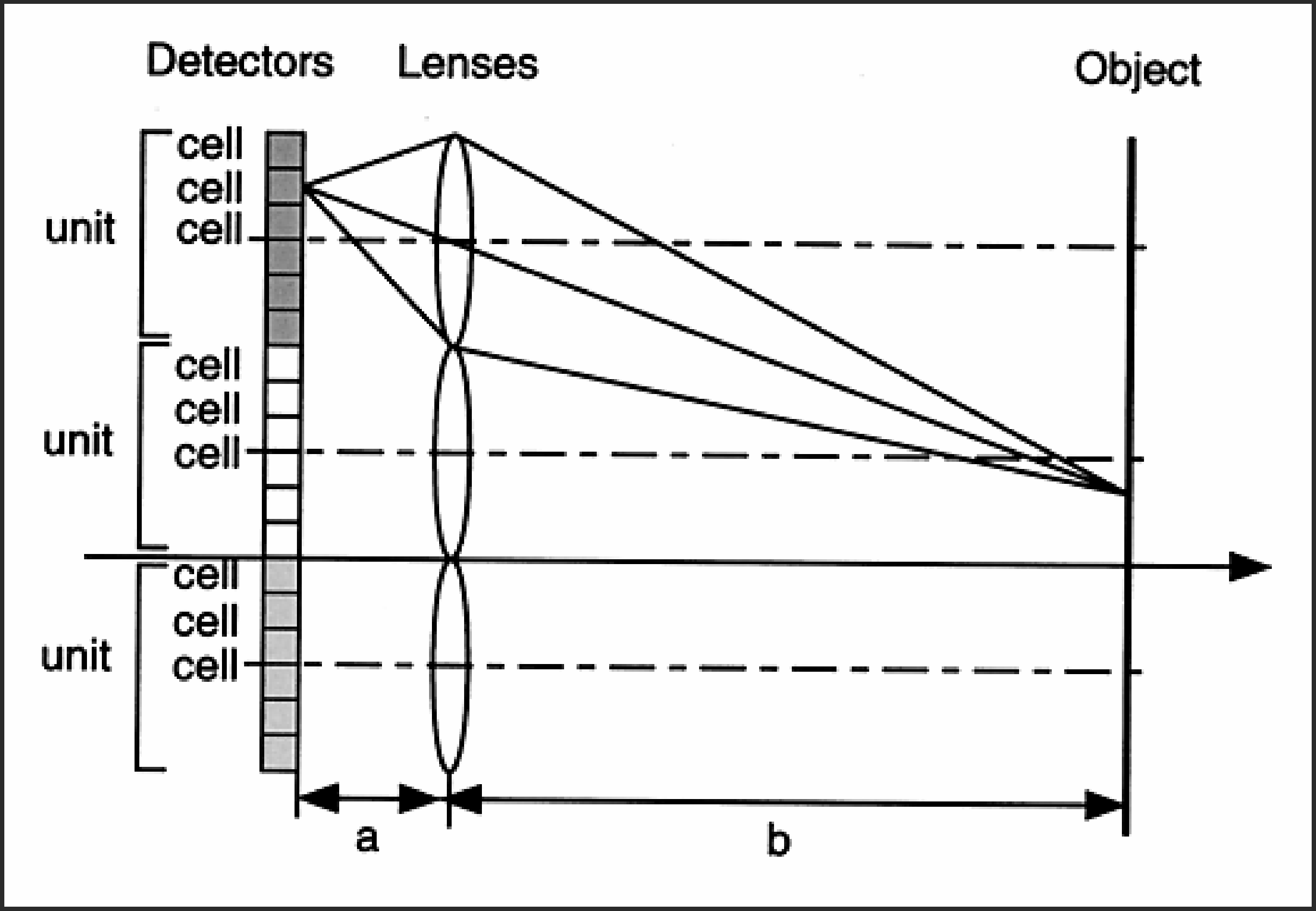


TOMBO: Thin Camera (2001)

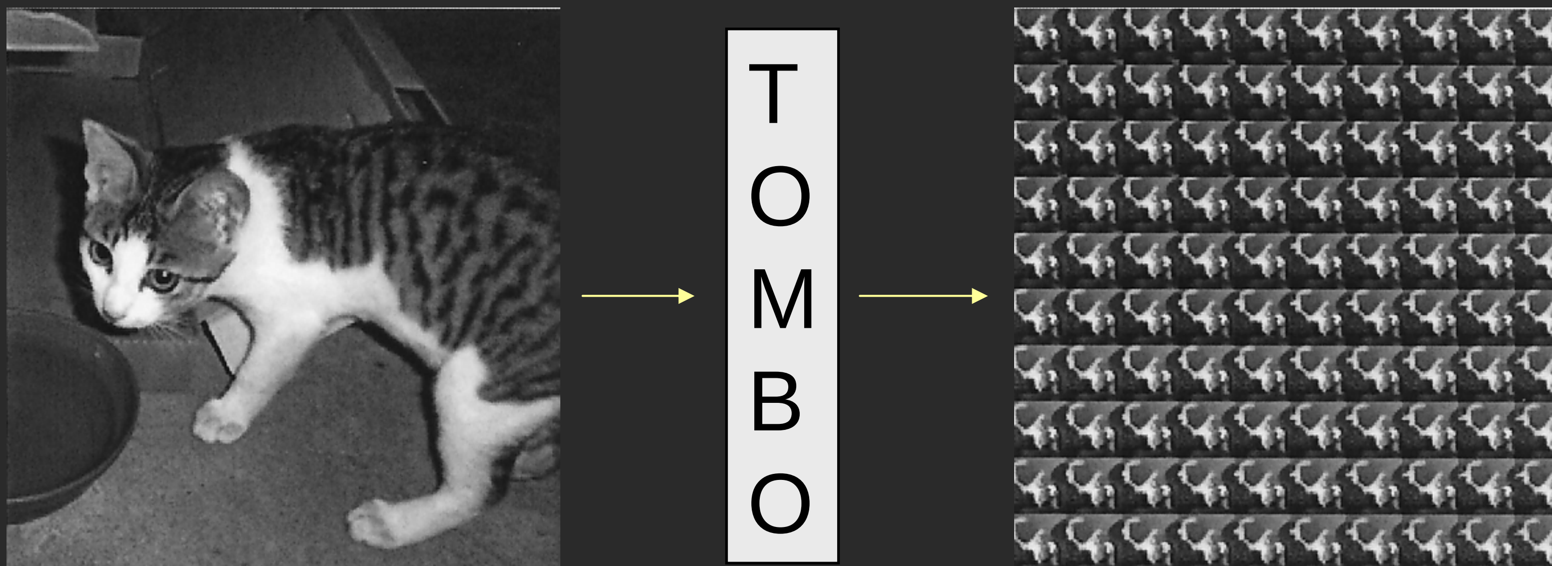


"Thin observation module by bound optics (TOMBO),"
J. Tanida, T. Kumagai, K. Yamada, S. Miyatake
Applied Optics, 2001

TOMBO: Thin Camera



Captured Image



Scene

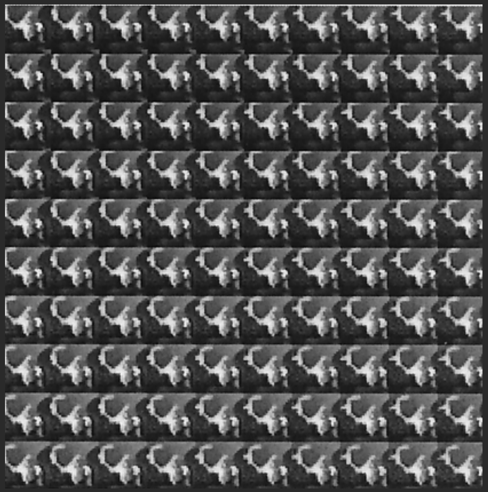
Captured Image

(Multiple low-resolution copies of the scene)

$$\mathbf{g} = \mathbf{H}\mathbf{f}$$

Image = Optics . Scene

Reconstructed Image



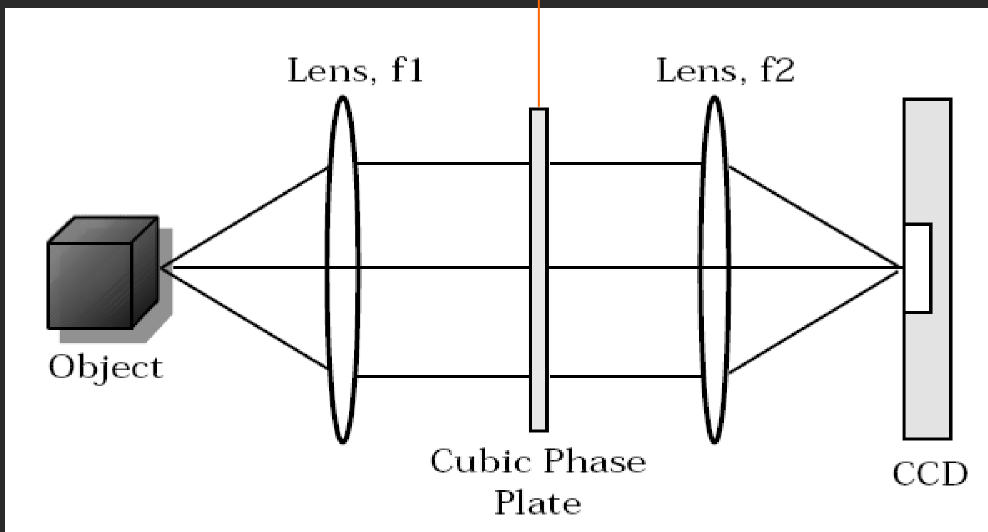
$$\mathbf{f} = \mathbf{H}^{+}\mathbf{g}$$

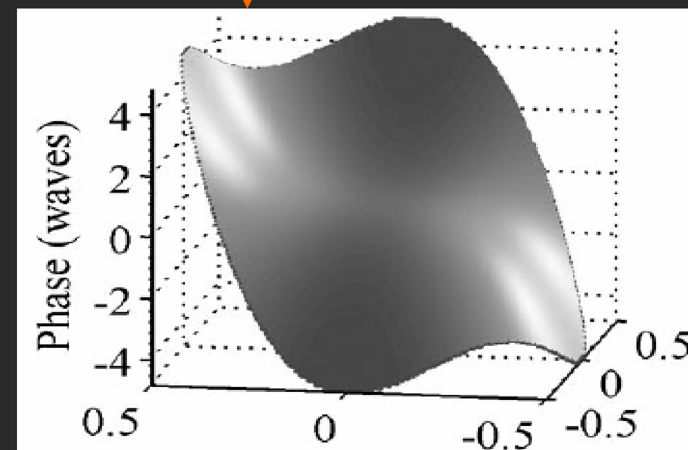
Conventional Lens: Limited Depth of Field

Open Aperture

Smaller Aperture

Wavefront Coding using Cubic Phase Plate

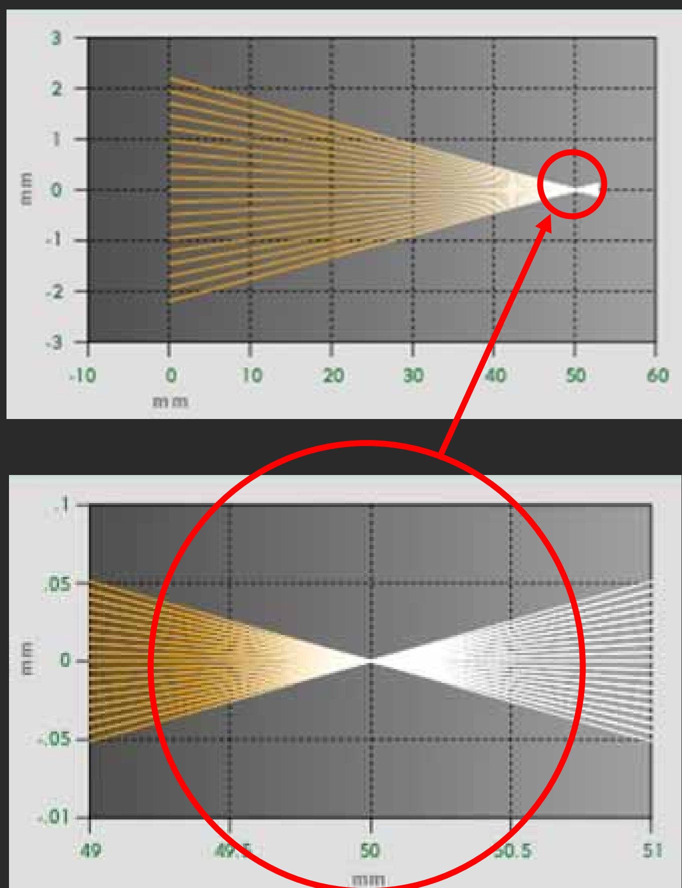




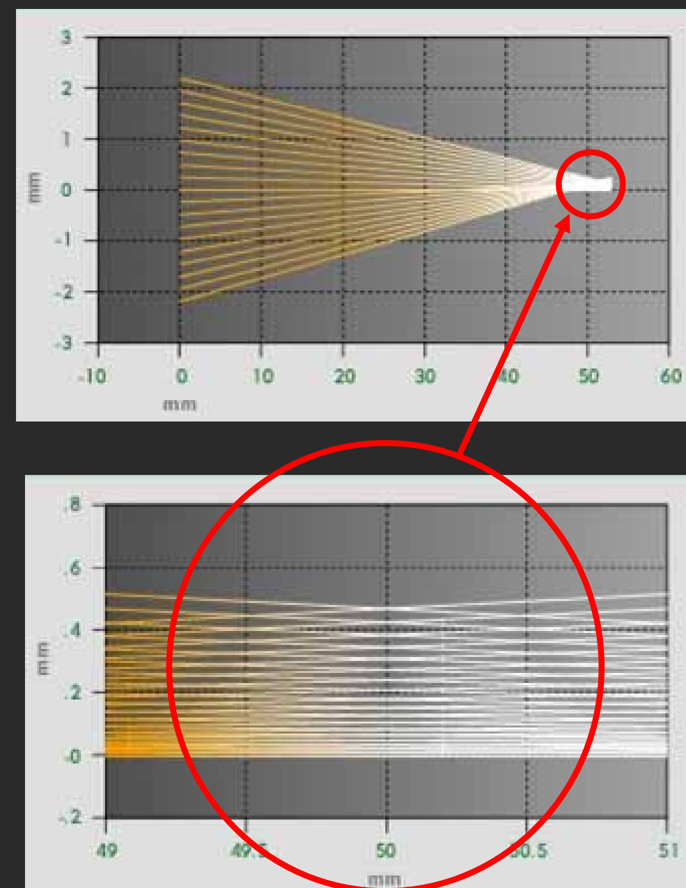
"*Wavefront Coding: jointly optimized optical and digital imaging systems*",
E. Dowski, R. H. Cormack and S. D. Sarama ,
Aerosense Conference, April 25, 2000

Depth Invariant Blur

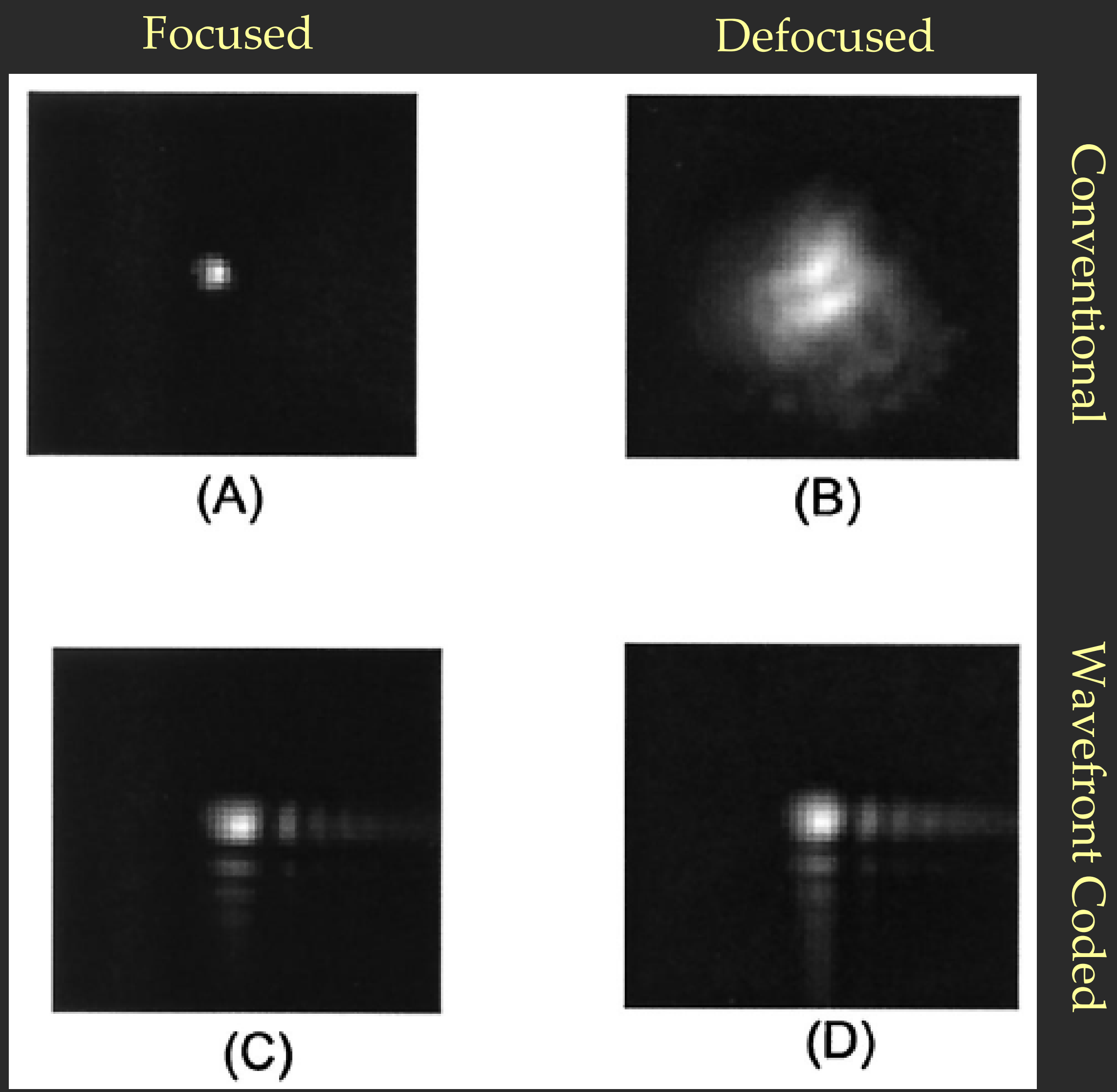
Conventional System



Wavefront Coded System



Point Spread Functions



Example

Conventional System

Wavefront Coded System

Open Aperture

Captured Image

Stopped Down

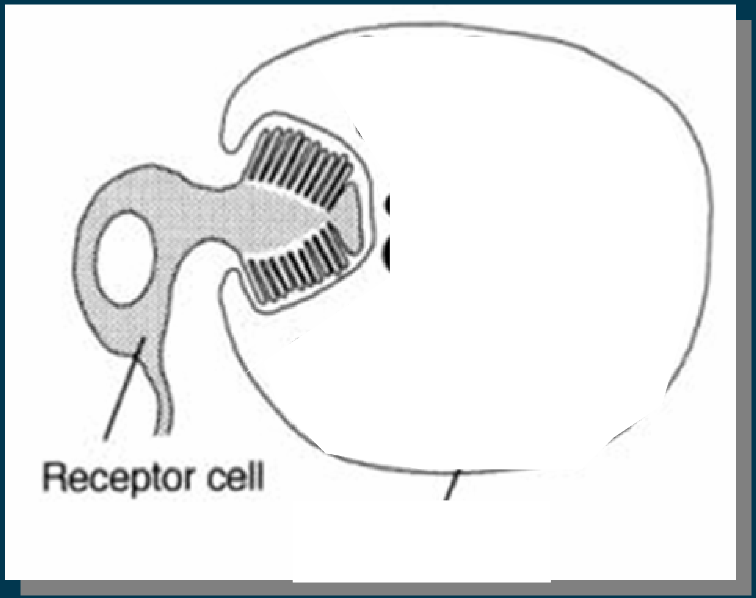
After Processing

Wavelength Manipulation

- Sunglasses changing color instantly
- Electrochromic Polymer sensitive to current levels

Chunye Xu, University of Washington

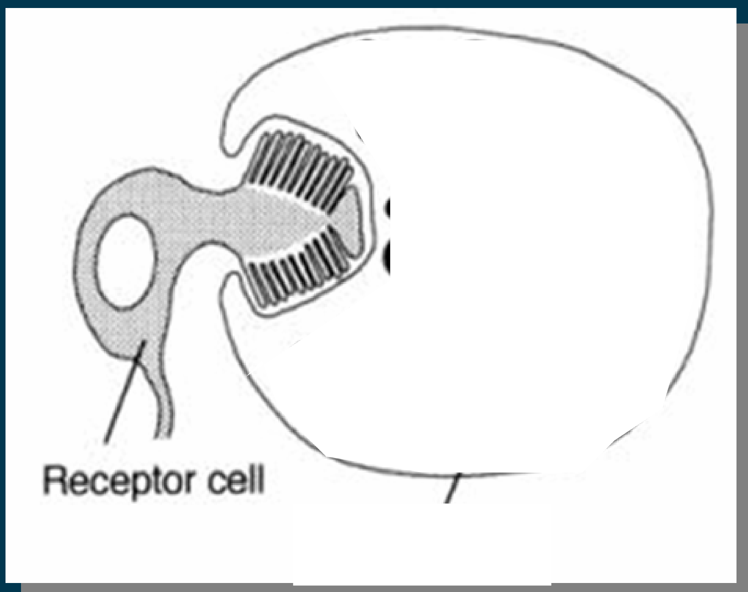
Simplest Visual Organs



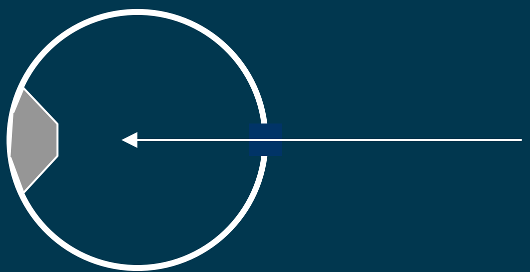
Larval Trematode Worm

‘Single Pixel’ Camera

Simplest Visual Organs

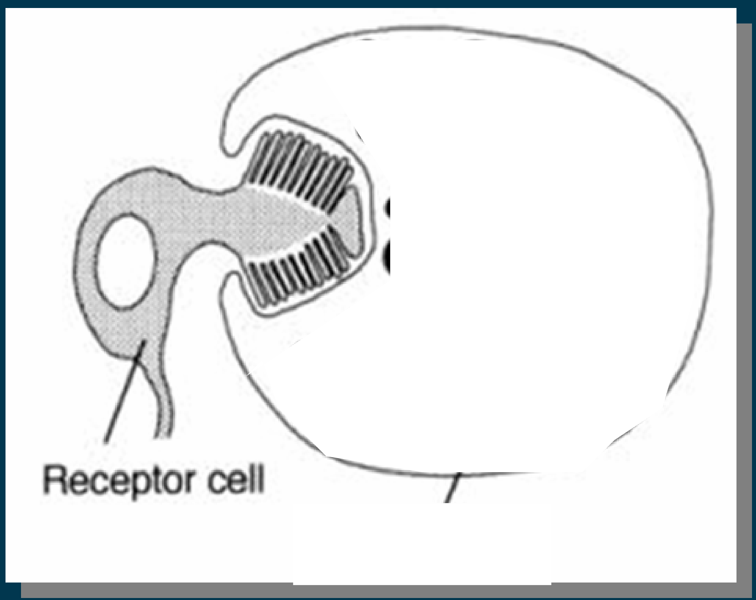


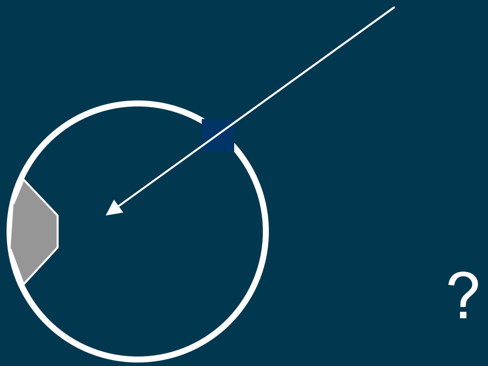
Larval Trematode Worm



'Single Pixel' Camera

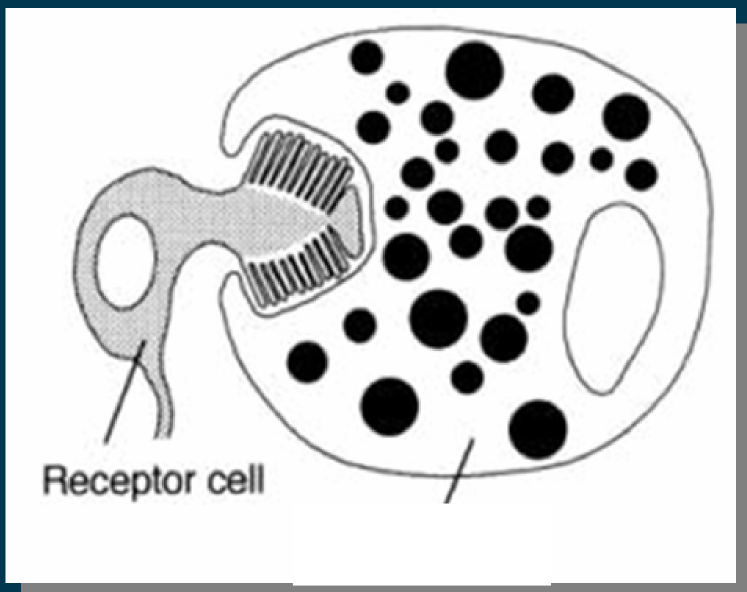
Simplest Visual Organs



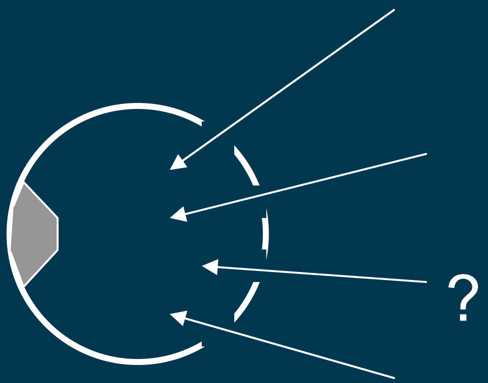


Larval Trematode Worm

Special Aperture



Larval Trematode Worm

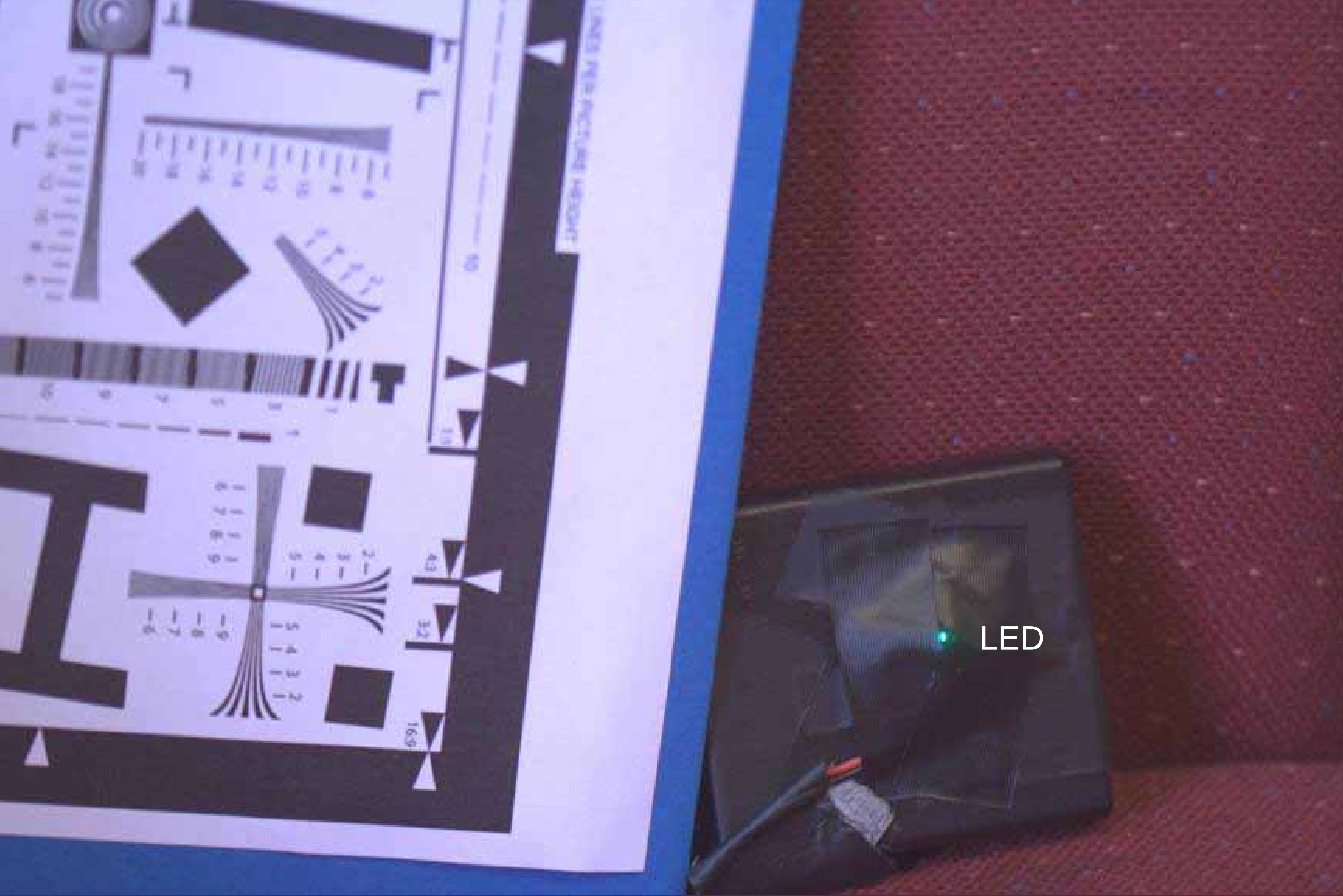


Special Aperture

The aperture of a 100 mm lens is modified

Insert a coded mask with chosen binary pattern

Rest of the camera is unmodified



In Focus Photo

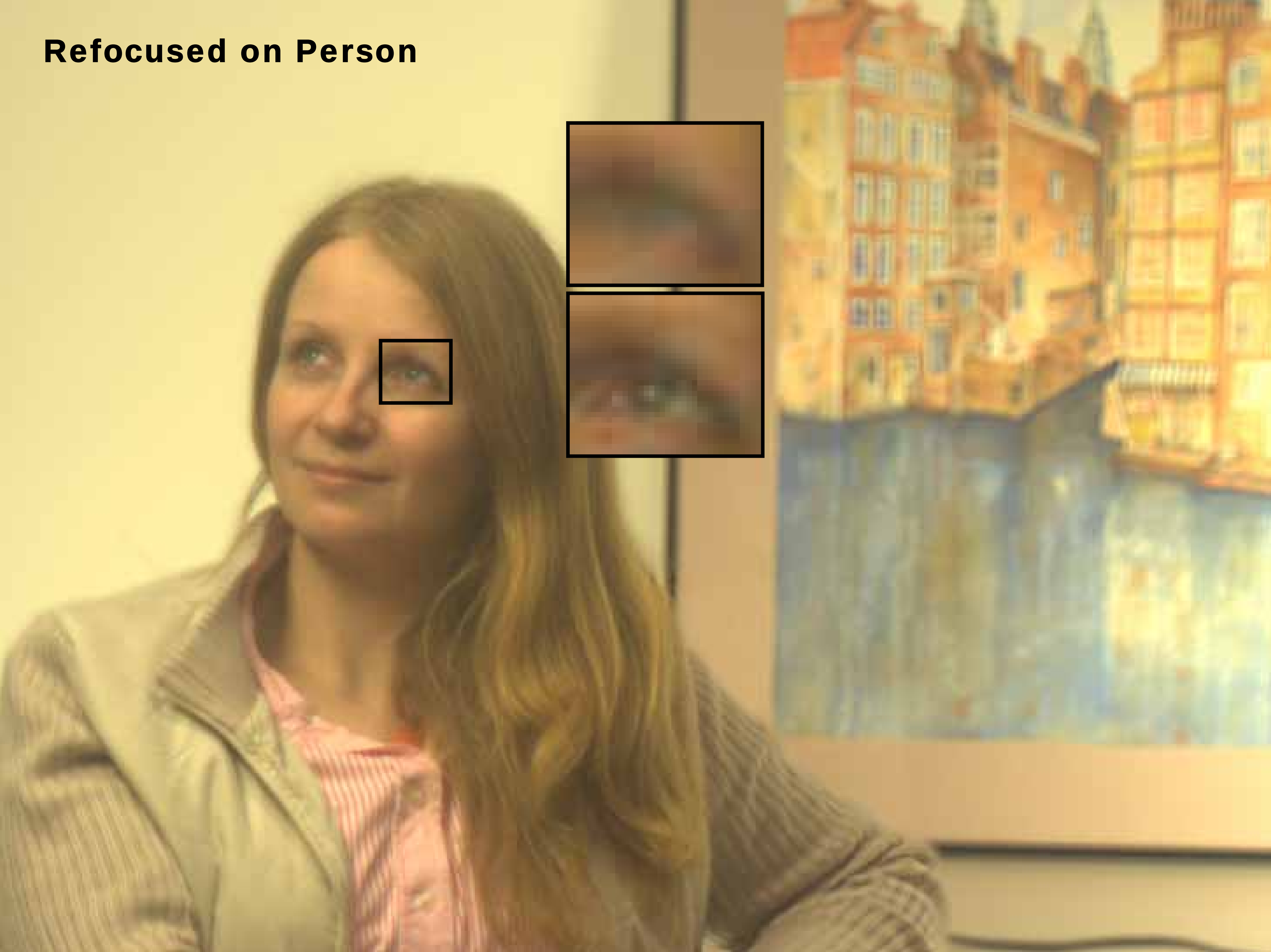
Out of Focus Photo: Open Aperture

Out of Focus Photo: Coded Aperture

Bokeh

Out of Focus Photo: Coded Aperture

Captured Blurred Photo

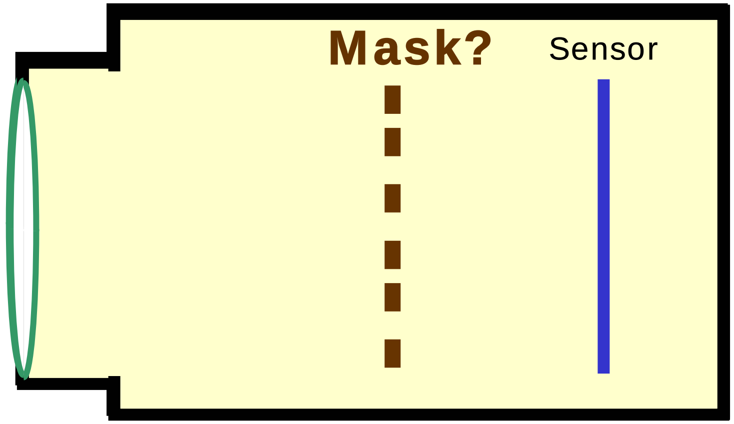

Refocused on Person

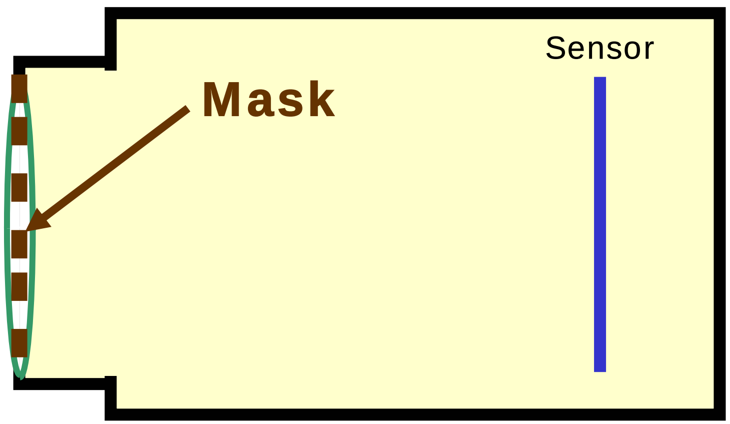
Digital Refocusing

Captured Blurred Photo

Digital Refocusing

Refocused Image on Person

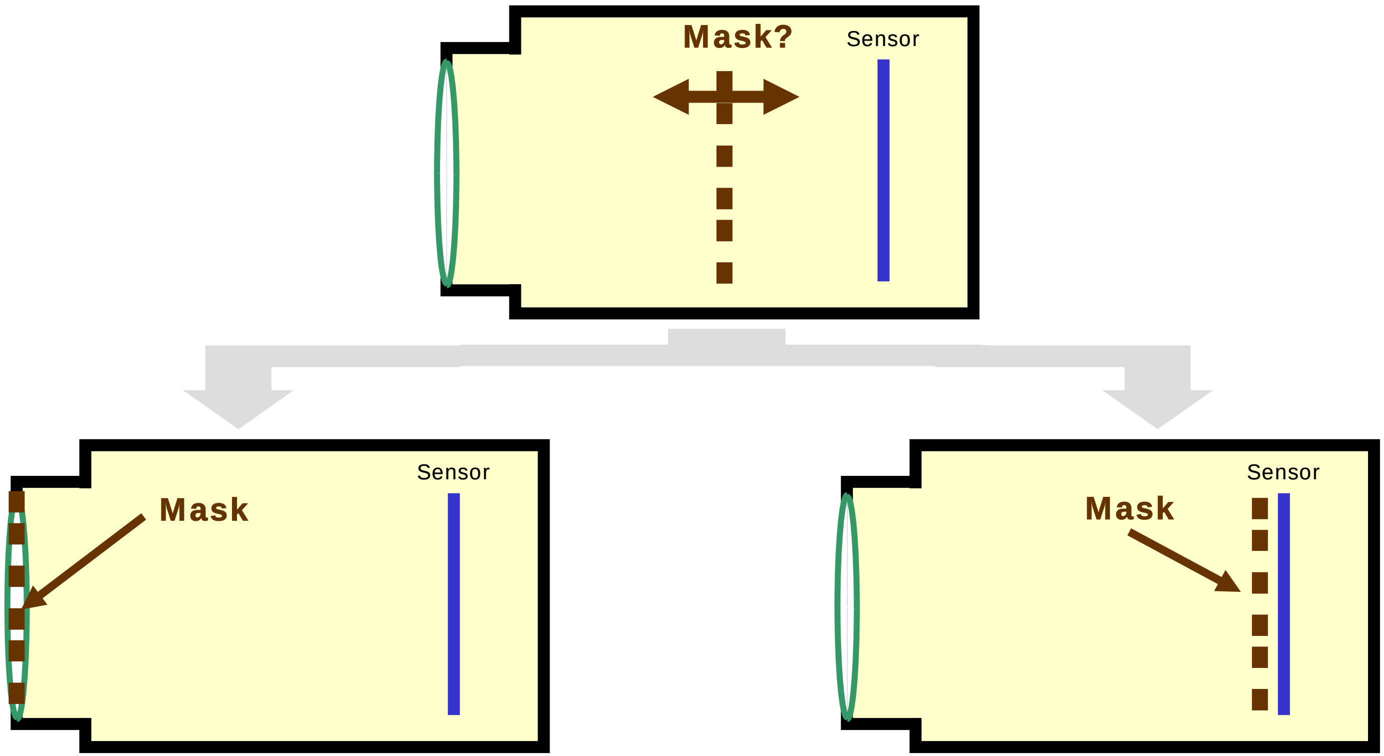




Digital Refocusing

Heterodyne Light Field Camera

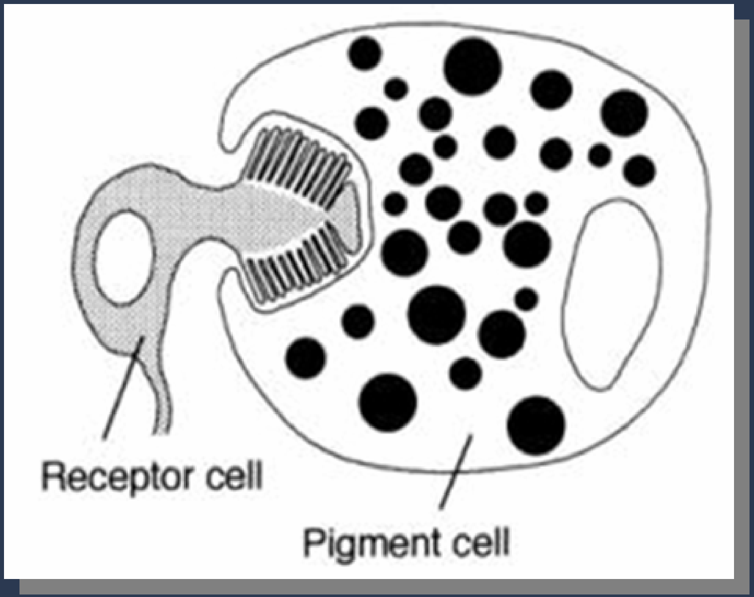
Mask = more information?



Digital Refocusing

Heterodyne Light Field Camera

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



Larval Trematode Worm

What *is* Photography?

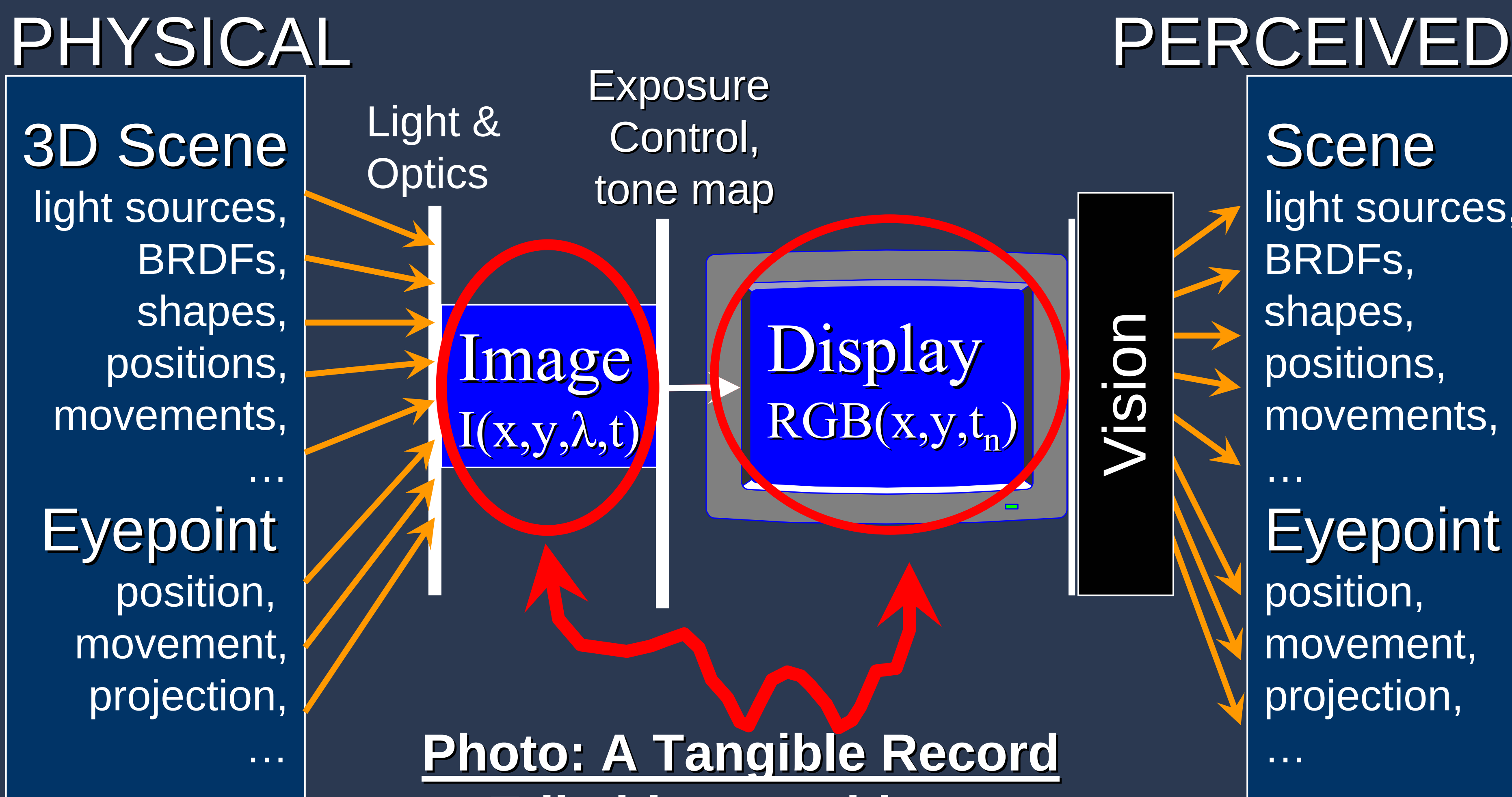
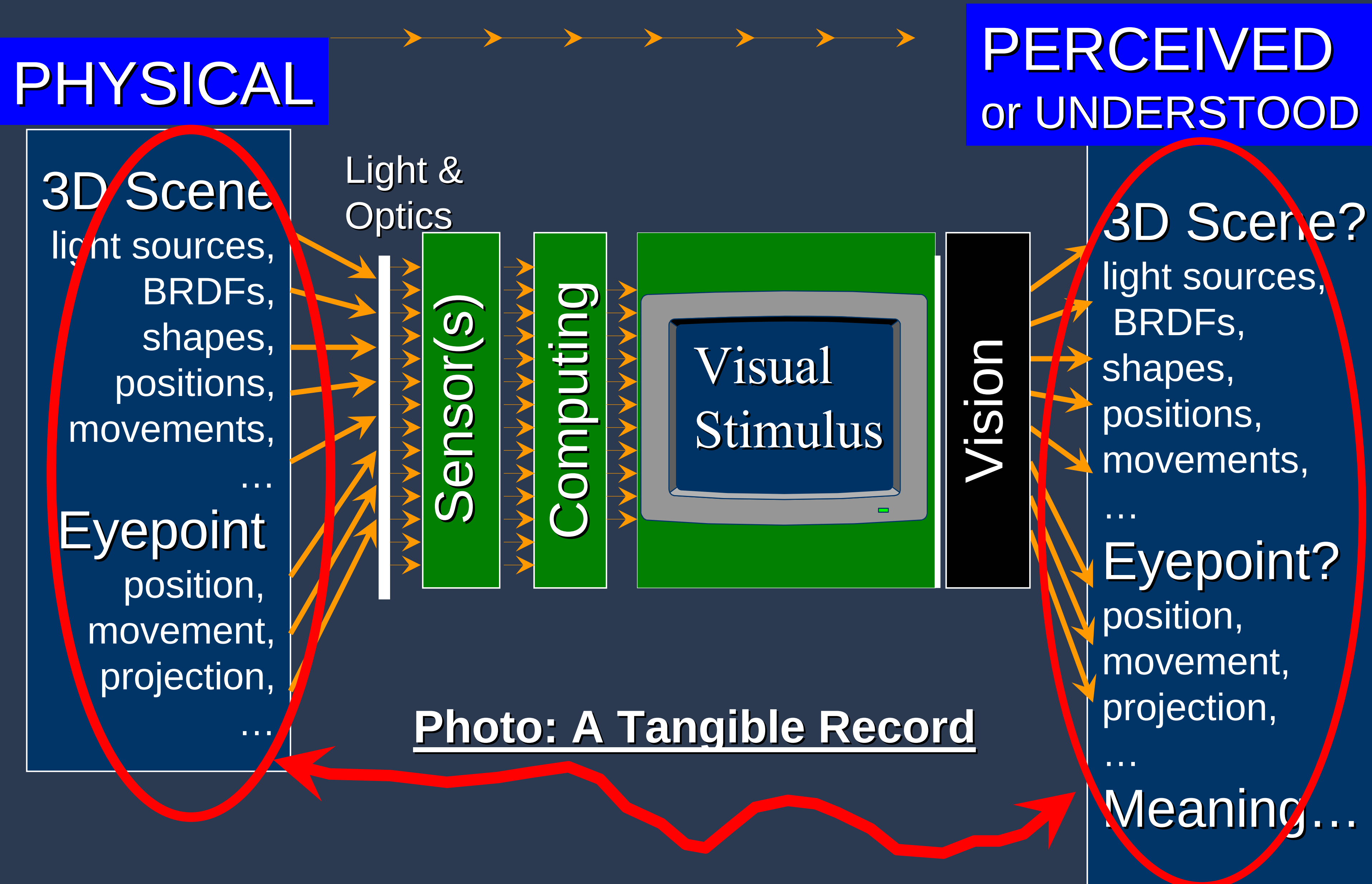


Photo: A Tangible Record

Editable, storable as

Film or Pixels

Ultimate Photographic Goals



Multiperspective Camera?

[Jingyi Yu' 2004]

Next Class

- Homework
  - How can we augment the camera to support best 'image search'?
  - Search=segment/identify/recognize/transform/compare/archive
  - How can we make the visual experience machine readable? Is this the key problem? 3D reconstruction? Hardware and software solutions? Crowdsourcing? Metadata tagging?
  - Material index/Segmentation/Repeatable view and illumination invariance/
  - Email to [raskar@media.mit..]
- Volunteer
  - Class notes
  - Select/read/present/paper
    - Visual Social Computing
    - Beyond Visible Spectrum
    - Mobile Photography
    - Emerging sensors
    - [Send me email ..]
  - (Extra Credit)

Next Wedn 3pm

Less is More: Coded Computational Photography

Speaker: Ramesh Raskar, Associate Professor, MIT Media Lab
Date: Wednesday, February 20 2008
Time: 3:00PM to 4:00PM
Refreshments: 2:45PM
Location: Star Seminar Room (32-D463)

	Topic	Topic	Guest Speaker
1	Feb 06	Introductions	
2	Wed 13 Feb	Imaging Devices, Modern Optics and Lenses	
3	Wed 20 Feb	Mobile Photography	
4	Wed 27 Feb	Visual Social Computing and Citizen Journalism	Google Maps Streetview (Luc Vincent, TBA)
5	Wed 05 Mar	Emerging Sensor Technologies	Nokia Research, Mobile Computational Photography (TBA)
6	Wed 12 Mar	Beyond Visible Spectrum	RedShift Technologies(Matthias Wagner, Thermal Imaging)
7	Wed 19 Mar		Intel Research (Rahul Sukthankar)
SPRING BREAK			
8	Wed 02 Apr	Trust in Imaging	Microsoft ?
9	Wed 09 Apr	Computational Imaging in Sciences	Canon USA (Consumer Imaging Group) (TBA)
10	Wed 16 Apr	Solutions for Visually Challenged	Sony EyeToy
11	Wed 23 Apr	NO class	
12	Wed 30 Apr	Cameras in Developing Countries Future Products and Business Models	HP Research Labs (Tom Malzbender on CameraPhone Usage, GPS-based tools)
13	Wed 07 May	Student Presentations	
14	Wed 14 Ma	Student Presentations	