


Computational Photography

Introduction

Jongmin Baek

CS 478 Lecture
Jan 9, 2012

Background

- Sales of digital cameras surpassed sales of film cameras in 2004.

Digital cameras are cool

- Free film
- Instant display
- Quality surpasses film
- Records metadata
  - shooting parameters, camera location & orientation

Digital cameras are boring

- Same experience as film cameras
  - Set zoom and focus
  - Set aperture and exposure
  - Press shutter to take a single picture
- Essentially, film camera with bits (0/1) ?

Digital cameras are boring

- The most common type of digital camera today: cellphone camera.

Can we leverage the computational power?

Course Information

- When: M/W 2:30-3:45
- Where: Gates 392
- Lecturers:
  - Jongmin Baek
  - Dave Jacobs
  - Kari Pulli (NVidia)

Course Information

- Office hours: TTh 2:30-3:45, Gates 360
- Grading:
  - 2 Assignments (15% each)
  - 1 Final project (70%)
- Perks:
  - Loaner NVidia Tegra 3 tablet (Thanks Kari)

Course Information

- (Mostly unenforced) Requirements:
  - Basic knowledge in graphics or vision or photography (CS148, CS178, etc)
  - Mathematical maturity
  - Good programming skills
    - Necessary: C++ or Java
    - Helpful: OpenCV, OpenGL, ImageStack

Course Information

- E-mail: cs478-win1112-staff@lists.stanford.edu
- URL: cs478.stanford.edu
- Schedule
- Lecture slides
- Schedule

Computational Photography: Definition

- Computational techniques that enhance or extend the capabilities of digital photography
- Output is an ordinary photograph, but one that could not have been taken by a traditional camera

Computational Photography: an Interdisciplinary Field

- Computer graphics
- Computer vision
- Image processing
- Signal processing
- Optics
- Embedded systems

Computational Photography

Film-like Photography with bits

Digital Photography

Image processing applied to captured images to produce better images.

Examples:
Interpolation, Filtering, Enhancement, Dynamic Range Compression, Color Management, Morphing, Hole Filling, Artistic Image Effects, Image Compression, Watermarking.

Computational Camera

Computational Processing

Processing of a set of captured images to create new images.

Examples:
Mosaicing, Matting, Super-Resolution, Multi-Exposure HDR, Light Field from Multiple View, Structure from Motion, Shape from X.

Computational Imaging/Optics

Capture of optically coded images and computational decoding to produce new images.

Examples:
Coded Aperture, Optical Tomography, Diaphanography, SA Microscopy, Integral Imaging, Assorted Pixels, Catadioptric Imaging, Holographic Imaging.

Computational Sensor

Detectors that combine sensing and processing to create smart pixels.

Examples:
Artificial Retina, Retinex Sensors, Adaptive Dynamic Range Sensors, Edge Detect Chips, Focus of Expansion Chips, Motion Sensors.

Smart Light

Computational Illumination

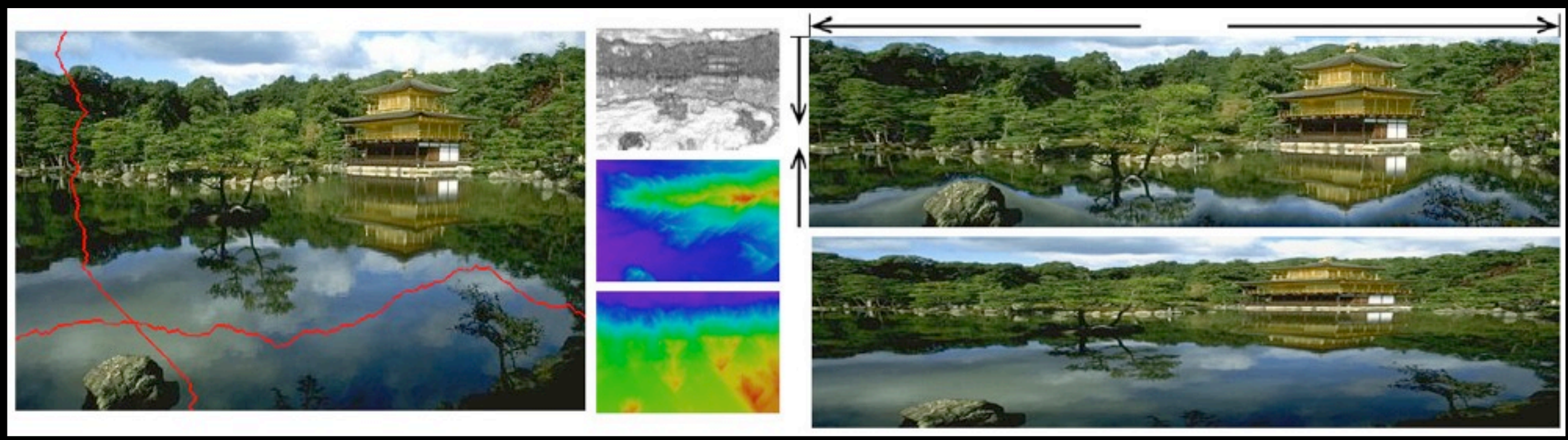
Adapting and Controlling Illumination to Create revealing image

Examples:
Flash/no flash, Lighting domes, Multi-flash for depth edges, Dual Photos, Polynomial texture Maps, 4D light source

[Nayar, Tumblin]

Seam Carving for Content-Aware Image Resizing
Avidan, Shamir (SIGGRAPH 2007)

- To expand: insert pixel along seams that, if removed, will yield original image.



Seam Carving for Content-Aware Image Resizing
Avidan, Shamir (SIGGRAPH 2007)

- To contract: remove pixels along the lowest-energy seams, found with dynamic programming
  - Object removal for an application?

A Bayesian Approach to Digital Matting
Chuang et al. (CVPR 2001)

- Generate local color model for foreground, background.
- Probabilistically assign alpha to unclassified pixels.

Removing Camera Shake from a Single Image
Fergus et al. (SIGGRAPH 2006)

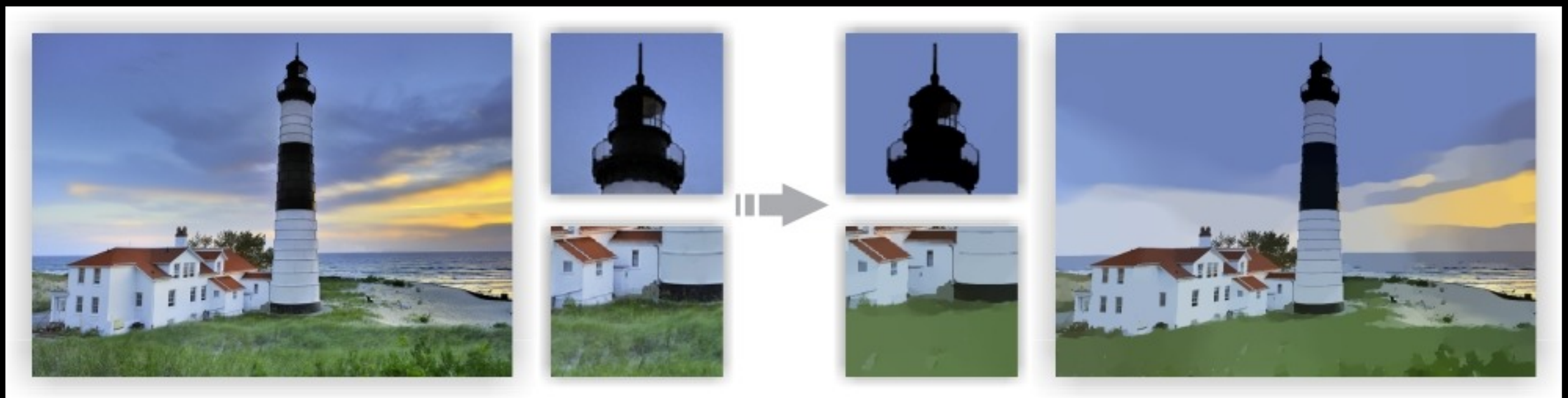
Fast Motion Deblurring
Cho, Lee (SIGGRAPH Asia 2009)

Local Laplacian Filters: Edge-aware Image Processing with a Laplacian Pyramid

Paris, Hasinoff, Kautz (SIGGRAPH 2011)

Image Smoothing via L_0 Gradient Minimization

Xu et al. (SIGGRAPH Asia 2011)



Computational Photography

Film-like Photography with bits	Computational Camera			Smart Light
Digital Photography	**Computational Processing**	**Computational Imaging/Optics**	**Computational Sensor**	**Computational Illumination**
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[Nayar, Tumblin]

Interative Digital Photomontage

Agarwala et al. (SIGGRAPH 2004)

Interative Digital Photomontage

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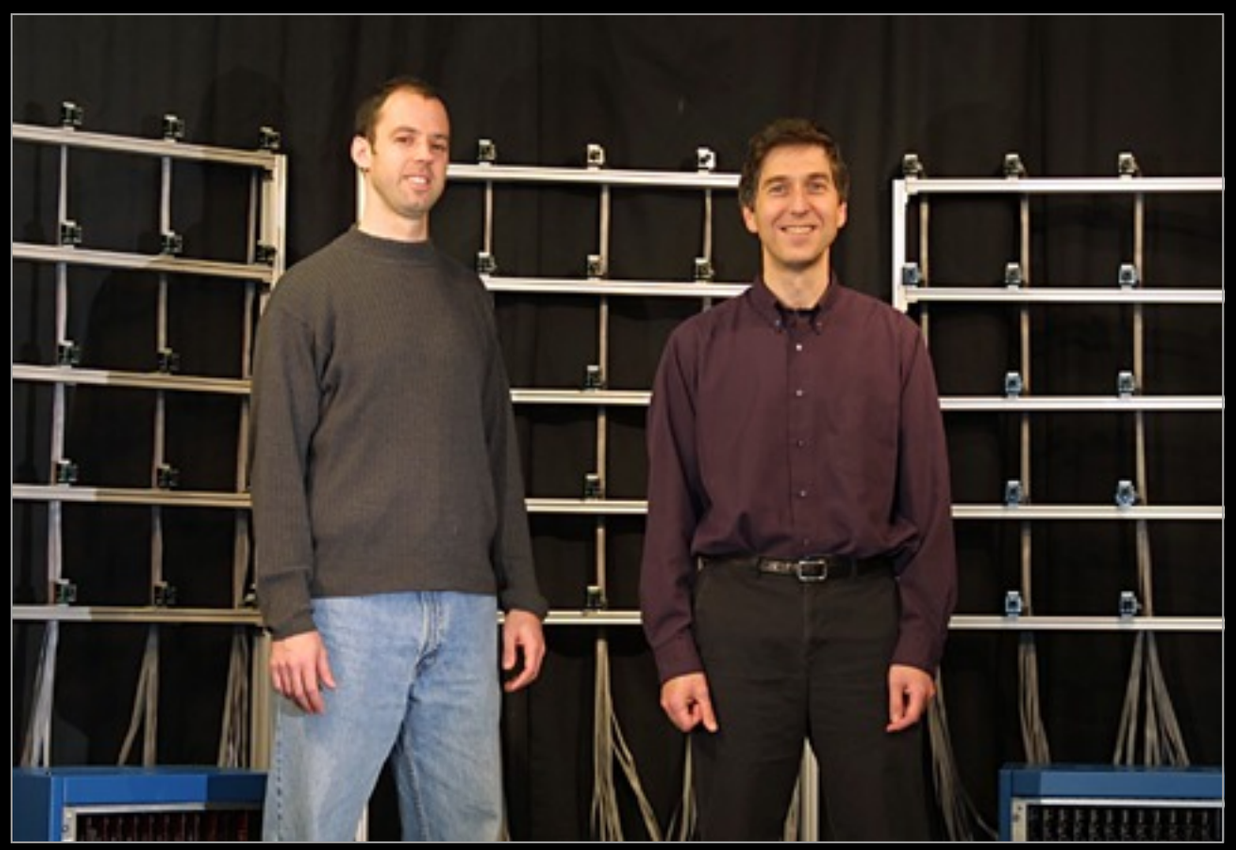
Agarwala et al. (SIGGRAPH 2004)

Interative Digital Photomontage
Agarwala et al. (SIGGRAPH 2004)

High Performance Imaging using Large Camera Arrays
Wilburn et al. (SIGGRAPH 2005)

- 640 × 480 pixels × 30 fps × 128 cameras

- synchronized timing
- continuous streaming
- flexible arrangement



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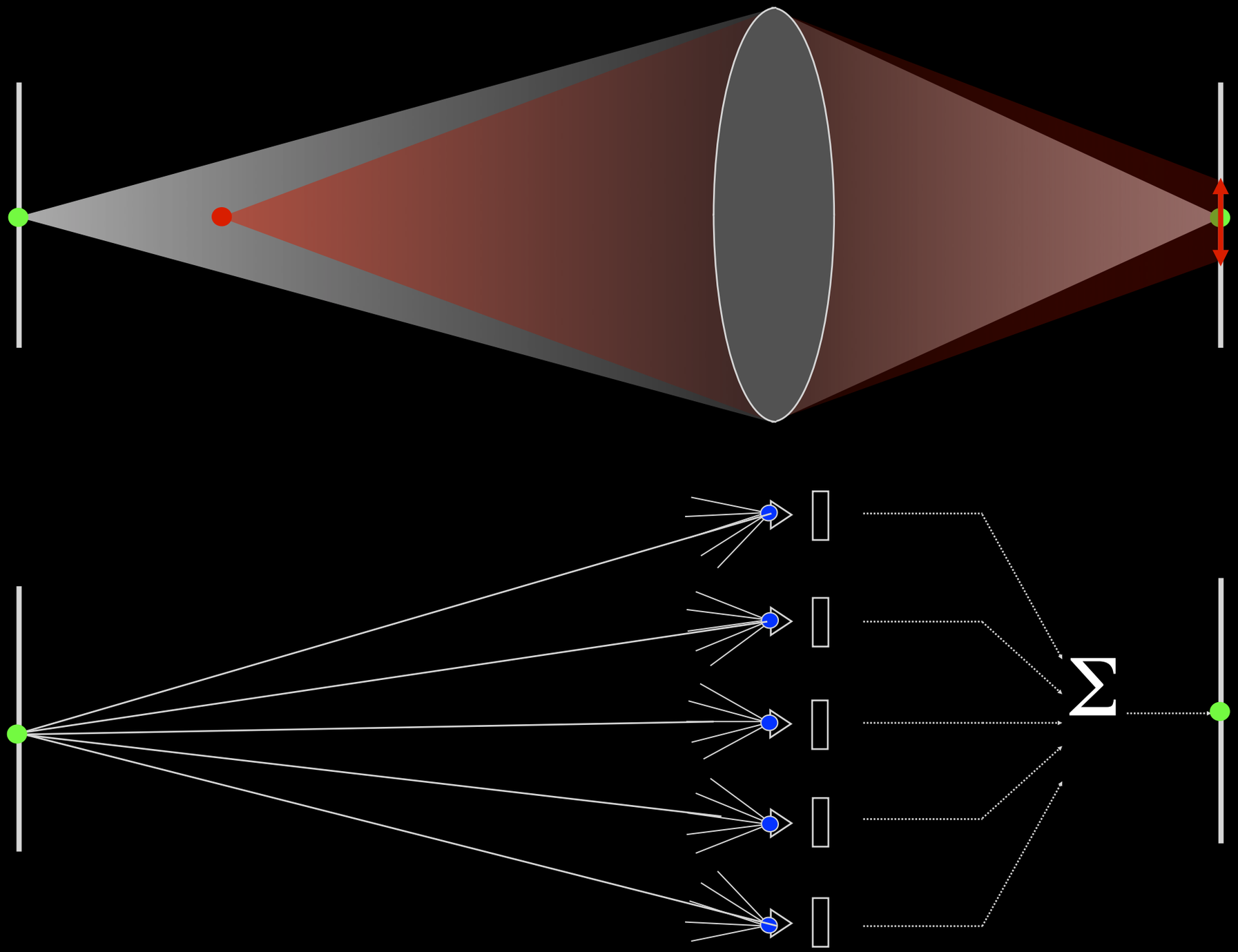


Multi-Exposure Imaging on Mobile Devices

Gelfand et al. (ACM Multimedia 2010)

short exposure
(outside ☻)

long exposure
(inside ☻)

combined result
(everywhere ☻)

Image Deblurring with Blurry/Noisy Image Pairs

Yuan et al. (SIGGRAPH 2007)

long exposure (blurry)

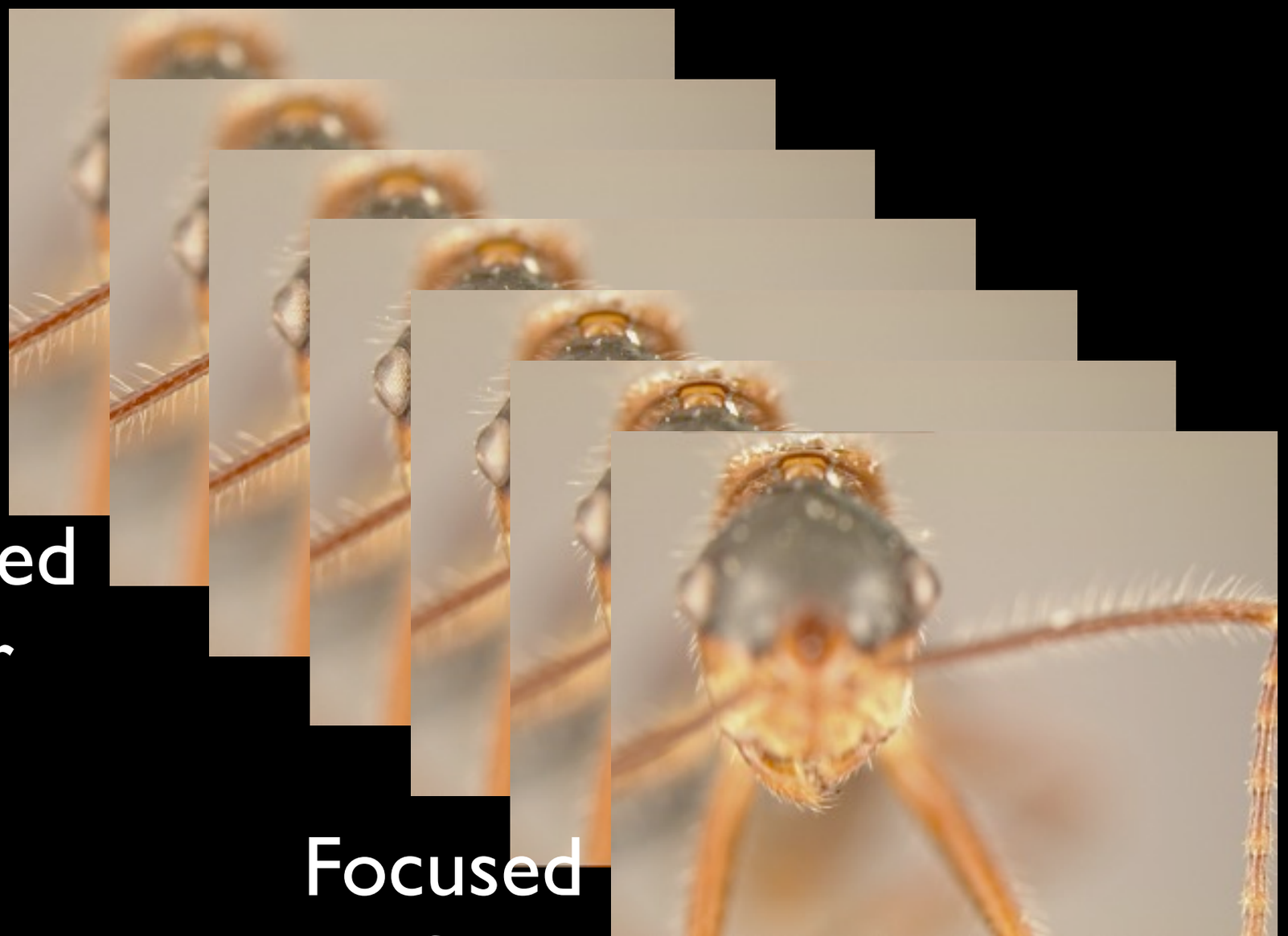
short exposure (dark)

same, scaled up (noisy)

joint deconvolution

Light Efficient Photography
Hasinoff, Kutulakos (ECCV 2008)
(+ many others)

- Combine many photos in a focal stack.



Focused near

Focused afar

Light Efficient Photography

Hasinoff, Kutulakos (ECCV 2008)

(+ many others)

Viewfinder Alignment

Adams, Gelfand, Pulli (Eurographics 2008)

- Store and align viewfinder images in real-time.

individual frames, aligned

panorama

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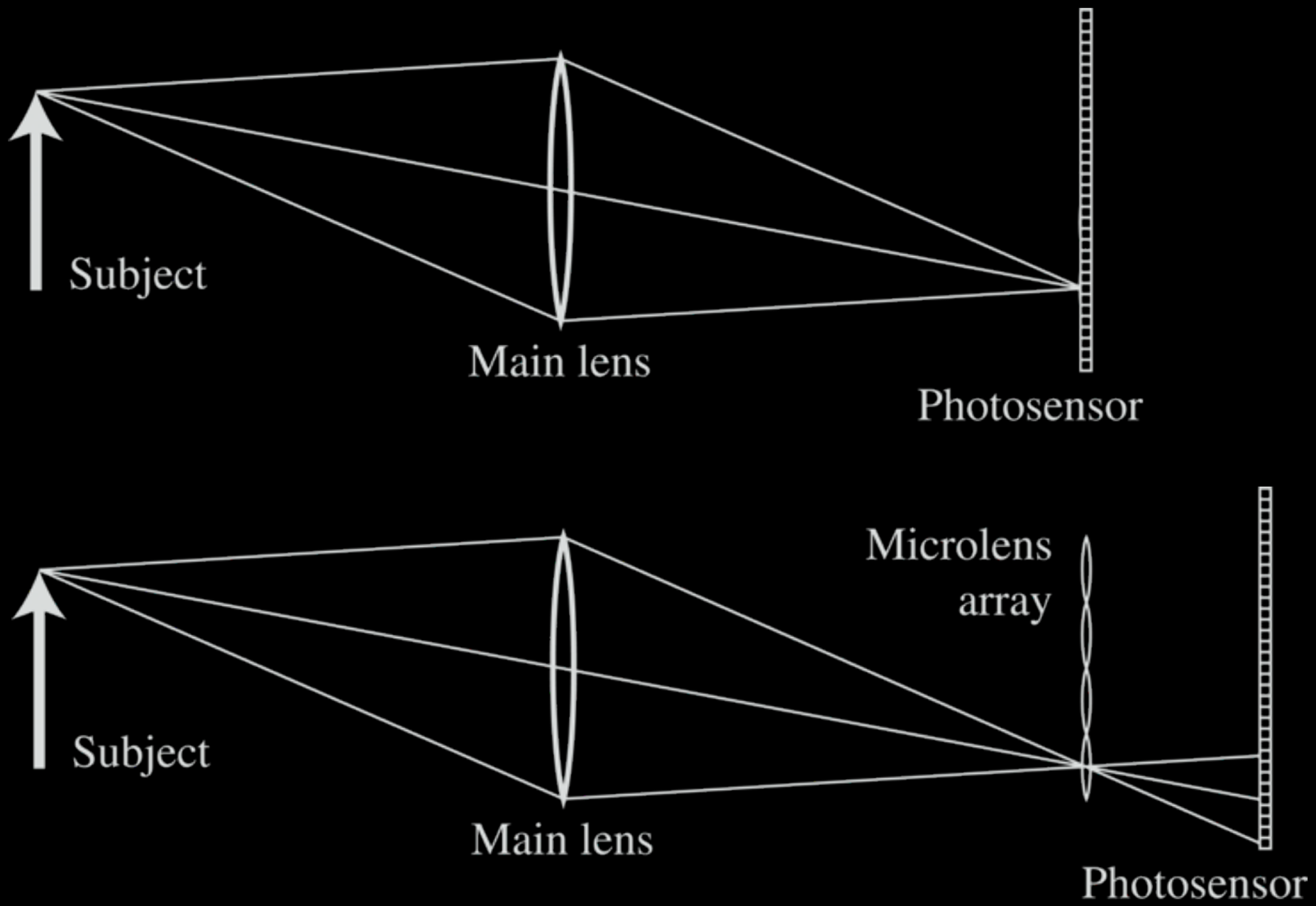
[Nayar, Tumblin]

Light Field Photography with a Hand-Held Plenoptic Camera

Ng et al. (SIGGRAPH 2005)



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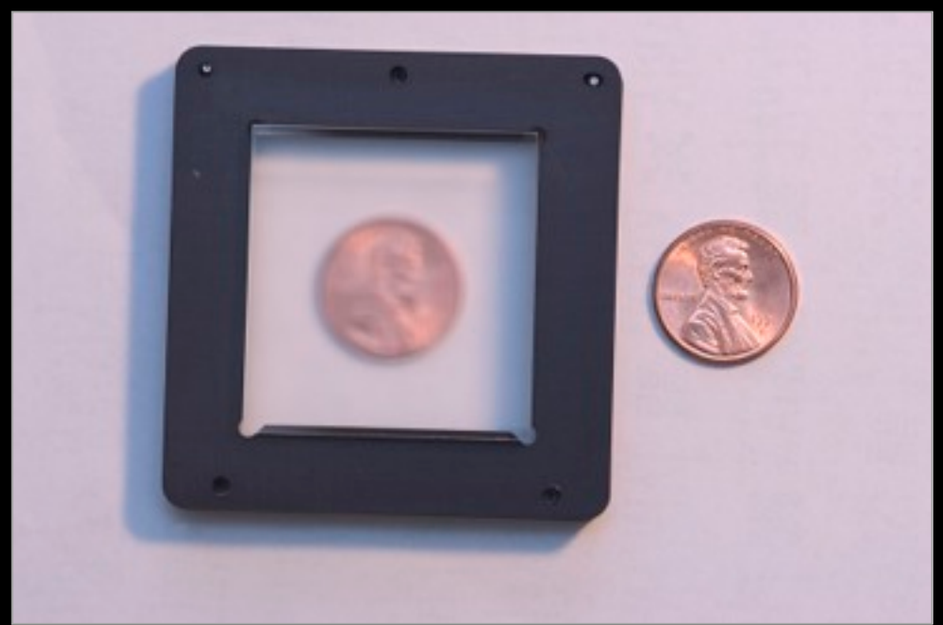
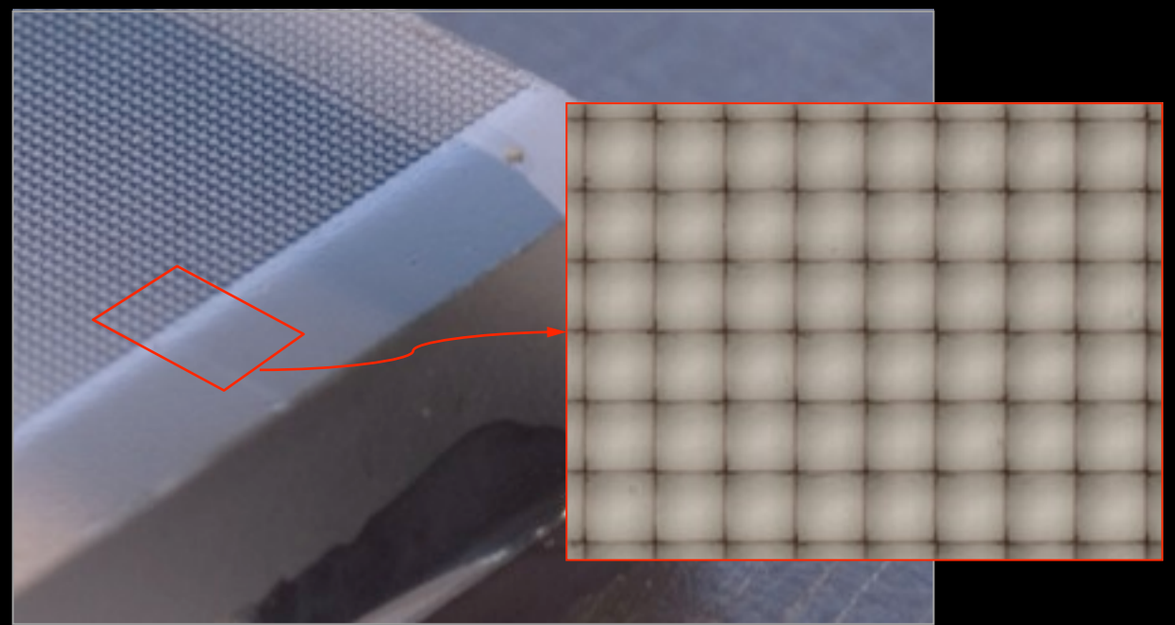


Adaptive Optics microlens array



125μ square-sided microlenses

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

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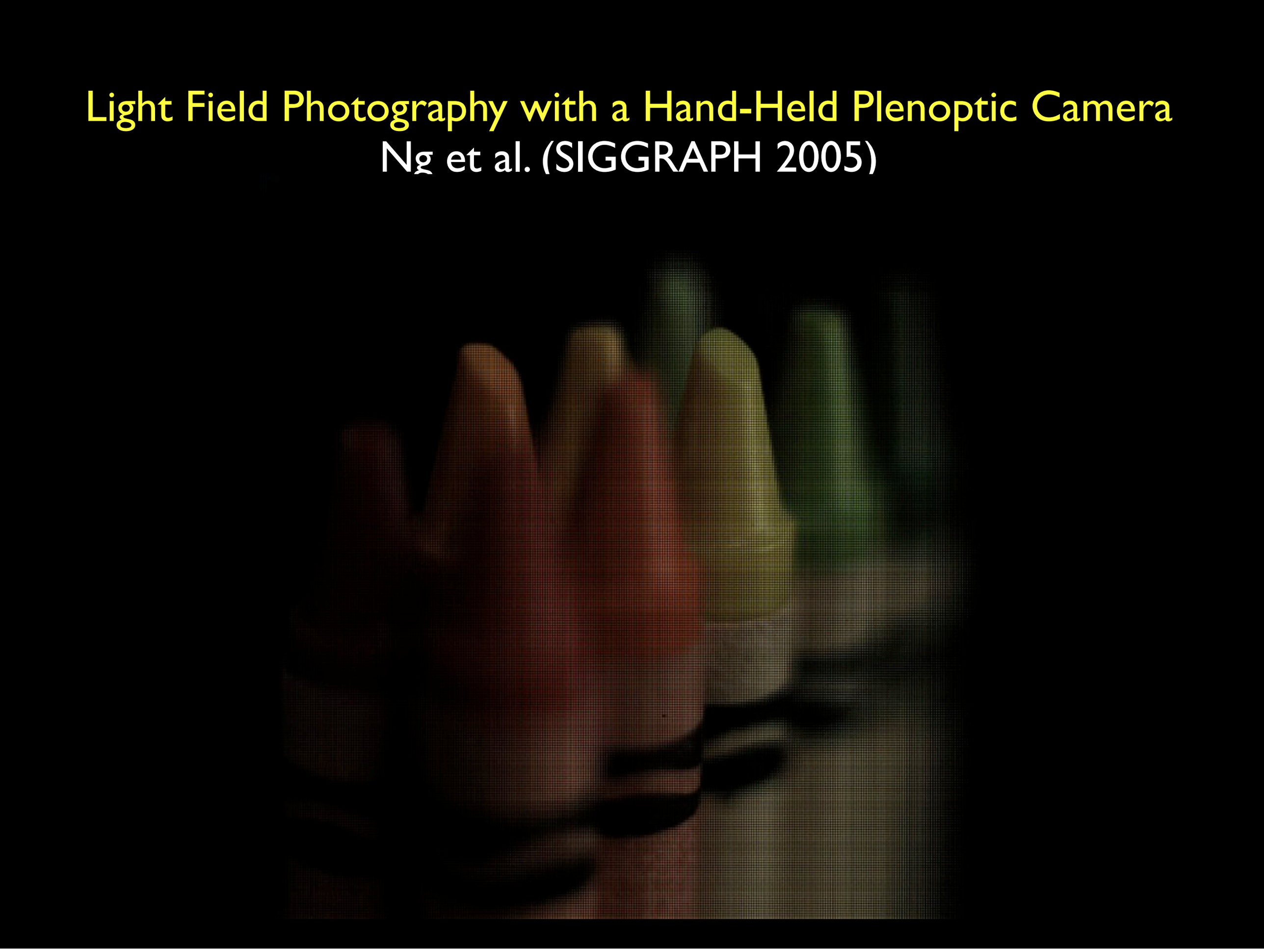
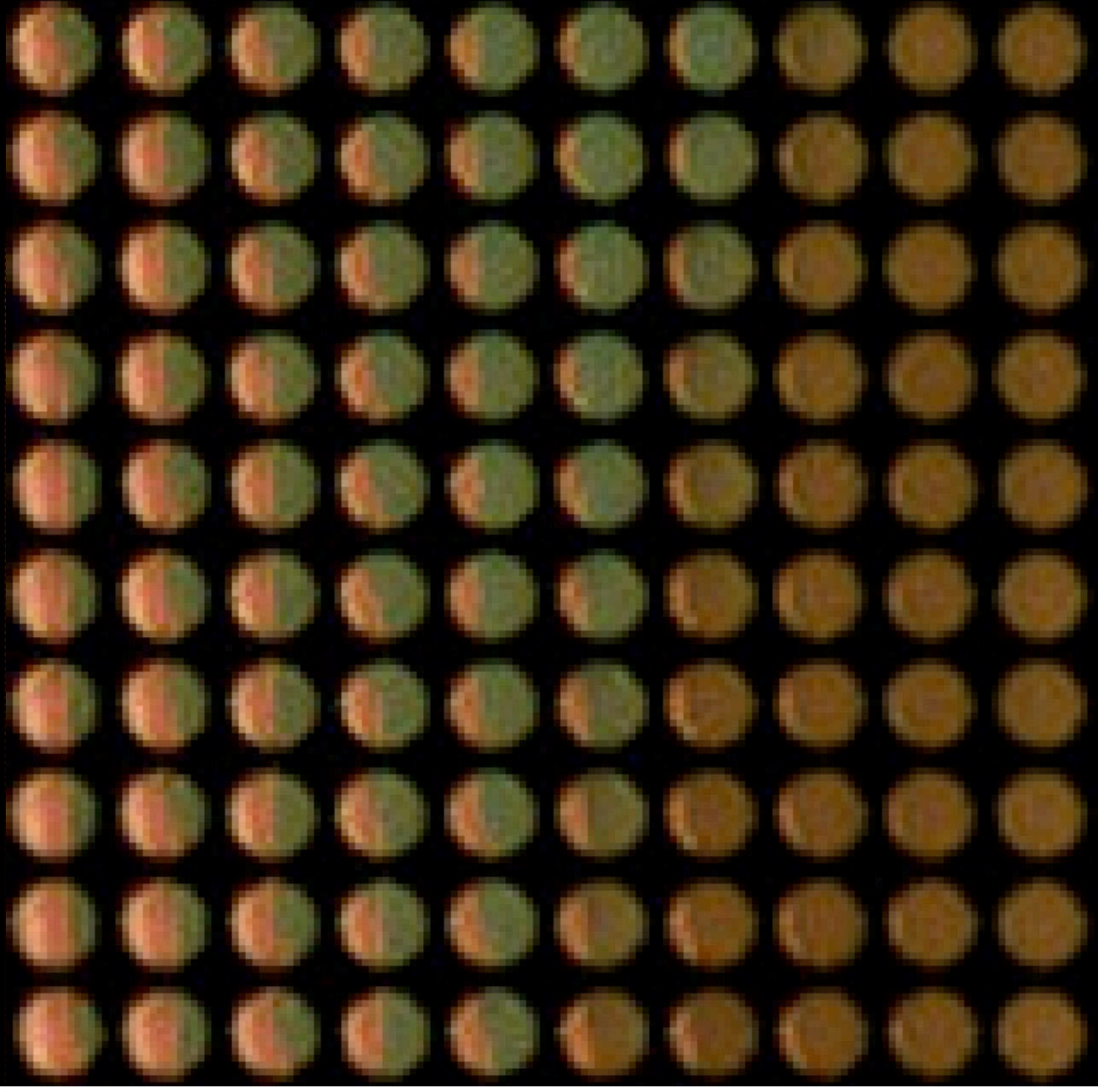




Light Field Photography with a Hand-Held Plenoptic Camera

Ng et al. (SIGGRAPH 2005)

Far

Near

(Now known as “Lytro” camera.)

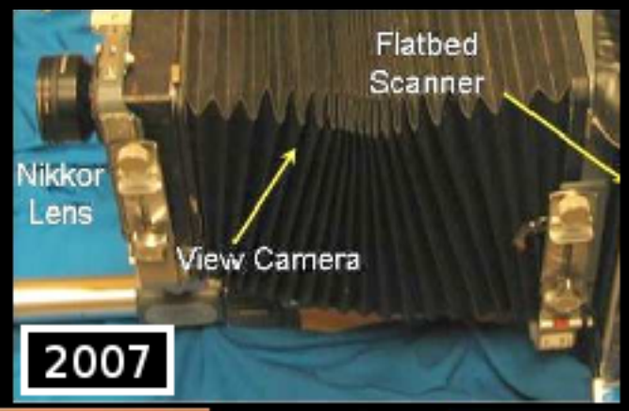
Spatiotemporal modulation of defocus blur ("coded aperture")

Levin et al. (SIGGRAPH 2007)

Veeraraghavan et al. (SIGGRAPH 2007)

Nagahara et al. (ECCV 2008)

Levin et al. (SIGGRAPH 2009)



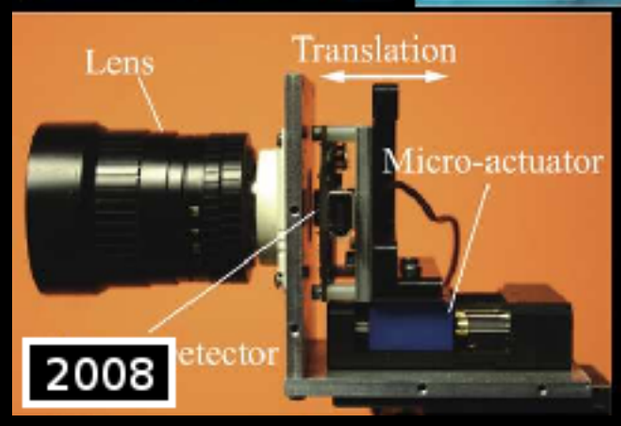
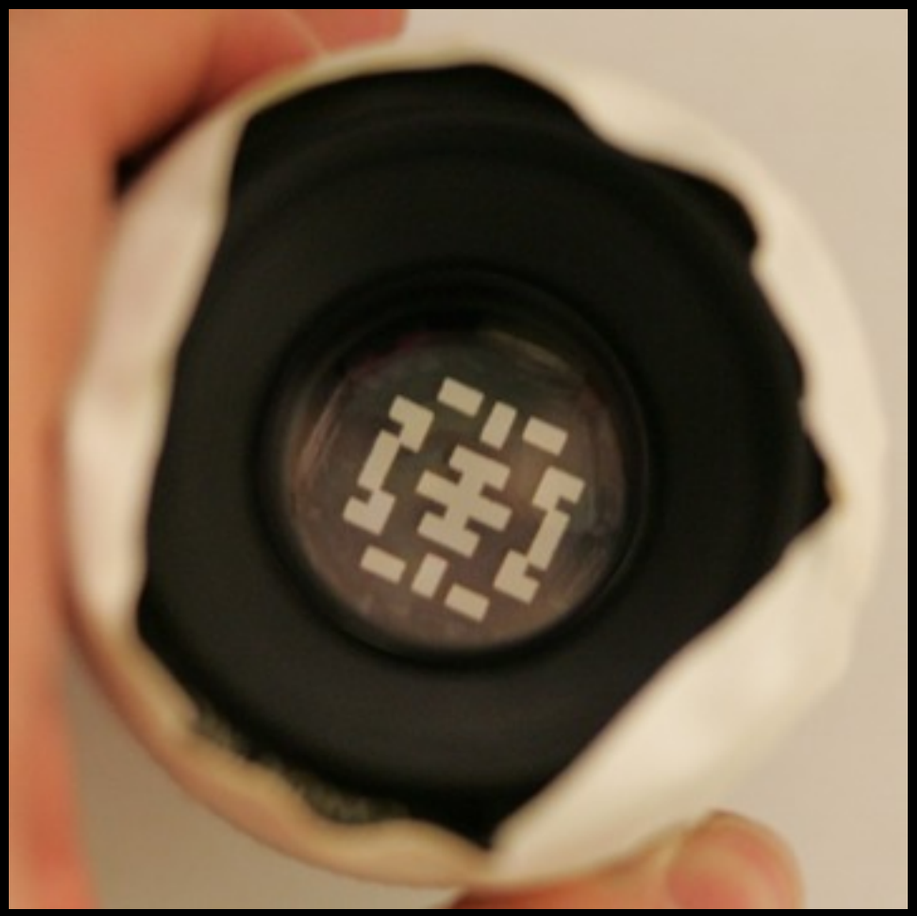


Image and Depth from a Conventional Camera with a Coded Aperture

Levin et al. (SIGGRAPH 2007)

conventional aperture



coded aperture

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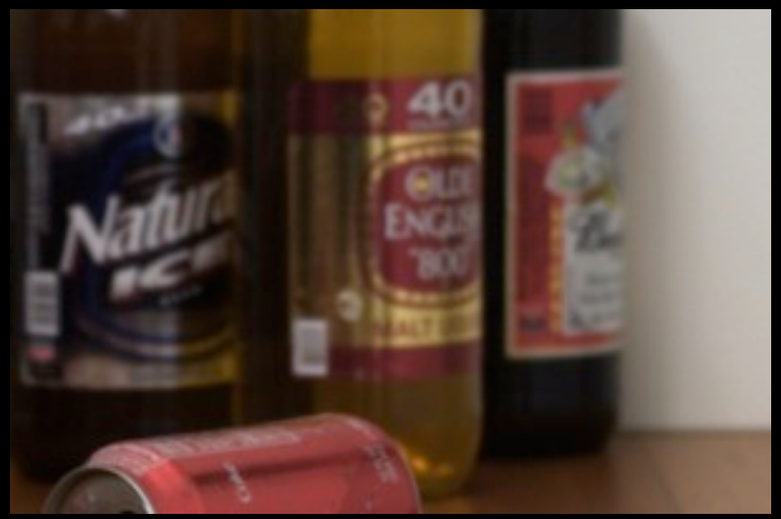
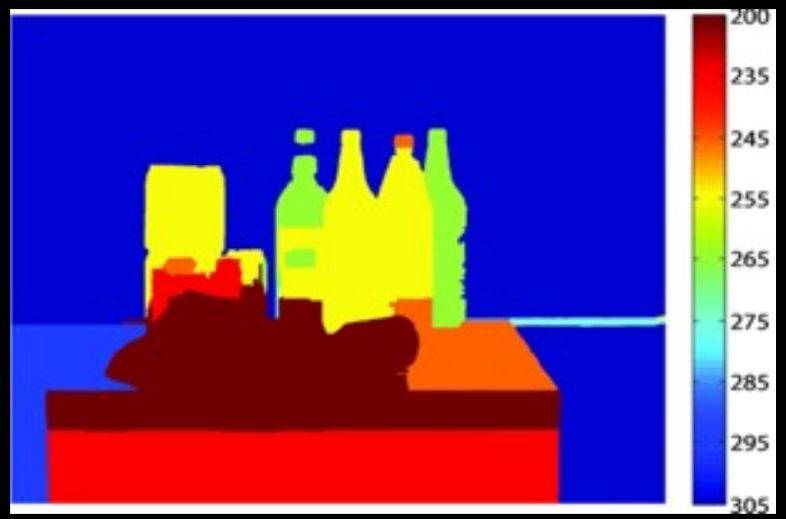


input
(blurred)

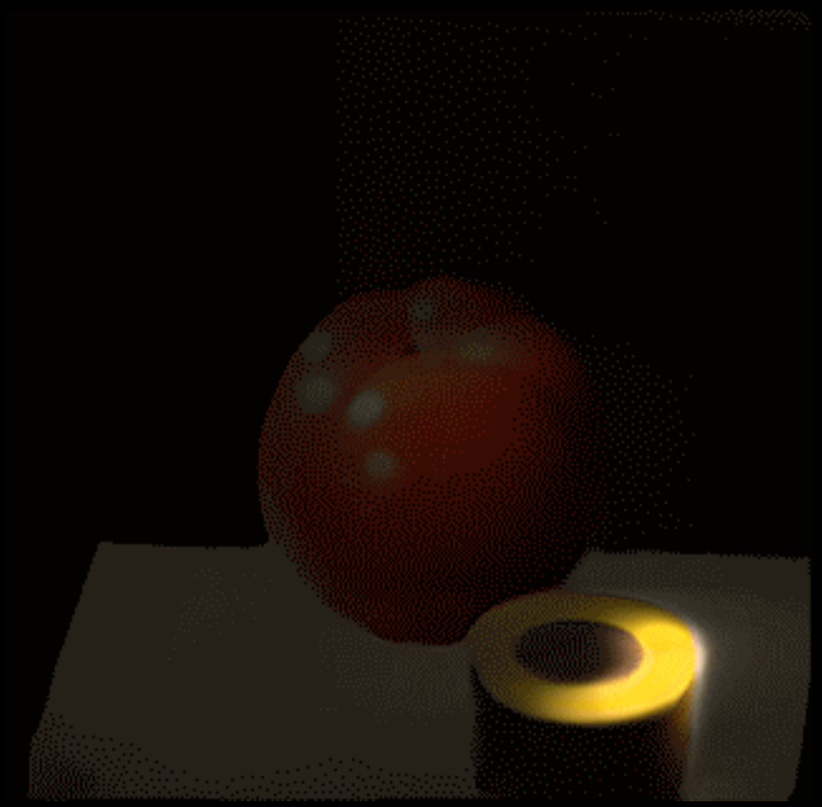
output
(deblurred)



depthmap

Visualizing Photons in Motion at a Trillion Frames per Second

Velten, Raskar, Bawendi (OSA 2011)



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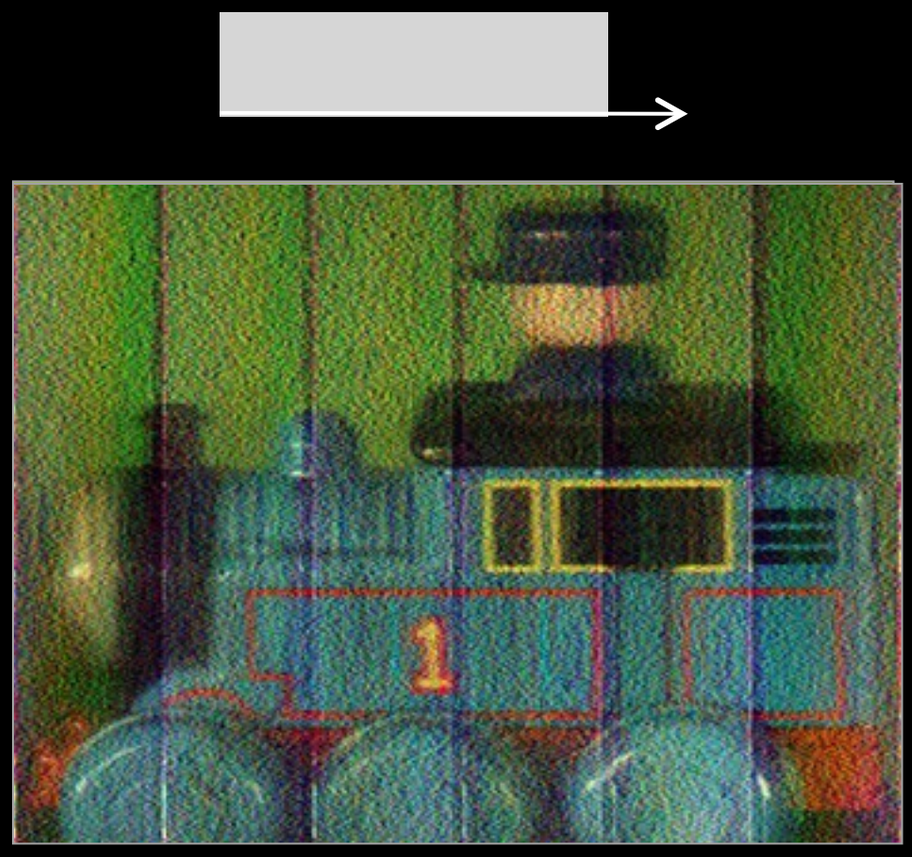
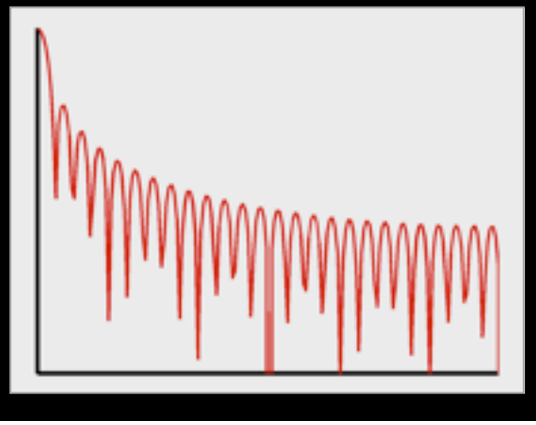
[Nayar, Tumblin]

Coded Exposure Photography: Motion Deblurring using Fluttered Shutter

Raskar, Agrawal, Tumblin (SIGGRAPH 2006)

continuous shutter





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Raskar, Agrawal, Tumblin (SIGGRAPH 2006)

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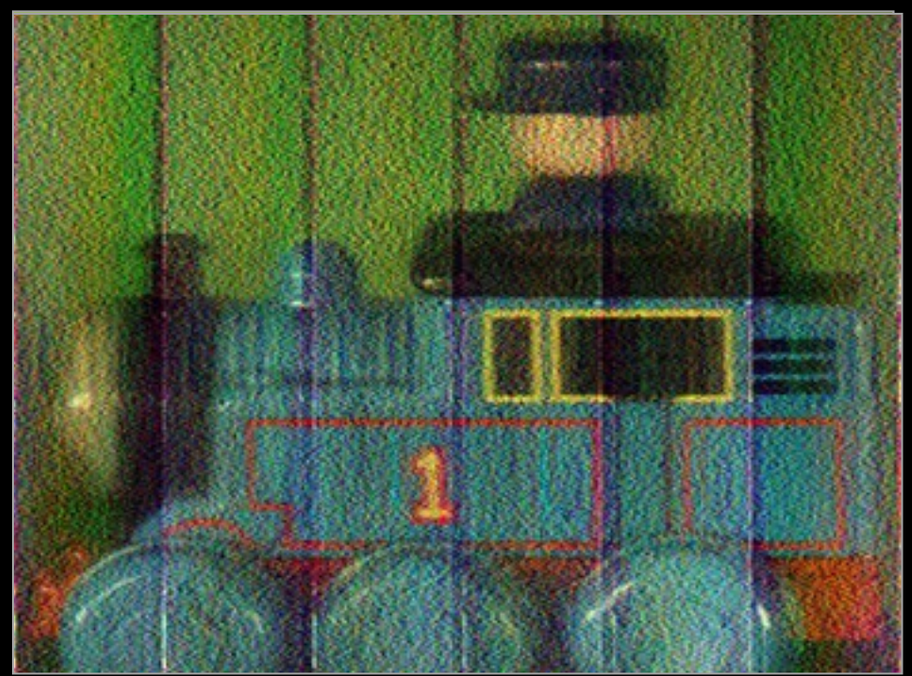
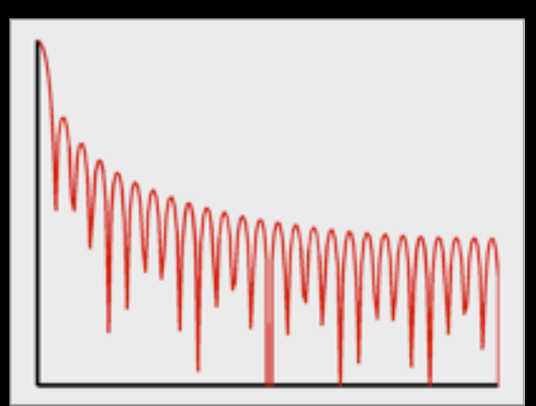
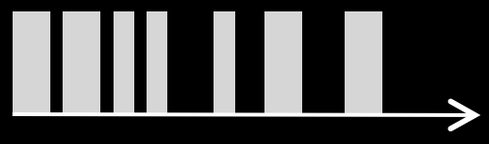
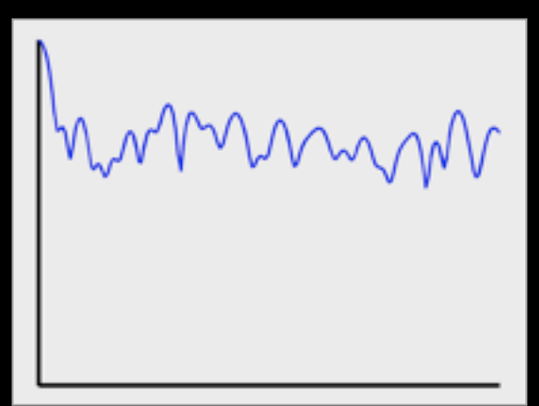




fluttered shutter





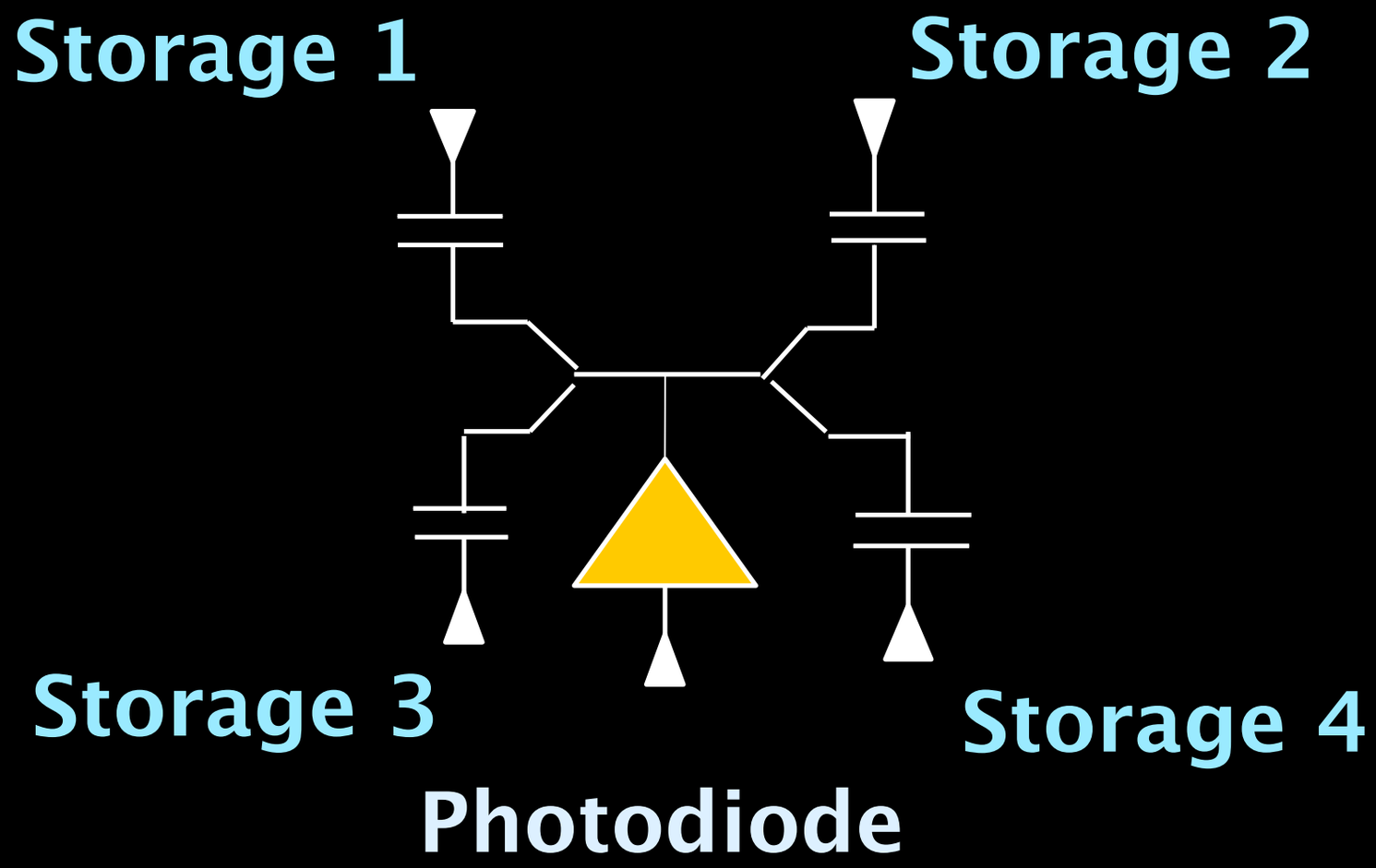
A Dual In-Pixel Memory CMOS Image Sensor for Computational Photography

Wan et al. (Symp. VLSI Circuits 2011)

"Ghosting"

A Dual In-Pixel Memory CMOS Image Sensor for Computational Photography

Wan et al. (Symp. VLSI Circuits 2011)



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[Nayar, Tumblin]

Digital Photography with Flash and No-Flash Image Pairs

Petschnigg et al. (SIGGRAPH 2004)

Flash No-Flash

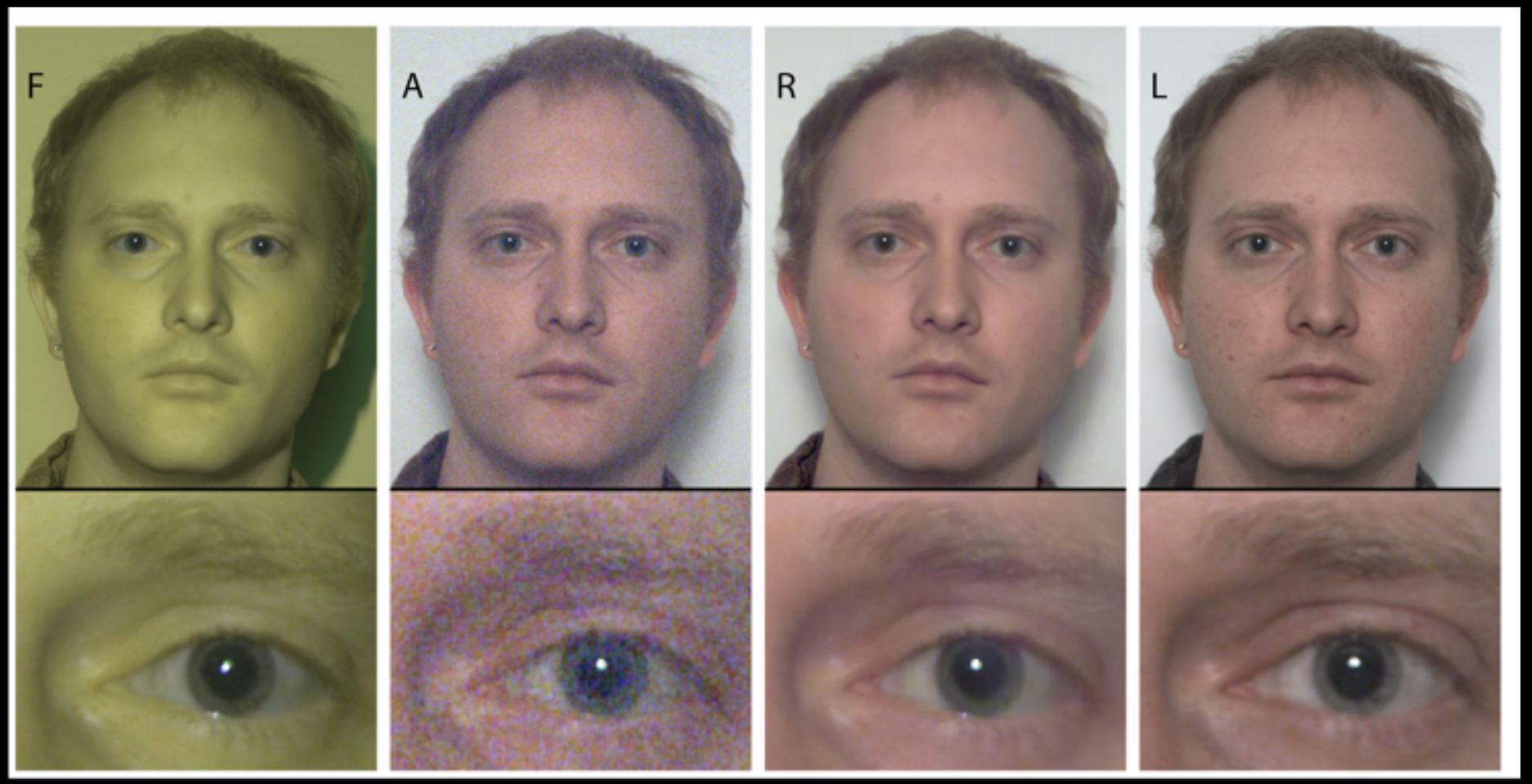
Digital Photography with Flash and No-Flash Image Pairs

Petschnigg et al. (SIGGRAPH 2004)

Flash No-Flash Combined

Dark Flash Photography

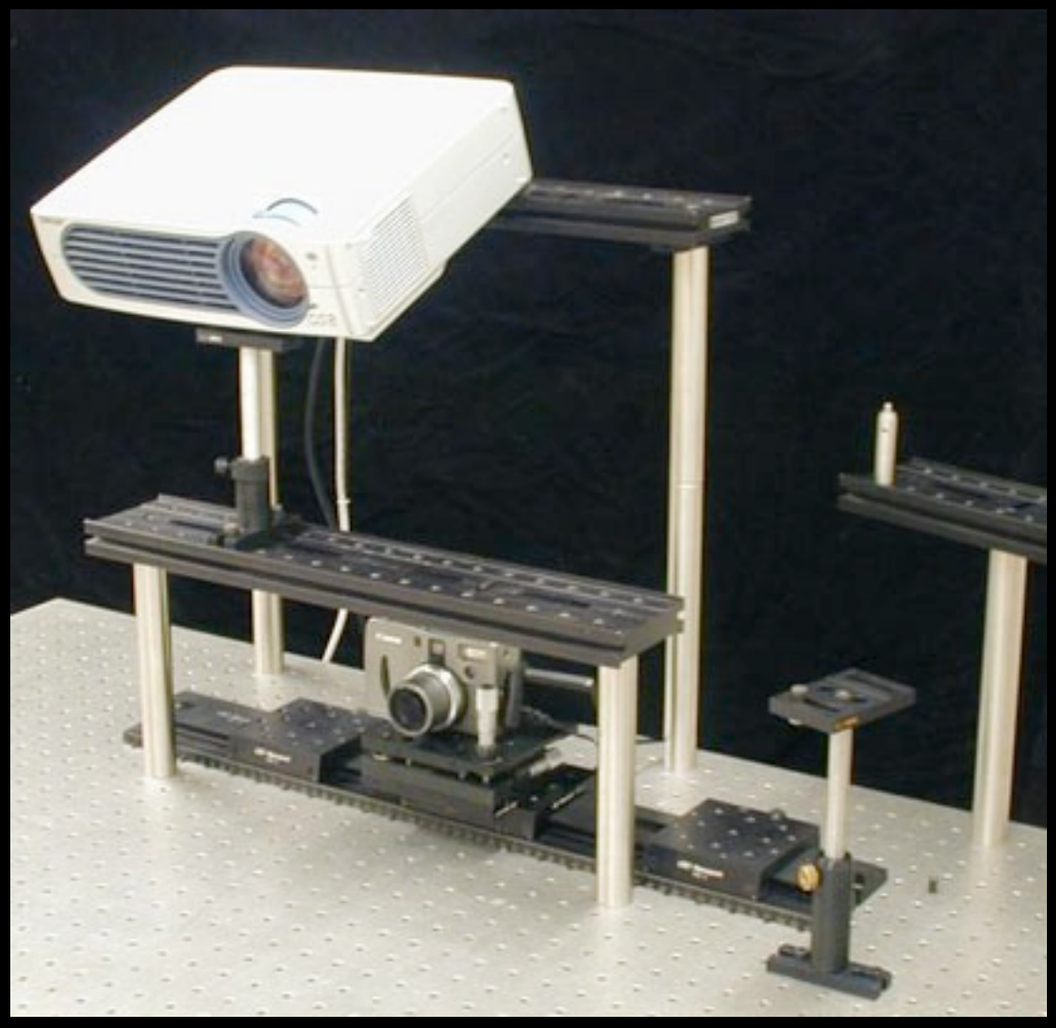
Krishnan, Fergus (SIGGRAPH 2009)

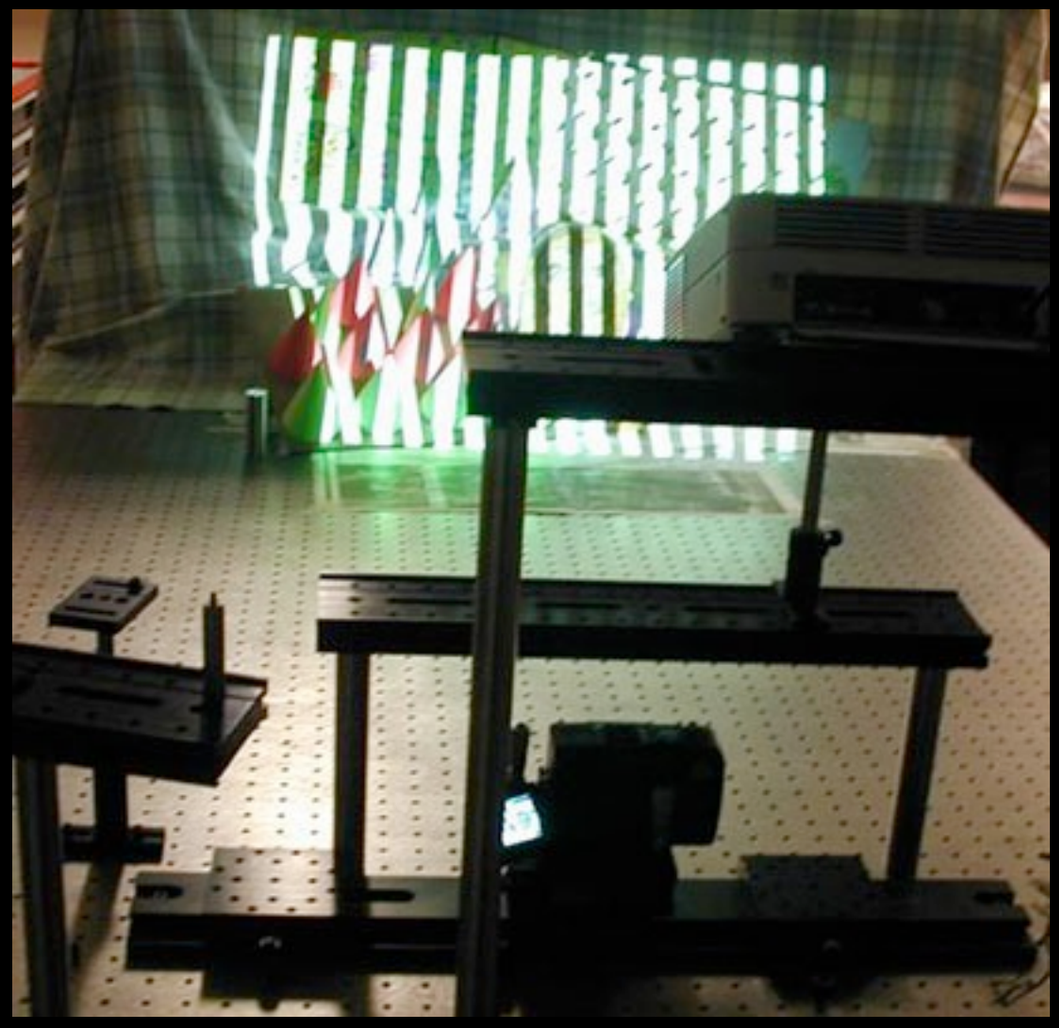


Infrared No-Flash Combined Groudtruth

High Accuracy Stereo Depth Map using Structured Light

Scharstein, Szeliski (CVPR 2003)

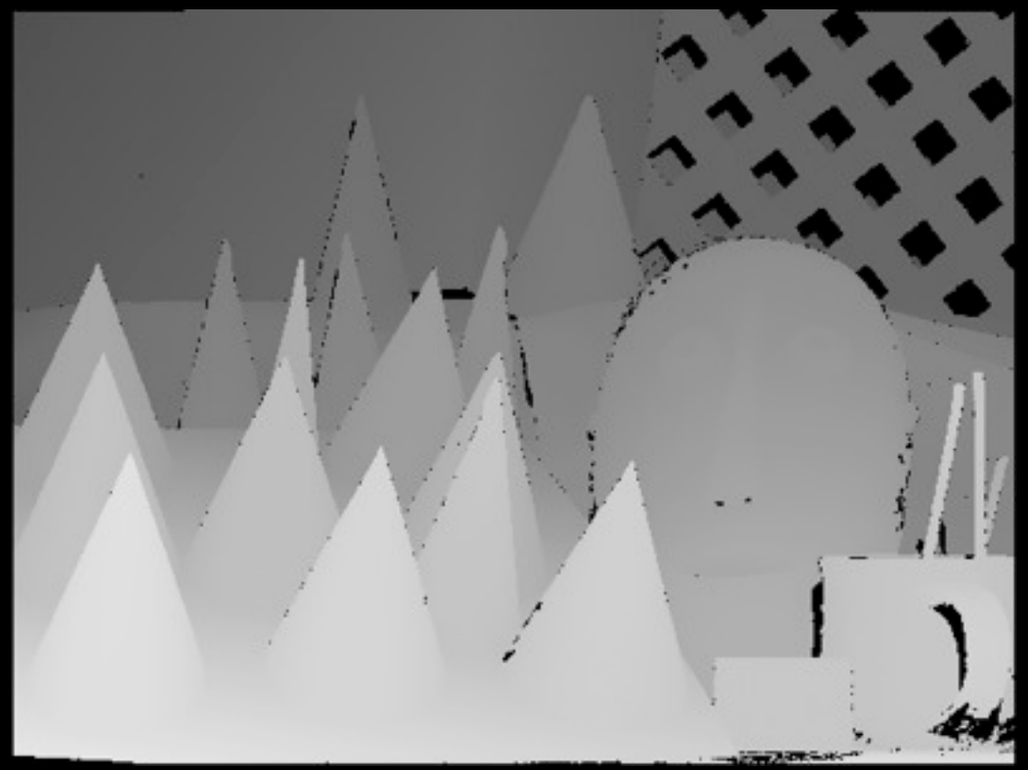




High Accuracy Stereo Depth Map using Structured Light

Scharstein, Szeliski (CVPR 2003)

scene



depth map

(Used in Kinect, etc.)

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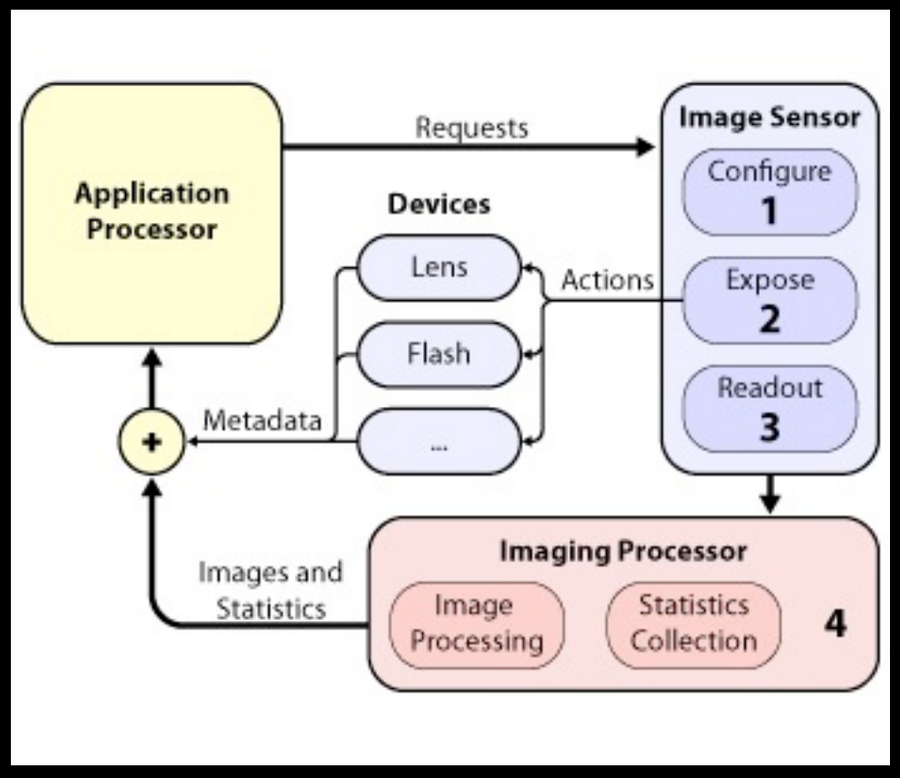
[Nayar, Tumblin]

Lots of Cool Stuff, but...

- Many of these techniques require modifying the camera.
- Many of these techniques require precise control of the camera parameters.
- Need a fully programmable and extensible platform!
  - Not really available prior to 2010 until the advent of ...

The Frankencamera: an Experimental Platform for Computational Photography

Adams et al. (SIGGRAPH 2010)



- a sensible API to control a camera

Course Summary

- Learn theories behind cool computational photography projects.
  - Attend lectures.
- Learn how to put the theories into practice on a mobile platform.
  - Assignment #1
  - Assignment #2
  - Final project

Assignment Summary

- Assignment #1 (15%)
  - Write an autofocus algorithm for a camera application on a Tegra 3 tablet.
- Assignment #2 (15%)
  - Image processing using OpenCV or ImageStack on Tegra 3 tablet.
- Final project (70%)
  - Do something cool (by yourself or in a pair.)

Questions?