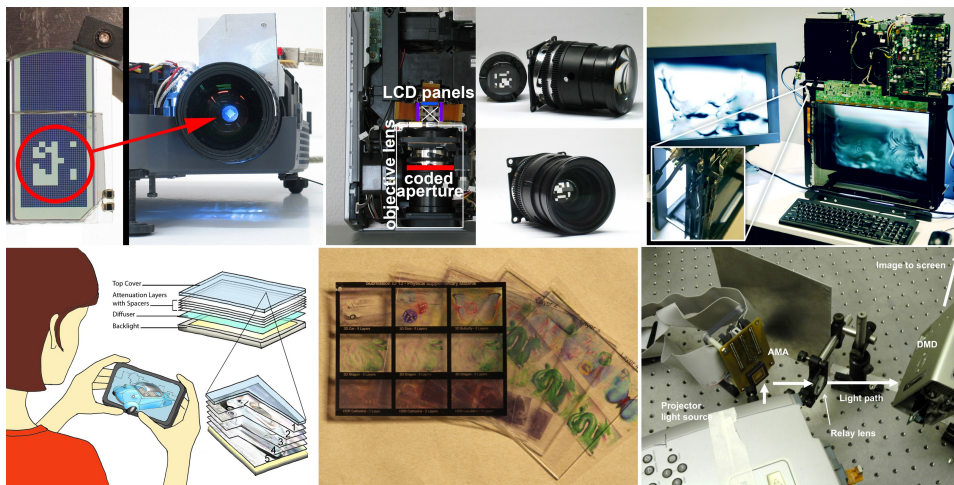


---

# Computational Displays:

## Combining Optical Fabrication, Computational Processing, and Perceptual Tricks to Build the Displays of the Future

---



Eurographics 2013  
Half-day Tutorial

**Gordon Wetzstein**  
MIT Media Lab  
[gordonw@media.mit.edu](mailto:gordonw@media.mit.edu)

**Douglas Lanman**  
Nvidia Research  
[dlanman@nvidia.com](mailto:dlanman@nvidia.com)

**Piotr Didyk**  
MIT CSAIL  
[pdidyk@csail.mit.edu](mailto:pdidyk@csail.mit.edu)

keywords: compressive light field displays, perceptually-driven displays, computational fabrication

---

## Abstract

With the invention of integral imaging and parallax barriers in the beginning of the 20th century, glasses-free 3D displays have become feasible. Only today —more than a century later— glasses-free 3D displays are finally emerging in the consumer market. The technologies being employed in current-generation devices, however, are fundamentally the same as what was invented 100 years ago. With rapid advances in optical fabrication, digital processing power, and computational models for human perception, a new generation of display technology is emerging: computational displays exploring the co-design of optical elements and computational processing while taking particular characteristics of the human visual system into account. This technology does not only encompass 3D displays, but also next-generation projection systems, high dynamic range displays, perceptually-driven devices, and computational probes.

This tutorial serves as an introduction to the emerging field of computational displays. The pedagogical goal of this tutorial is to provide the audience with the tools necessary to expand their research endeavors by providing step-by-step instructions on all aspects of computational displays: display optics, mathematical analysis, efficient computational processing, computational perception, and, most importantly, the effective combination of all these aspects. Specifically, we will discuss a wide variety of different applications and hardware setups of computational displays, including high dynamic range displays, advanced projection systems as well as glasses-free 3D display. The latter example, computational light field displays, will be discussed in detail. In the tutorial presentation, supplementary notes, and an accompanying website, we will provide source code that drives various display incarnations at real-time framerates, detailed instructions on how to fabricate novel displays from off-the-shelf components, and intuitive mathematical analyses that will make it easy for researchers with various backgrounds to get started in the emerging field of computational displays. We believe that computational display technology is one of the “hottest” topics in the graphics community today; with this tutorial we will make it accessible for a diverse audience. This tutorial was previously taught as a course at SIGGRAPH 2012.

We will discuss all aspects of computational displays in detail. Specifically, we begin by introducing the concept and discussing a variety of example displays that exploit the joint-design of optical components and computational processing for applications such as high dynamic range image and wide color gamut display, extended depth of field projection, and

---

high-dimensional information display for computer vision applications. We will then proceed to discussing state-of-the-art computational light field displays in detail. In particular, we will focus on how high-speed displays, multiple stacked LCDs, and directional backlighting combined with advanced mathematical analysis and efficient computational processing provide the foundations of 3D displays of the future. Finally, we will review psycho-physiological aspects that are of importance for display design and demonstrate how perceptually-driven computational displays can enhance the capability of current technology.

## **Prerequisites**

For this intermediate-level tutorial, some familiarity with Matlab, C/C++, OpenGL, as well as a general understanding of linear algebra and Fourier analysis is assumed, although the tutorial also functions as a brief, application-driven introduction to each of these tools.

---

## Speaker Biographies

### **Gordon Wetzstein**

MIT Media Lab

[gordonw@media.mit.edu](mailto:gordonw@media.mit.edu)

<http://web.media.mit.edu/~gordonw>

Gordon Wetzstein is a Postdoctoral Researcher with Prof. Ramesh Raskar in the Camera Culture Group at the MIT Media Lab. His research interests are at the intersection of computer graphics, machine vision, optics, scientific computing, and perception. Gordon received a Diplom in Media System Science with Honors from the Bauhaus-University Weimar in 2006 and a Ph.D. in Computer Science at the University of British Columbia in 2011. His doctoral dissertation focuses on computational light modulation for image acquisition and display and won the Alain Fournier Ph.D. Dissertation Annual Award. He organized the IEEE CVPR 2012 Workshop on Computational Cameras and Displays, presented the “Computational Displays” and “Computational Plenoptic Imaging” courses at ACM SIGGRAPH 2012, and won a best paper award for “Hand-Held Schlieren Photography with Light Field Probes” at ICCP 2011, introducing light field probes as computational displays for computer vision and fluid mechanics applications.

### **Douglas Lanman**

Nvidia Research

[dlanman@nvidia.com](mailto:dlanman@nvidia.com)

<http://web.media.mit.edu/~dlanman>

Douglas Lanman is a researcher at Nvidia Research and was formerly a Postdoctoral Associate at the MIT Media Lab. His research is focused on computational photography and displays, including light field capture, automultiscopic 3D displays, and active illumination for 3D reconstruction. He received a B.S. in Applied Physics with Honors from Caltech in 2002 and M.S. and Ph.D. degrees in Electrical Engineering from Brown University in 2006 and 2010, respectively. Prior to joining MIT and Brown, he was an Assistant Research Staff Member at MIT Lincoln Laboratory from 2002 to 2005. Douglas has worked as an intern at Intel, Los Alamos National Laboratory, INRIA Rhône-Alpes, Mitsubishi Electric Research Laboratories (MERL), and the MIT Media Lab. He presented the “Build

---

Your Own Glasses-free 3D Display” course at SIGGRAPH 2011, the “Build Your Own 3D Scanner” course at SIGGRAPH 2009 and SIGGRAPH Asia 2009, the “Build Your Own 3D Display” course at SIGGRAPH 2010 and SIGGRAPH Asia 2010, and the “Computational Plenoptic Imaging” and “Computational Displays” courses at SIGGRAPH 2012.

**Piotr Didyk**

MIT CSAIL

[pdidyk@csail.mit.edu](mailto:pdidyk@csail.mit.edu)

[people.csail.mit.edu/pdidyk](http://people.csail.mit.edu/pdidyk)

Piotr Didyk is a postdoctoral associate at the Computer Science and Artificial Intelligence Laboratory of Massachusetts Institute of Technology. He works in the Computer Graphics Group under the supervision of Wojciech Matusik. He obtained his PhD degree in Max-Planck-Institute for Computer Science working in the Computer Graphics Department. His work on perceptual display was supervised by Karol Myszkowski and Hans-Peter Seidel. During his studies, he was a visiting student at MIT. Before joining Max-Planck-Institute, he received his M.S. degree in Computer Science from University of Wroclaw. In 2007, he was awarded with a fellowship award from the “Polish Talents” organization, supported by the Polish Academy of Science.

His main research focuses on new display technologies, where by exploiting properties of the human visual system the efficiency and perceived quality of displayed imagery can be improved. He develops methods that using perceptual effects can overcome physical limitations of display devices and enhance apparent image qualities. More precisely, he is interested in human visual perception, new display technologies, high dynamic range imaging as well as image and video enhancement.

---

## Course Outline

### **5 minutes: Introduction and Overview**

*Gordon Wetzstein*

This part will introduce the speakers, present a motivation of the course, and outline the individual parts.

### **25 minutes: Computational Displays as a Next-generation Technology**

*Gordon Wetzstein*

This part will introduce the emerging field of computational displays. We will discuss the fundamental building blocks of computational displays: optical components, computational processing as well as the human visual system. This part will also serve as an overview of computational displays, such as adaptive coded aperture projection, high dynamic range displays, and emerging projection systems. In addition to displays intended for the human visual system, we also plan to provide an overview of computational probes: high-dimensional displays targeted toward computer vision applications rather than the human visual system.

### **55 minutes: Computational Light Field Displays - Hardware Architectures, Fabrication, Content Generation and Optimization**

*Douglas Lanman and Gordon Wetzstein*

The combination of numerical optimization, display fabrication, and efficient computational processing provides the foundation of future glasses-free 3D display design. This part will present the latest light field display designs exploiting high-speed LCDs as well as stacked layers of light-attenuating and polarization-rotating LCDs. We will present detailed instructions on how to build arbitrary combinations of high-speed see-through LCD panels and refractive optical elements from off-the-shelf parts. In addition, we will provide source code and instructions for driving these with efficient GPU-based implementations of the most important algorithms: tomographic light field synthesis, non-negative matrix factorizations as well as non-negative tensor factorizations. Furthermore, this part will discuss how important display characteristics, such as depth of field, field of view, and contrast, are theoretically analyzed. This analysis along with hardware and software-related implementation details will be presented as step-by-step instructions so as to provide

---

other researchers with intuitive tools that facilitate them to get started in this exciting new field and build their own computational light field displays.

**55 minutes: Perceptually-driven Computational Displays**

*Piotr Didyk*

This part will review aspects of the human visual system that are of particular importance for designing displays. In particular, we will discuss sensitivity to contrast, spatial frequencies, stereo disparities and other depth cues as well as temporally-multiplexed signals. The goal of this part is to emphasize how the limitations of the human visual system can be exploited to enhance the perceived capabilities of computational displays.

**10 minutes: Summary and Q & A**

*All*

This part will summarize how computational displays are changing current display architectures by exploiting the co-design of display optics and computational processing targeted toward human observers. We will outline future directions of this emerging field and allow for sufficient time to answer questions and stimulate discussions.

# Computational Displays as Next-generation Technology

## Fast Forward!

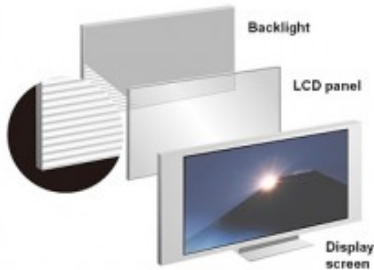
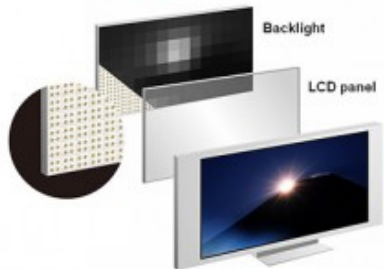
Gordon Wetzstein  
MIT Media Lab

# HDR Display Systems



## TRILUMINOS

RGB Dynamic LED



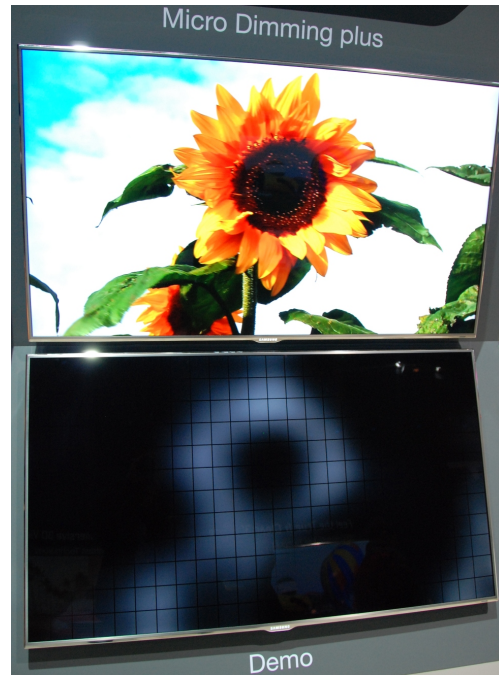
Display screen  
with local  
dimming  
backlighting



Display screen  
with CCFL  
backlighting



Local dimming, Sony



Micro-dimming, Samsung

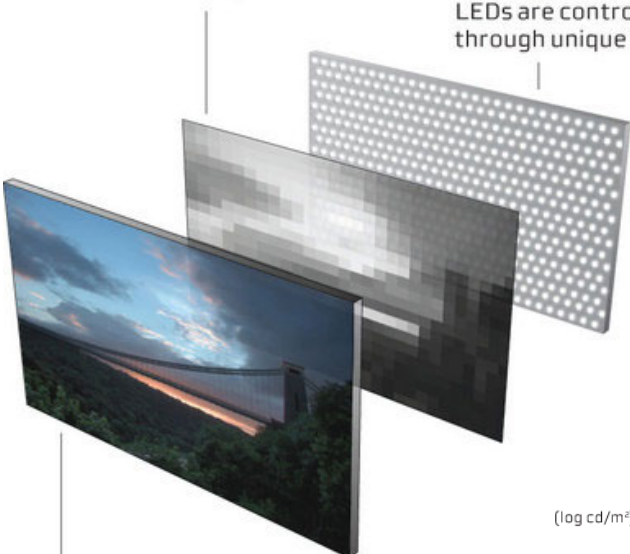
# HDR Display Systems – Dual Modulation



**Backlight Simulation**

**LED Dynamic Backlight**

LEDs are controlled through unique signals.

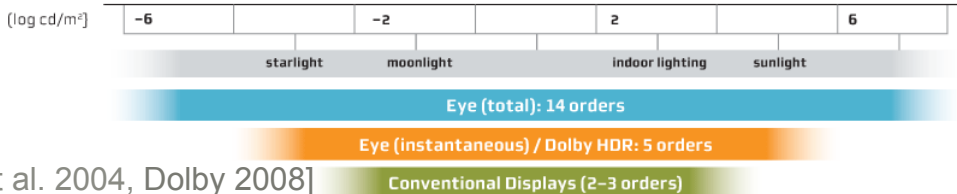


**LCD**

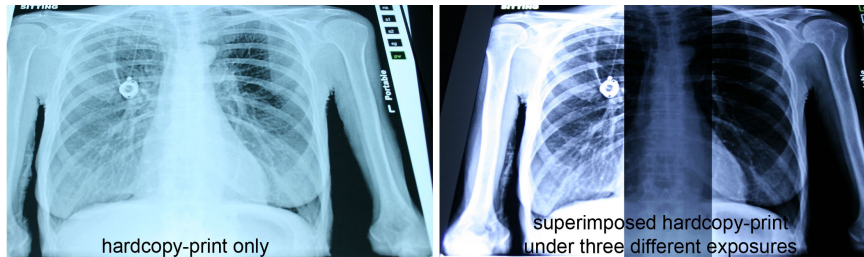
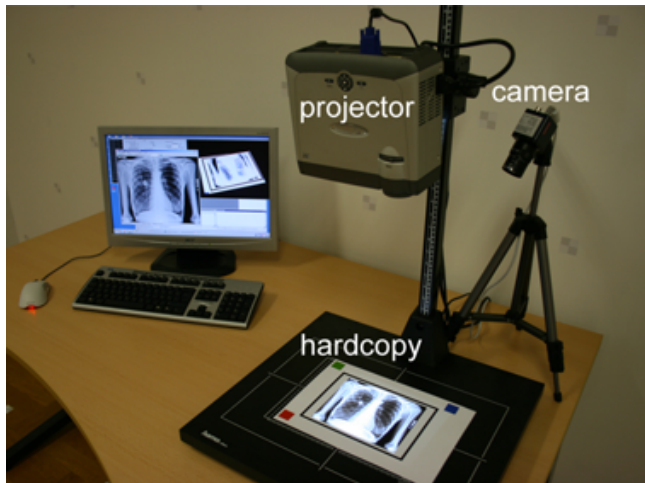
Provides color, resolution, and contrast. Contrast and image created by combining LED and LCD images.

[Seetzen et al. 2004, Dolby 2008]

**Dolby's HDR Technologies: Matching the Human Eye**

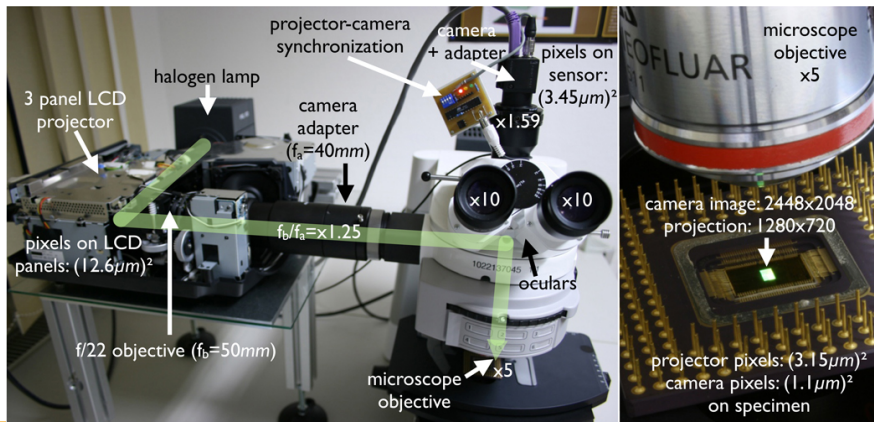


# HDR Display Systems – Dual Modulation

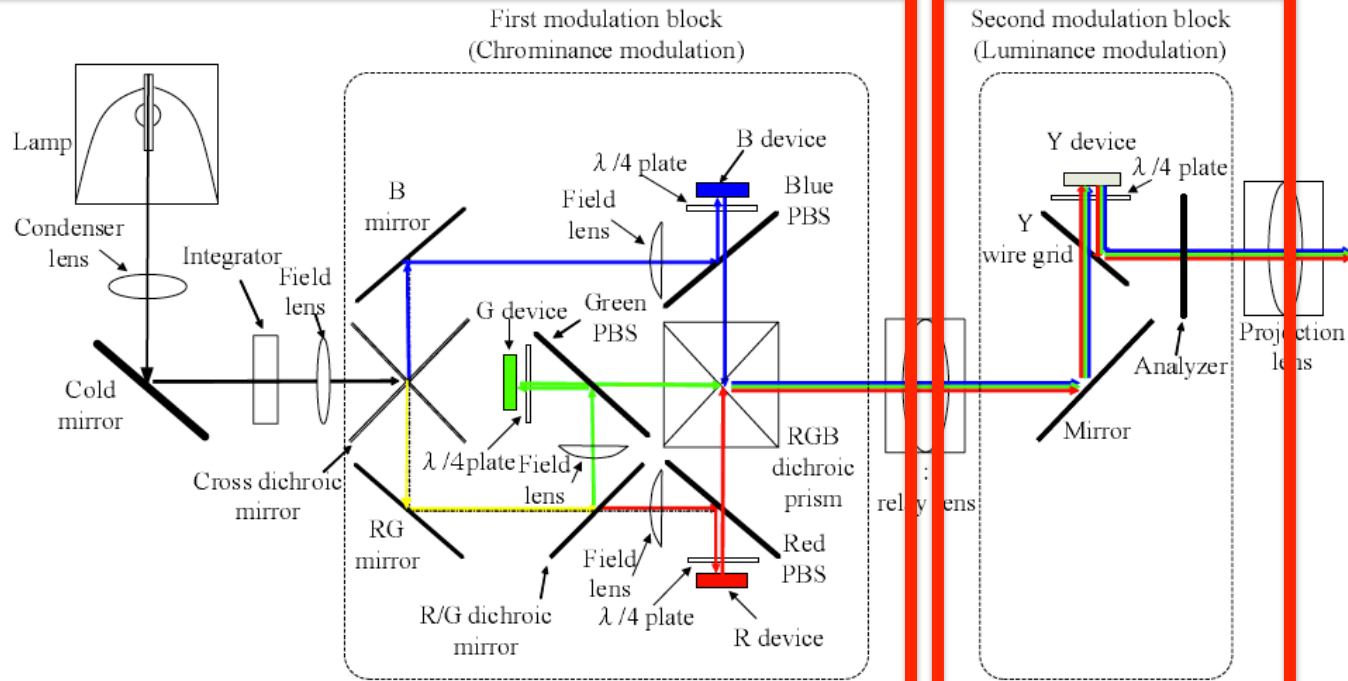


[Bimber and Iwai 2008]

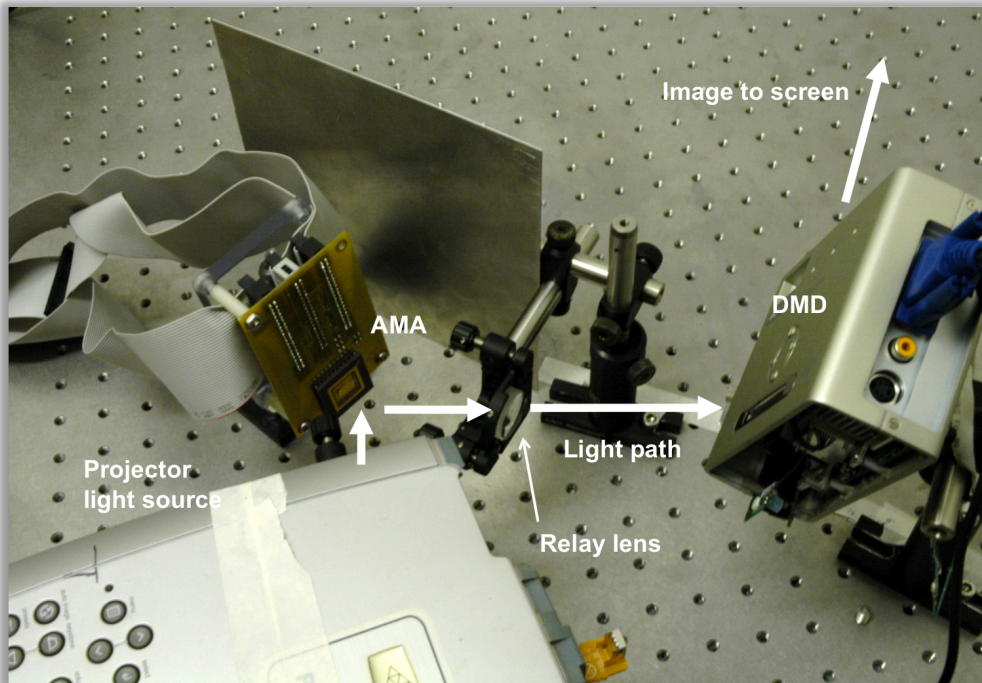
[Bimber et al. 2010]



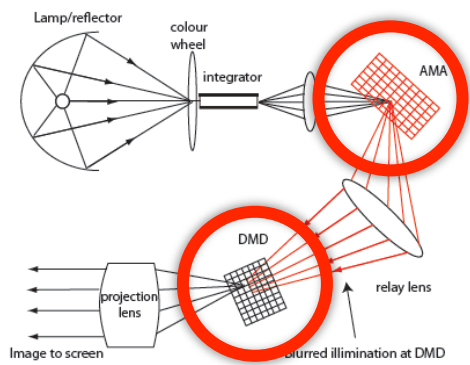
# HDR Display Systems – Dual Modulation



# HDR Projection – Light Reallocation



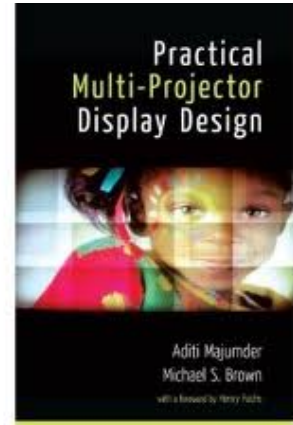
[Hoskinson 2010]



# Computational Projectors – Multi-device Systems

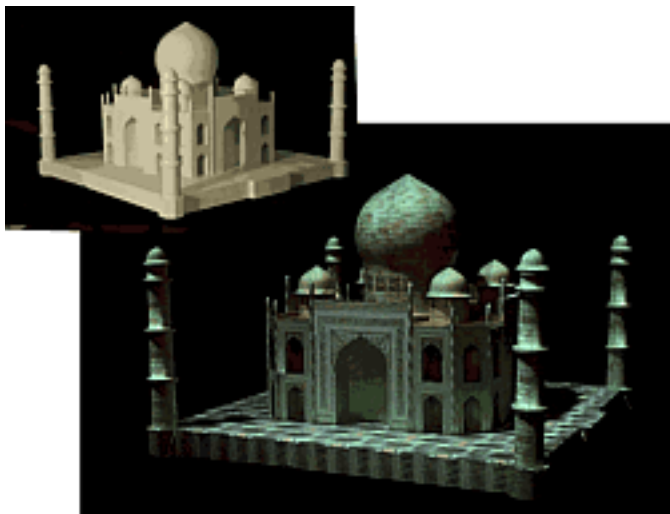


[Raskar et al. 1998]

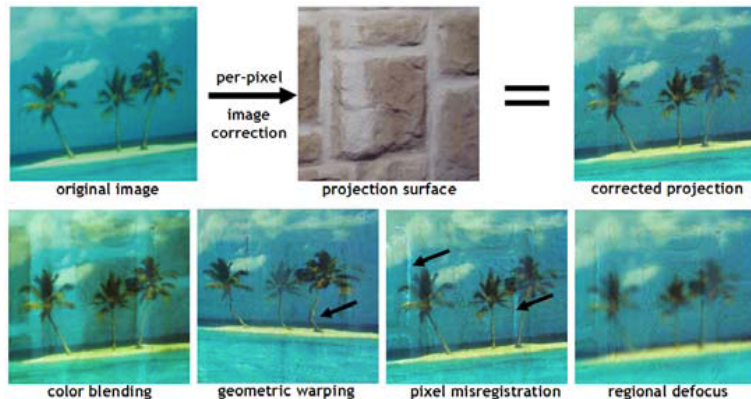


[Majumder and Brown 2007]

# Computational Projectors – Radiometric Compensation

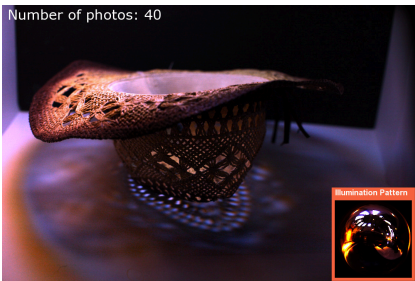


[Raskar et al. 2001]



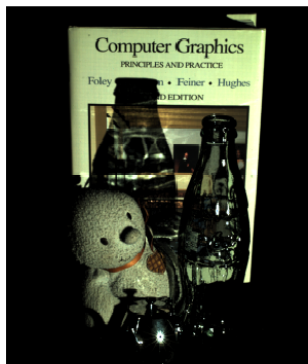
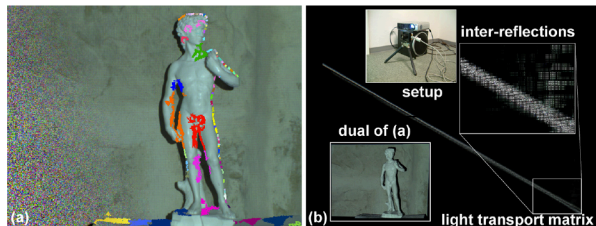
[Bimber et al. 2007]

# Computational Projectors – Dual Photography

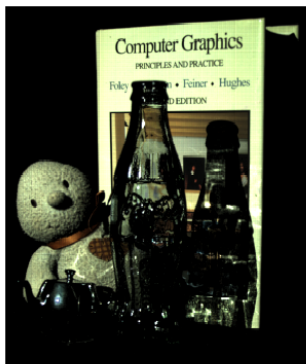


[O'Toole and Kutulakos 2010]

[Wetzstein and Bimber 2007]



(a)



(b)



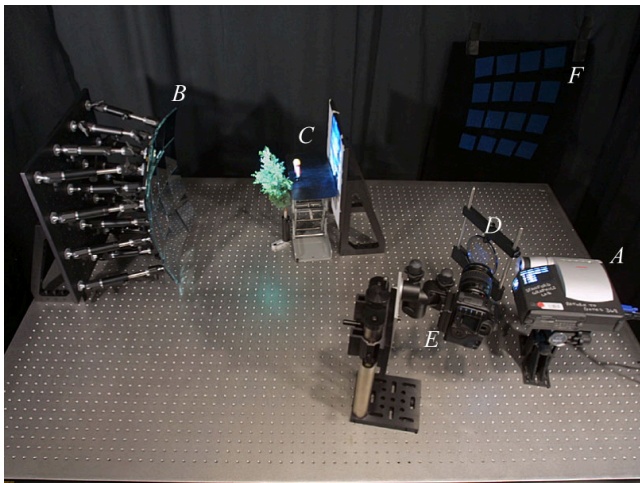
(c)



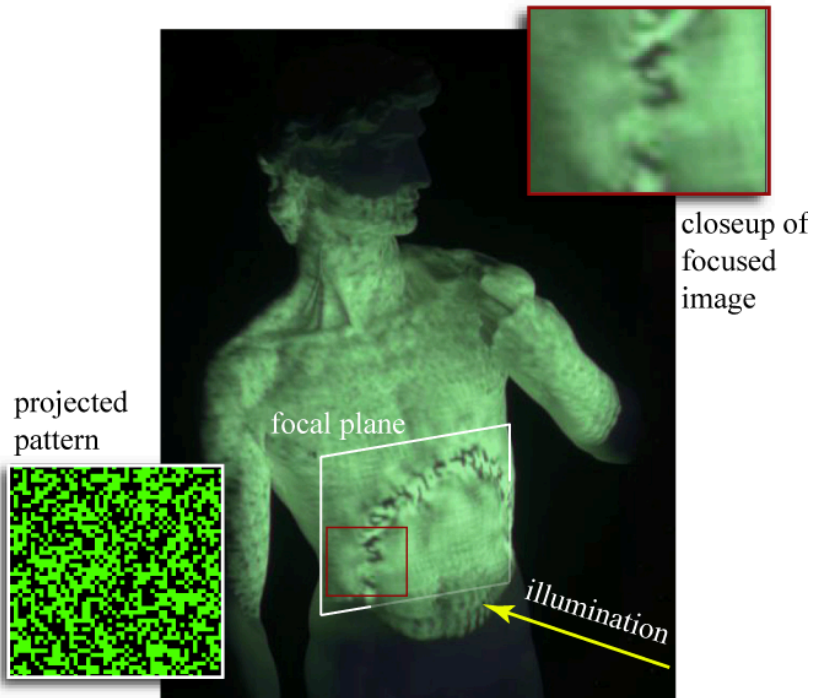
(d)

[Sen et al. 2005]

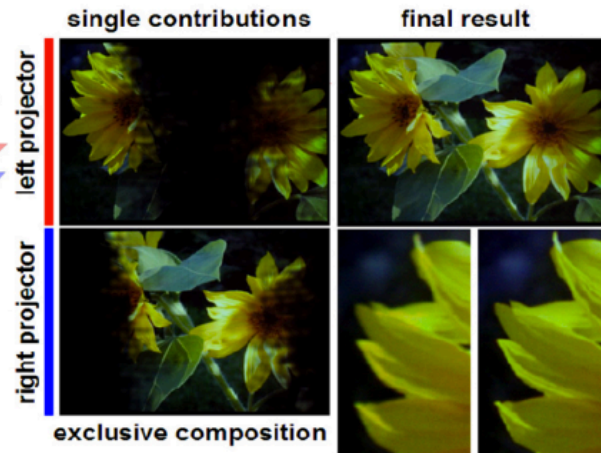
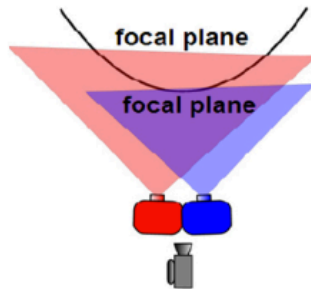
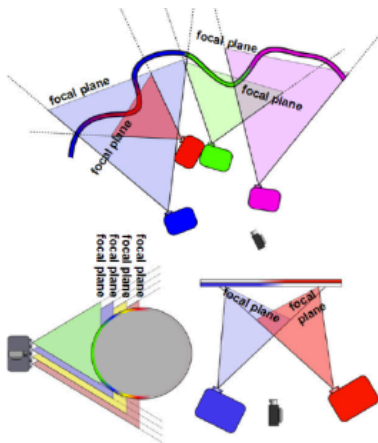
# Computational Projectors – Synthetic Aperture



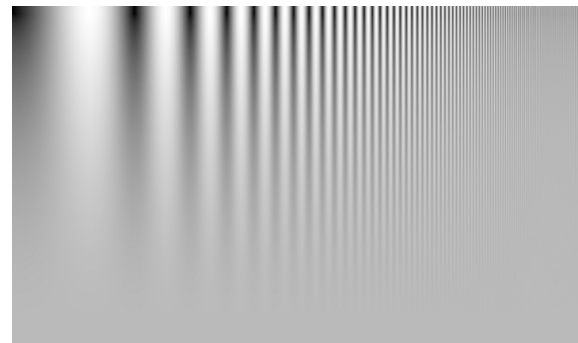
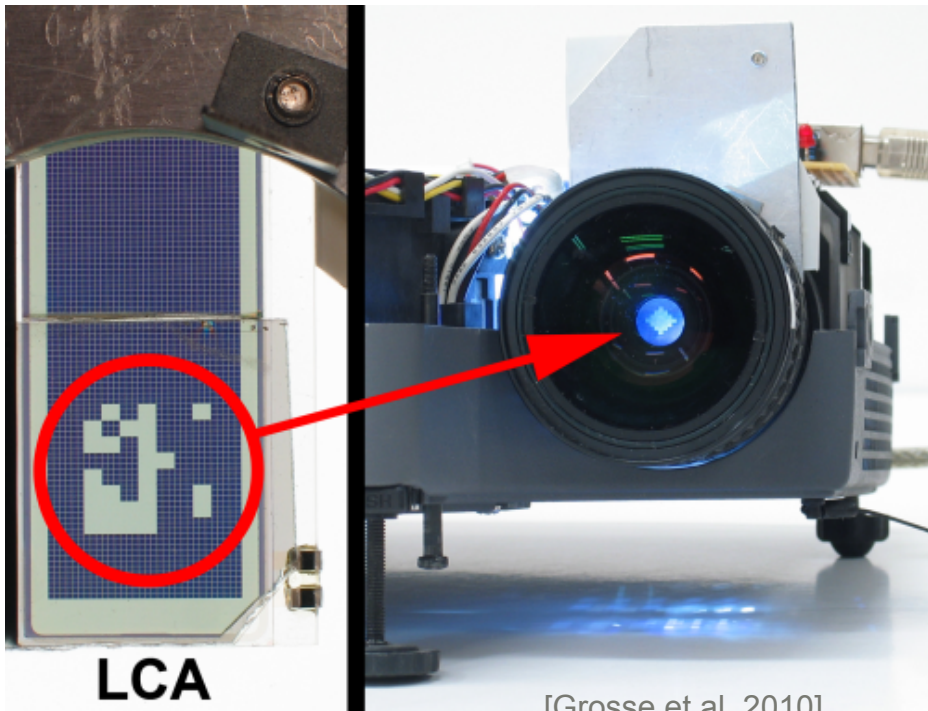
[Levoy et al. 2004]



# Computational Projectors – Multi-focal Display



# Computational Projectors – Coded Apertures



Contrast Sensitivity Function

[Grosse et al. 2010]

# Computational Projectors – Coded Apertures

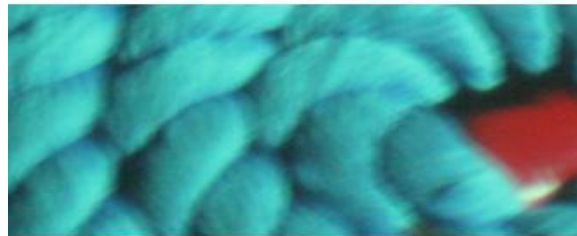
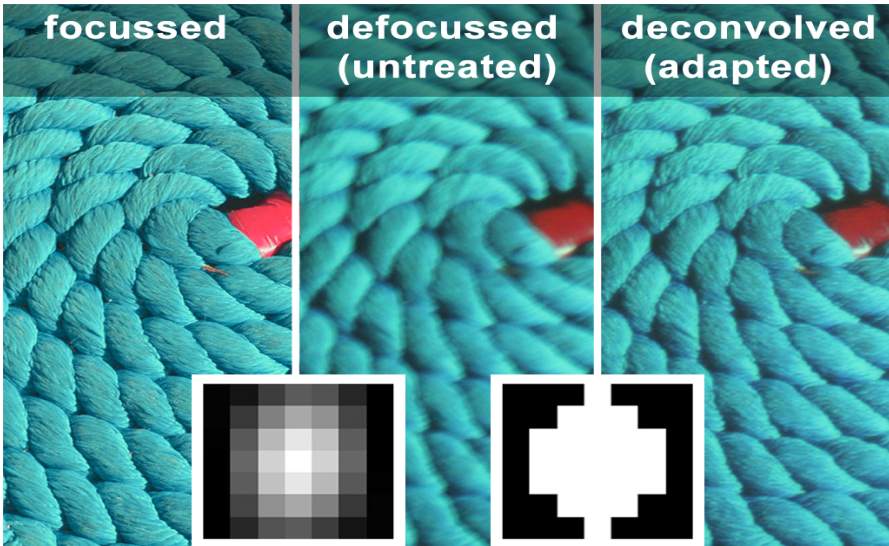


[Grosse et al. 2010]

**focussed**

**defocussed  
(untreated)**

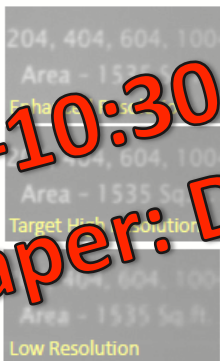
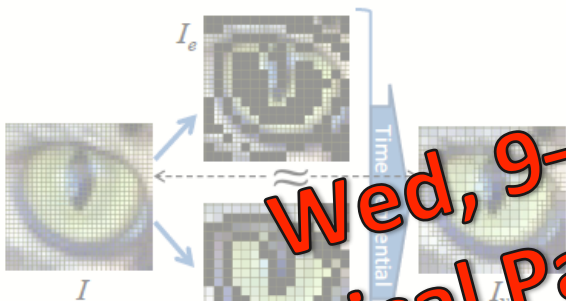
**deconvolved  
(adapted)**



# Computational Projectors – Superresolution

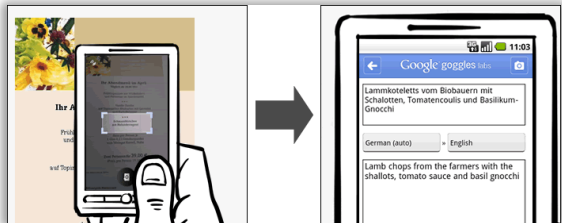


[Sajadi et al. 2012]



**Wed, 9-10:30 pm, 408A**  
**Technical Paper: Displays Session**

# Eyeworn Displays



Google



Steve Mann - Eyetap



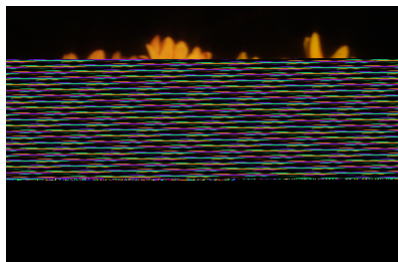
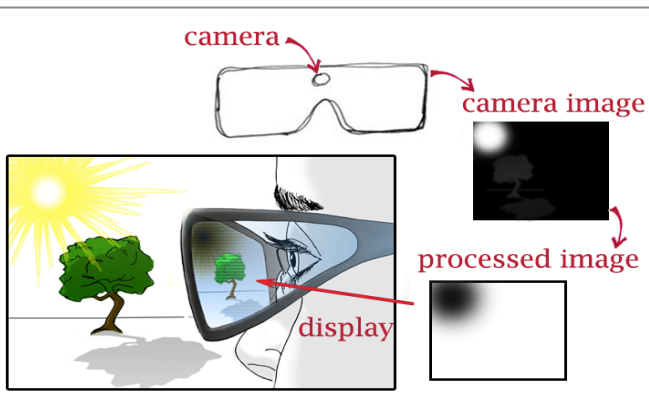
ARToolKit

# Eyeworn Displays

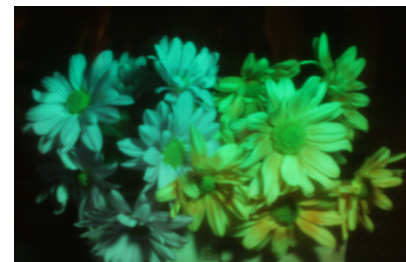


[Wetzstein et al. 2010]

# Eyeworn Displays

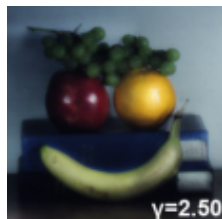


Modulation off



Modulation on

Color de-metamerization

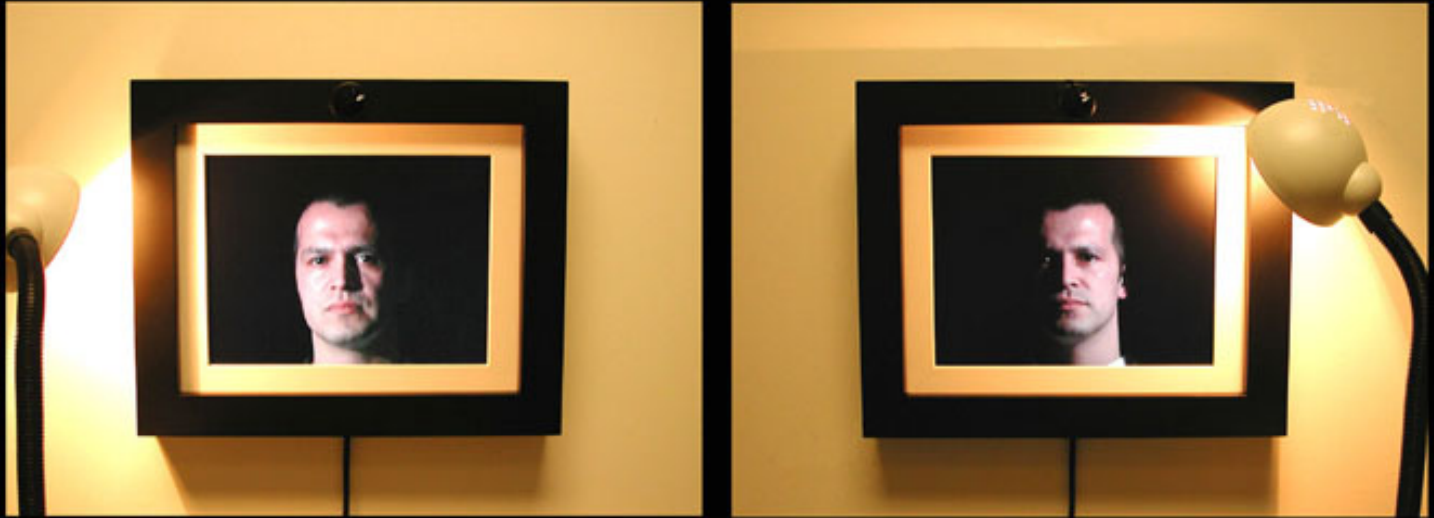


Contrast manipulation

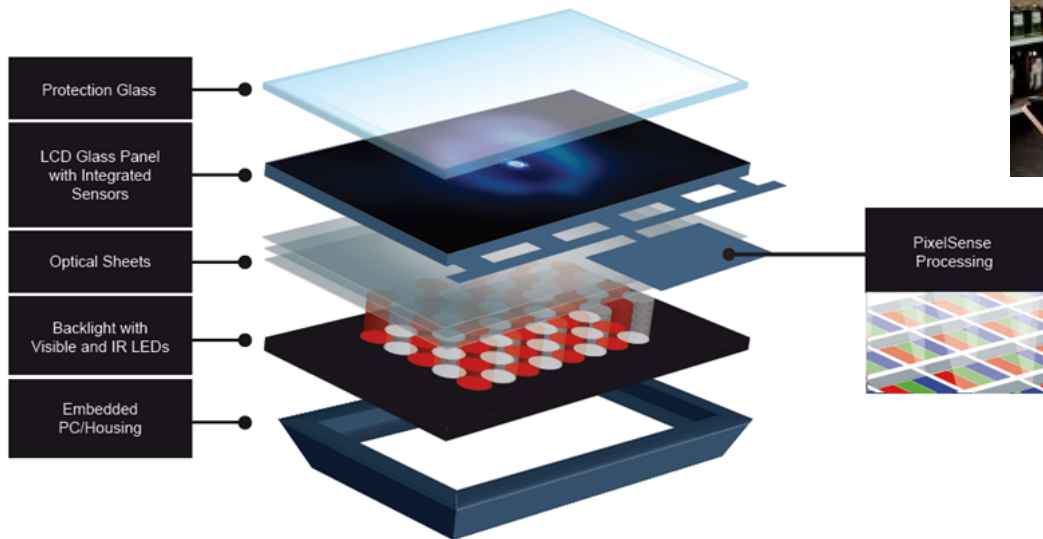


Optical object highlighting

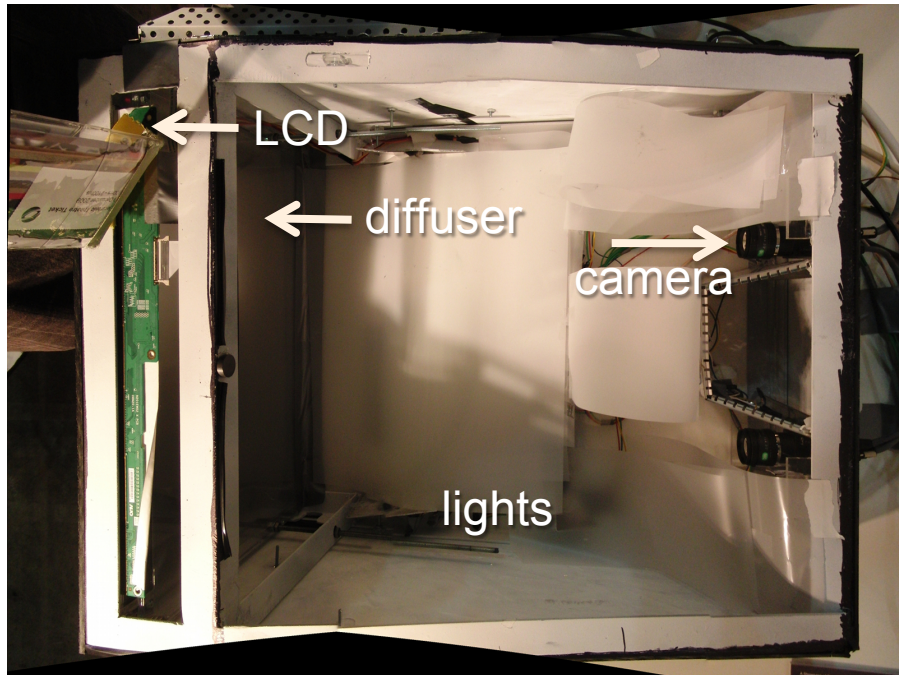
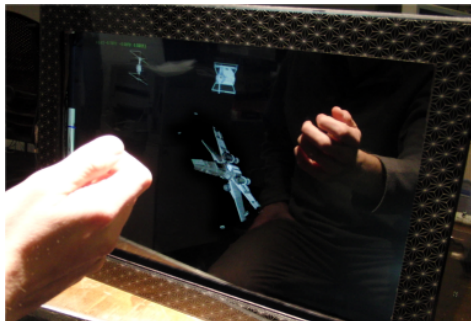
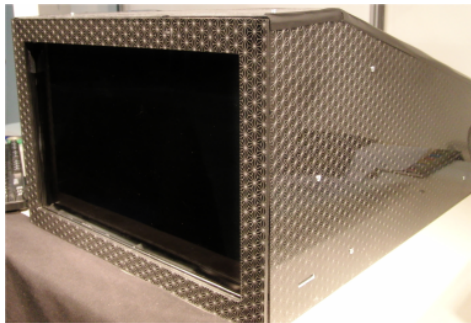
# Lighting-Sensitive Displays (4D)



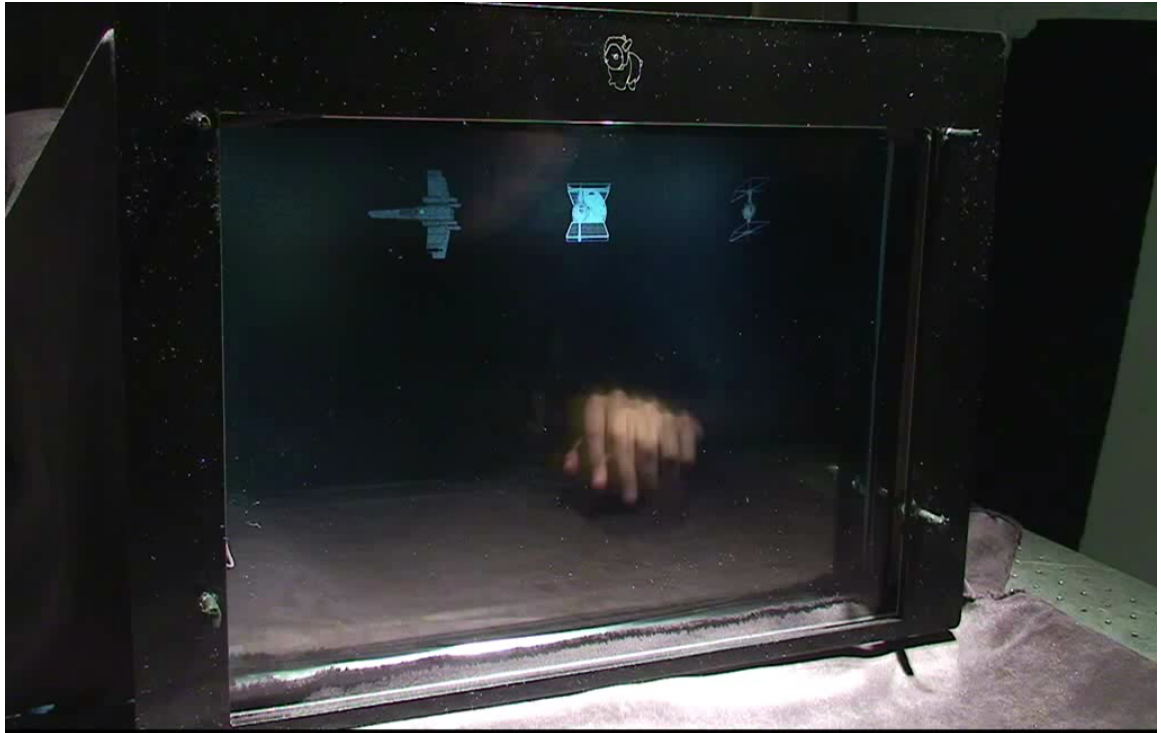
# Lighting-Sensitive Displays – PixelSense (4D)



# Lighting-Sensitive Displays – Bidi Screen (6D)



# Lighting-Sensitive Displays – Bidi Screen (6D)



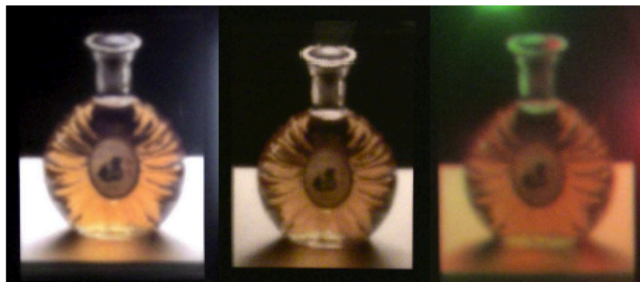
[Hirsch et al. 2011]

# Lighting-Sensitive Displays – Bidi Screen (6D)



[Hirsch et al. 2011]

# Lighting-Sensitive Displays – 6D display



area

distant top

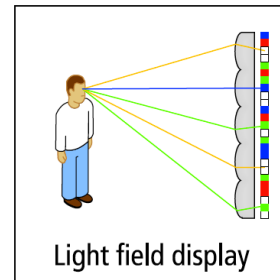
red and green



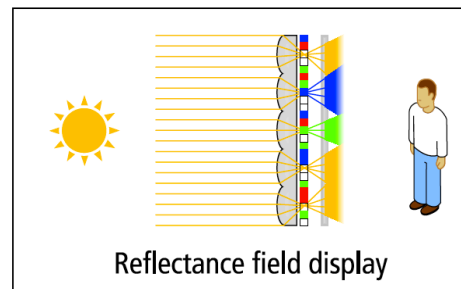
overcast



time lapse



Light field display

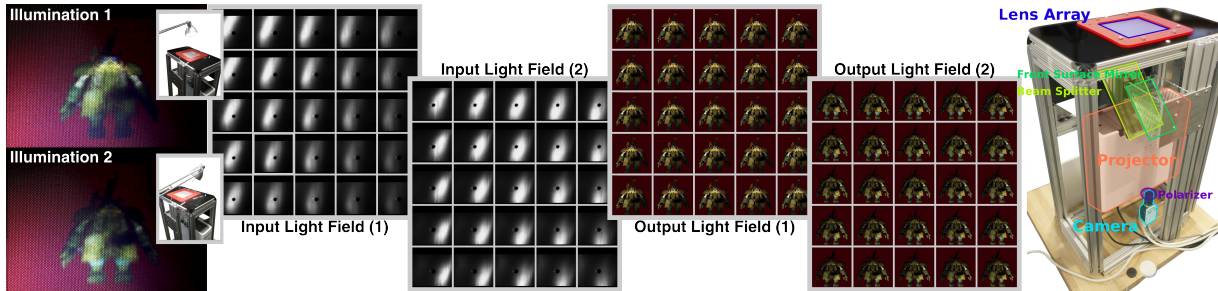


Reflectance field display

# Lighting-Sensitive Displays – 8D displays



[Hirsch et al. 2012]



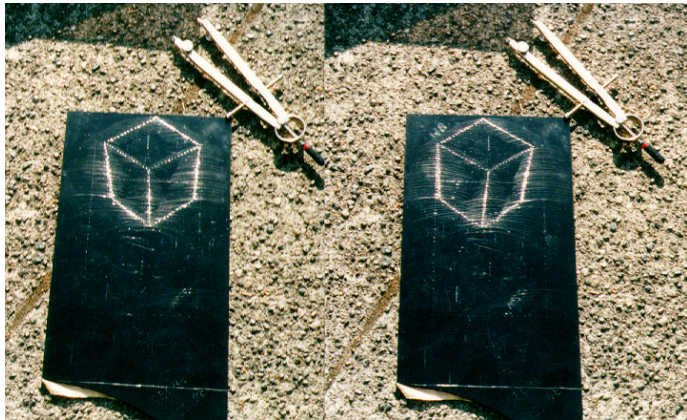
[Tompkin et al. 2012]



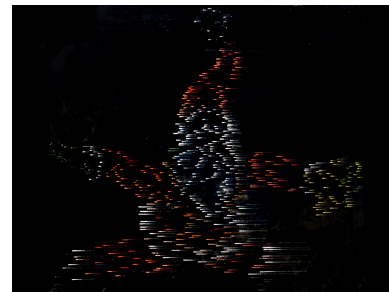
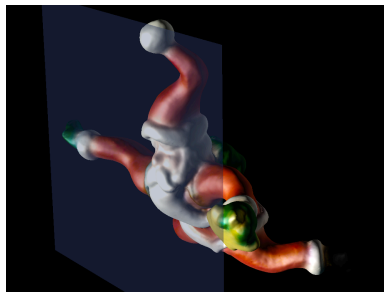
SIGGRAPH 2012 Poster

SIGGRAPH 2012 ETech

# Computational Reflectance Displays

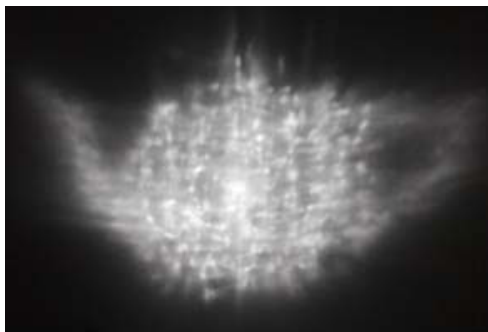
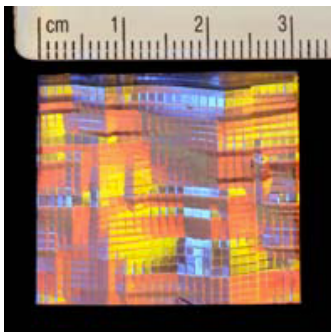


Scratch Holograms  
[W. Beaty 1995]



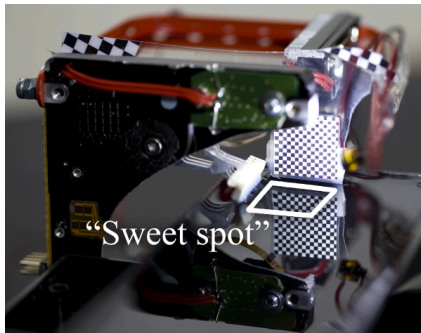
[Regg et al. 2010]

# Computational Reflectance Displays



[Weyrich et al. 09]

BRDF Display

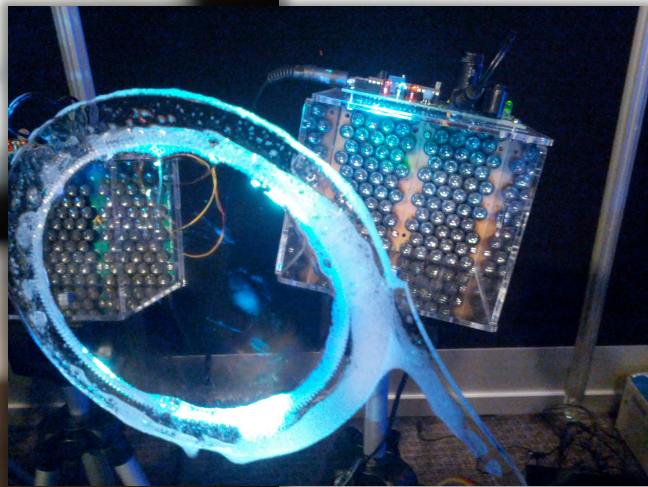


[Hullin et al. 11]

# Computational Reflectance Displays

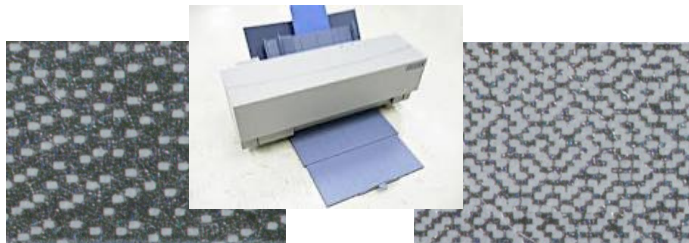
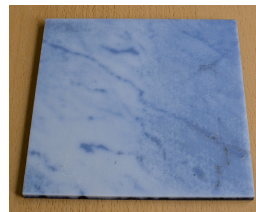
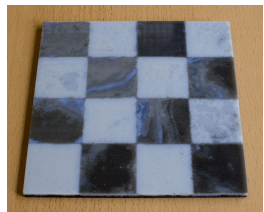
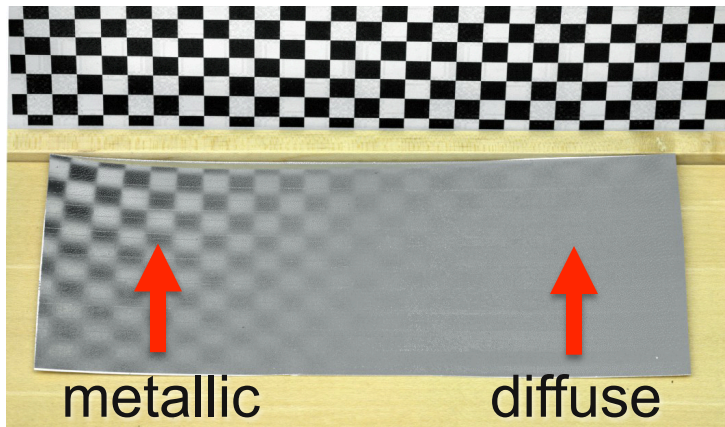


SIGGRAPH 2012 ETech



[Ochiai et al. 12]

# Computational Reflectance Displays

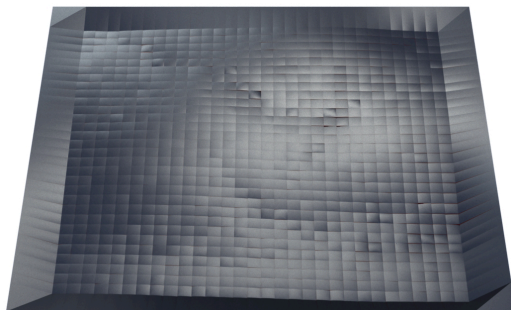
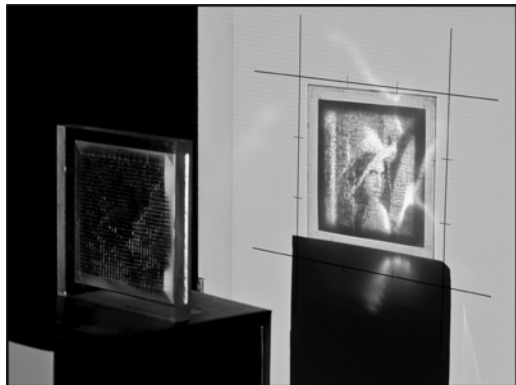


[Matusik et al. 2009]



[Hasan et al. 2010]

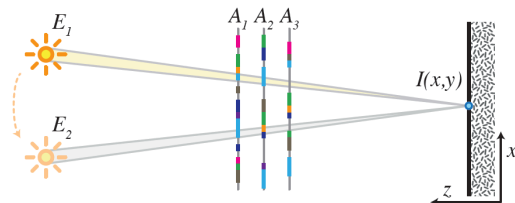
# Computational Transmission Displays



[Papas et al. 11]

## Goal-based Caustics

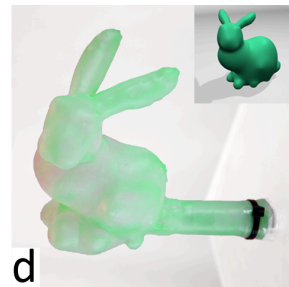
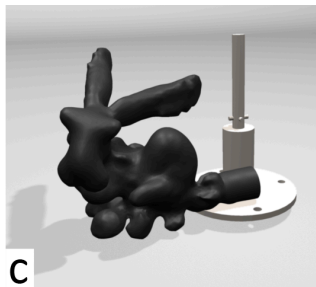
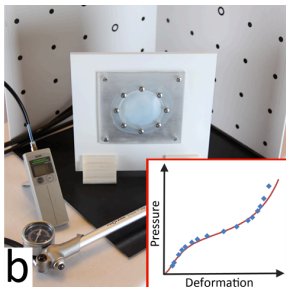
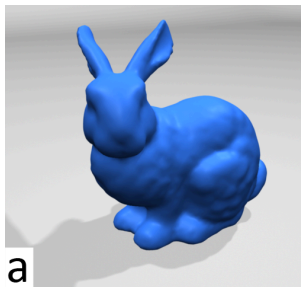
## & Shadows



[Baran et al. 12]



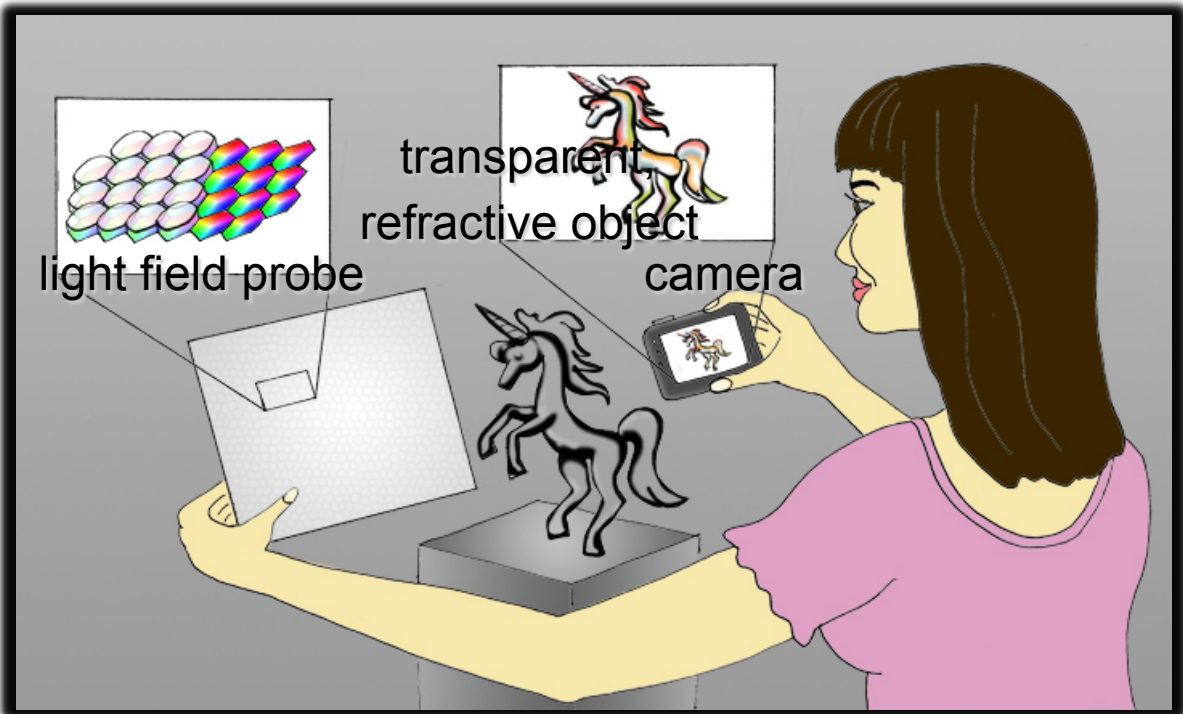
# Computational Rubber Balloons



# Computational Probes



[Wetzstein et al. 2011a, 2011b]



# Computational Probes



[Wetzstein et al. 2011a, 2011b]

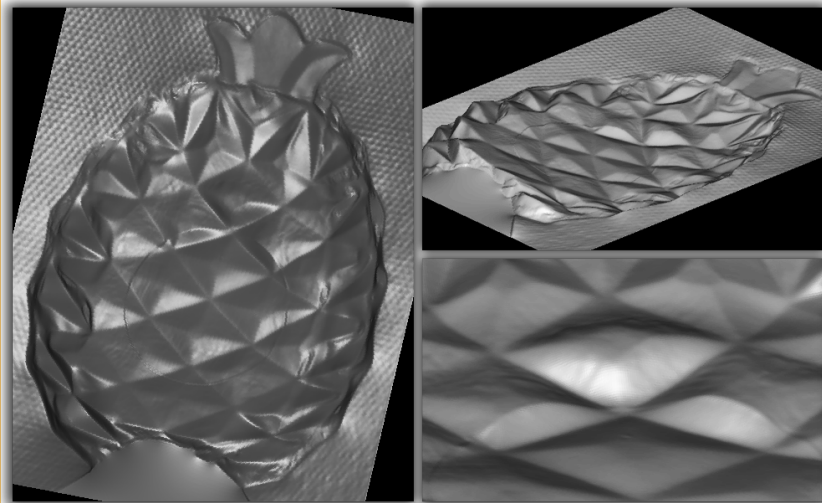


uniform illumination

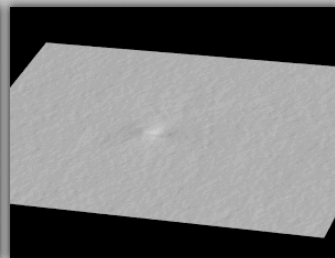
light field probe



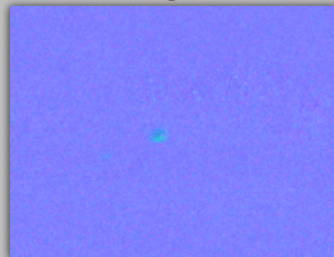
# Computational Probes



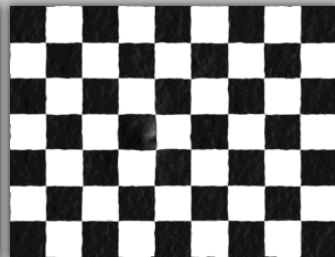
Camera Image



Reconstructed Surface



Extracted Normals



Synthetic Rendering

# Computational Ophthalmology

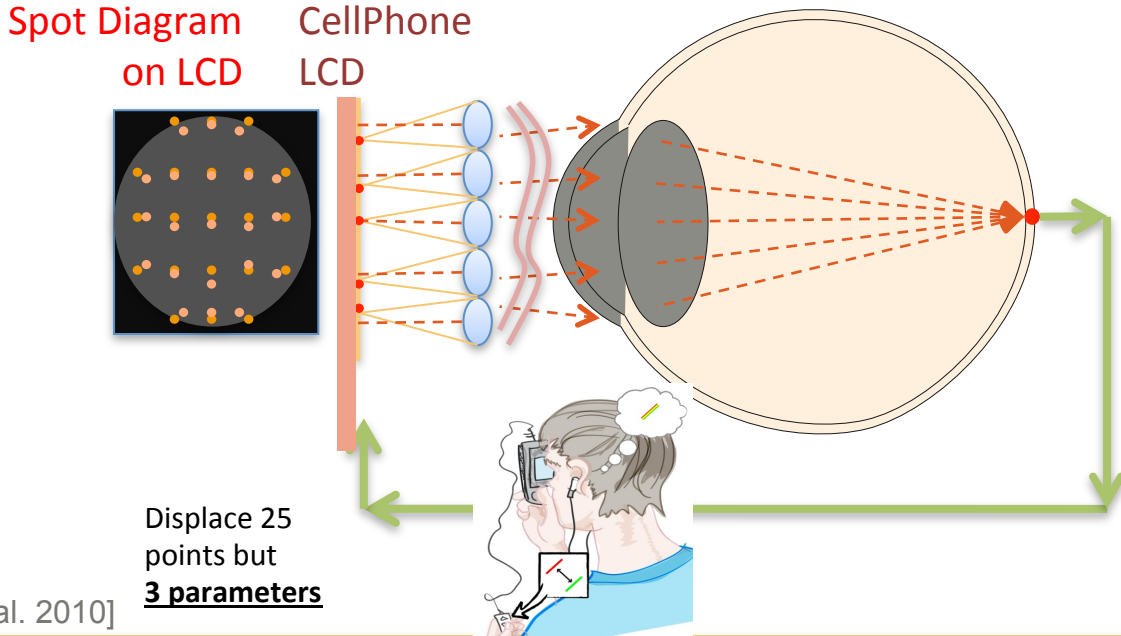


[Pamplona 2010]

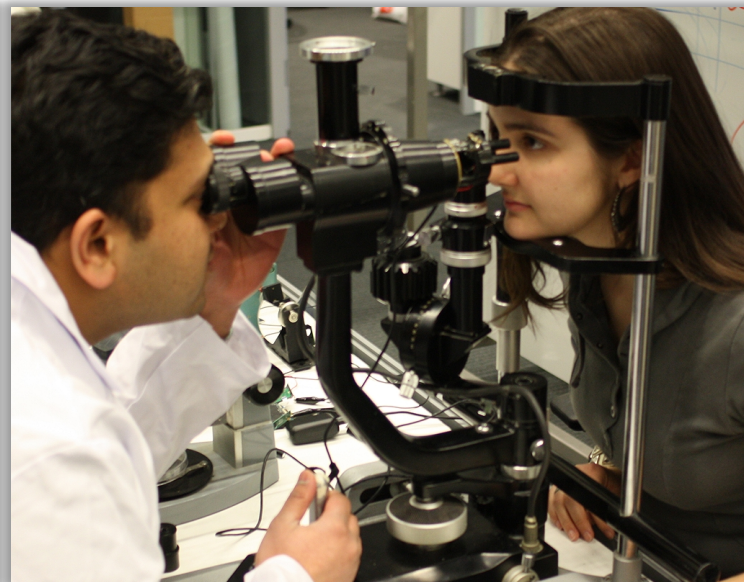




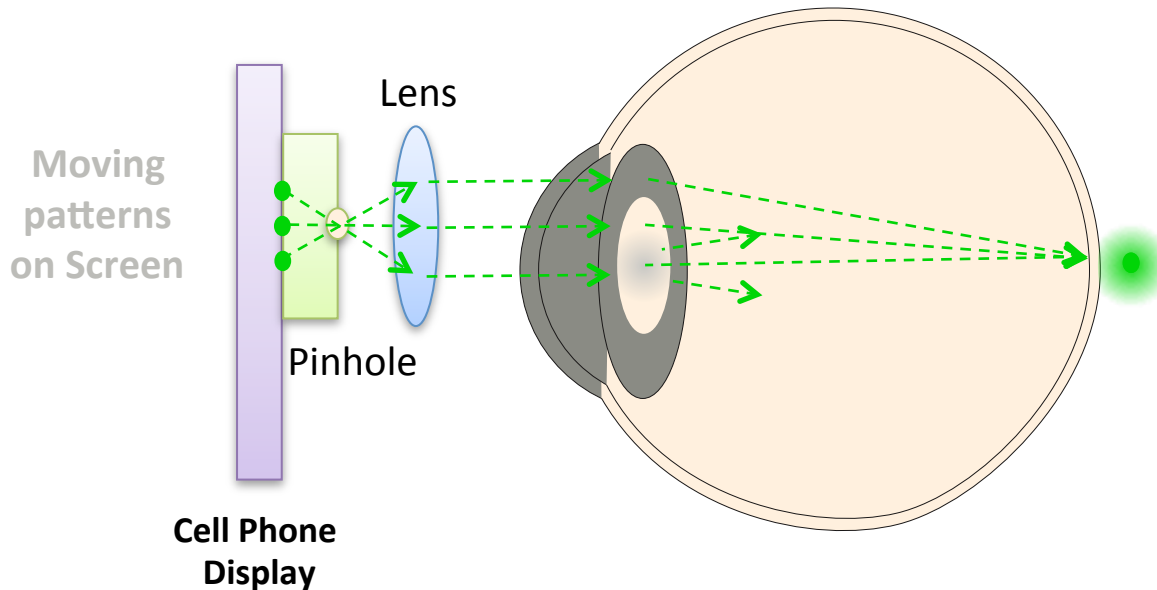
## Inverse of Shack-Hartmann, *user interactive!*



# Computational Ophthalmology - Cataracts



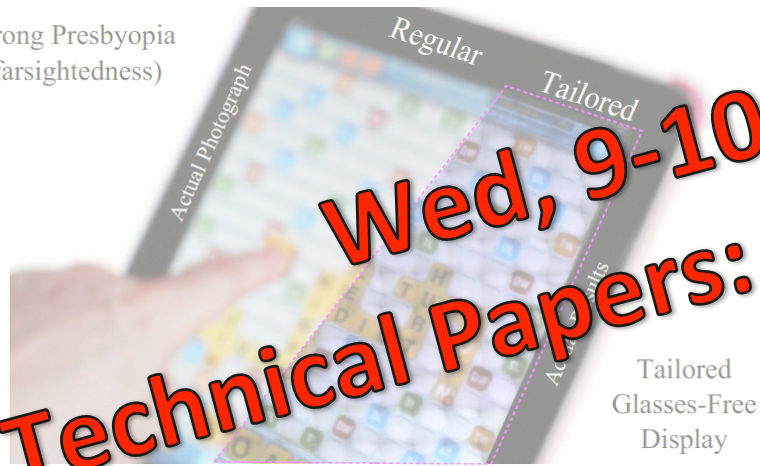
# Computational Ophthalmology - Cataracts



# Computational Ophthalmology – Tailored Displays



Strong Presbyopia  
(farsightedness)



**Wed, 9-10:30 am,  
Technical Papers: Displays Session**



(a) Input Image

(b) Regular Display

(c) Tailored Display

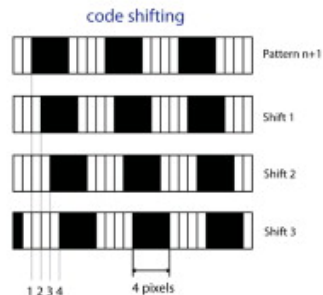
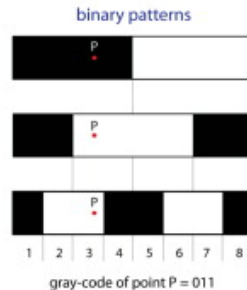
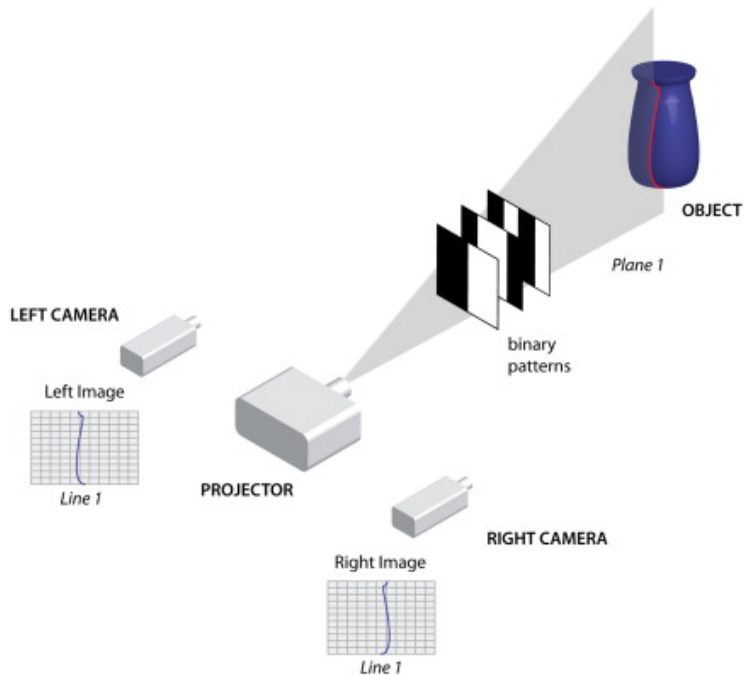


**Wed, 10:45–12:15,  
Talks: Capture the World**



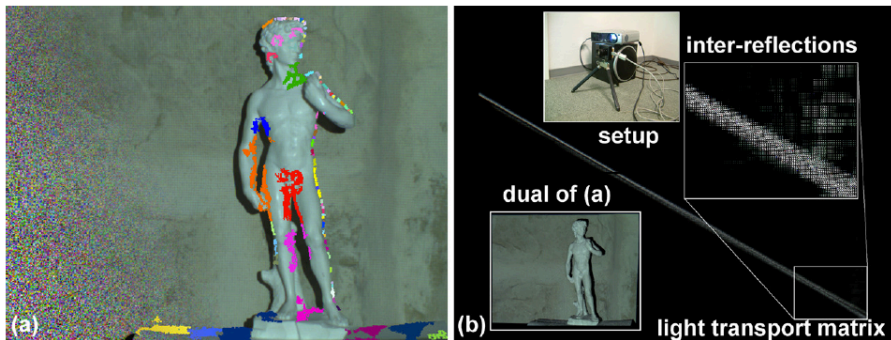


# Computational Projectors – Structured Illumination

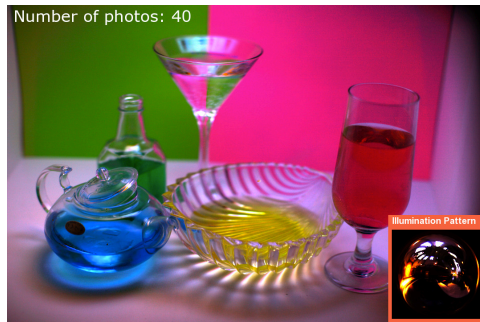
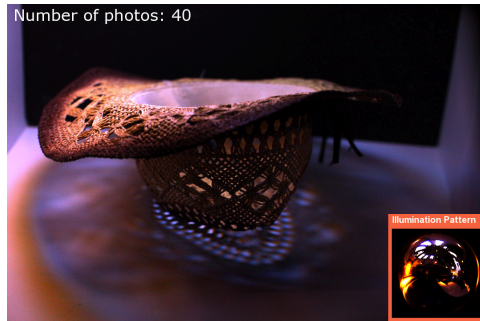


[Bruno et al. 2011]

# Computational Projectors – Inverse Light Transport

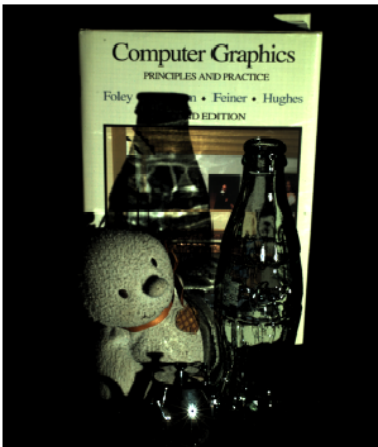


[Wetzstein and Bimber 2007]

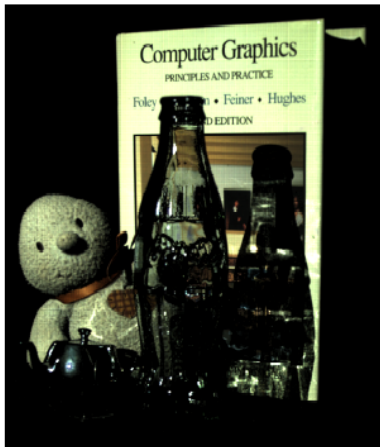


[O'Toole and Kutulakos 2010]

# Computational Projectors – Dual Photography



(a)



(b)



(c)

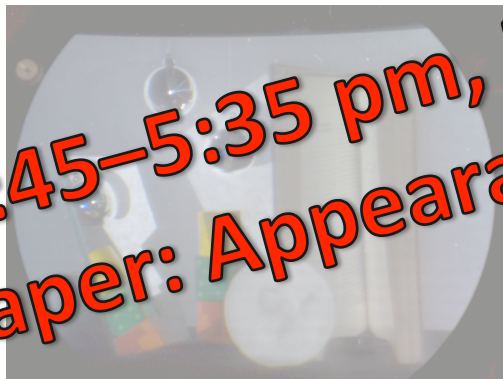


(d)

[Sen et al. 2005]



All-optical operations!



**Mon, 3:45–5:35 pm, 515AB**  
**Technical Paper: Appearance Session**

Photograph

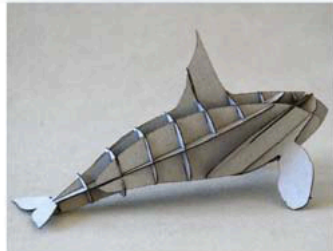
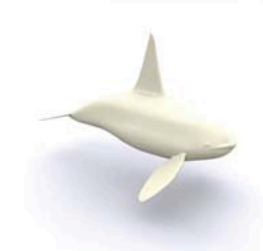
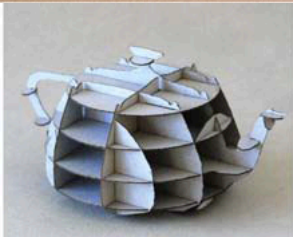
Indirect Illumination

Direct Illumination

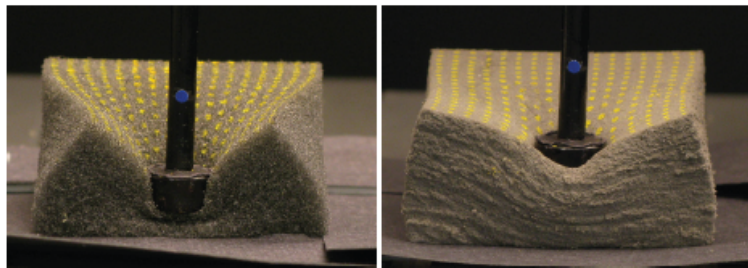
# Fabricating Cardboard Models



[Hildebrand et al. 12]



# Computational Slippers



[Bickel et al. 2010]

# Fabricating Articulated Characters



Skinned mesh



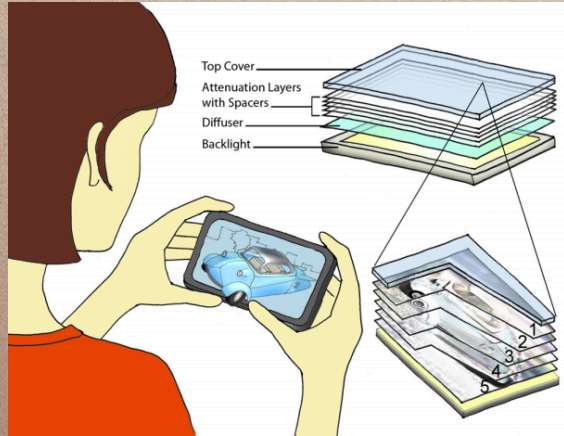
Optimized joints



3D printed model

**Tue, 9–10:30 am, 502AB**  
**Technical Paper: Fabrication Session**

# Computational Light Field Displays



Douglas Lanman  
MIT Media Lab

# Is “glasses-free 3D” ready?



**Nintendo 3DS**  
E3 2010



**MasterImage 3D**  
Computex 2011



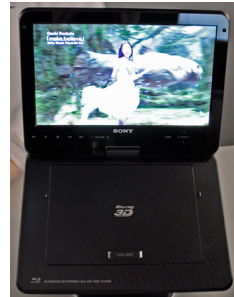
**Asus Eee Pad MeMO 3D**  
Computex 2011



**LG Optimus 3D**  
Mobile World Congress 2011



**Toshiba 3DTV Prototype**  
CES 2011



**Sony 3DTV Prototype**  
CES 2011



**LG 3DTV Prototype**  
CES 2011

# Taxonomy of Direct 3D Displays:

SIGGRAPH2012



## Glasses-bound vs. Unencumbered Designs

### Glasses-bound Stereoscopic

#### Head-mounted

(eyepiece-objective and microdisplay)

#### Immersive

(blocks direct-viewing of real world)

#### See-through

(superimposes synthetic images onto real world)

#### Multiplexed

(stereo pair with same display surface)

#### Spatially-multiplexed (field-concurrent)

(color filters, polarizers, autostereograms, etc.)

#### Temporally-multiplexed (field-sequential)

(LCD shutter glasses)

### Unencumbered Automultiscopic

#### Parallax-based

(2D display with light-directing elements)

#### Parallax Barriers

(uniform array of 1D slits or 2D pinhole arrays)

#### Integral Imaging

(lenticular sheets or fly's eye lenslet arrays)

#### Volumetric

(directly illuminate points within a volume)

#### Multi-planar

(time-sequential projection onto swept surfaces)

#### Transparent Substrates

(intersecting laser beams, fog layers, etc.)

#### Holographic

(reconstructs wavefront using 2D element)

#### Static

(holographic films)

#### Dynamic

(holovideo)

# Taxonomy of 3D Displays:

## Immersive Head-mounted Displays (HMDs)



Glasses-bound  
Stereoscopic

**Head-mounted**  
(eyepiece-objective and microdisplay)

**Multiplexed**  
(stereo pair with same display surface)

**Immersive**  
(blocks direct-viewing of real world)

# Taxonomy of 3D Displays:

SIGGRAPH2012



## See-through Head-mounted Displays (HMDs)



Glasses-bound  
Stereoscopic

**Head-mounted**  
(eyepiece-objective and microdisplay)

**Multiplexed**  
(stereo pair with same display surface)

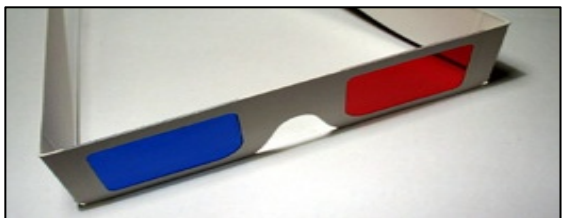
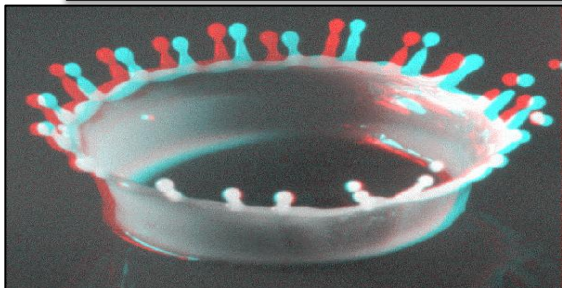
**Immersive**  
(blocks direct-viewing of real world)

**See-through**  
(superimposes synthetic images onto real world)

# Taxonomy of 3D Displays:

## Spatial Multiplexing (e.g., Anaglyphs)

SIGGRAPH2012



**Glasses-bound Stereoscopic**

**Head-mounted**  
(eyepiece-objective and microdisplay)

**Multiplexed**  
(stereo pair with same display surface)

**Immersive**  
(blocks direct-viewing of real world)

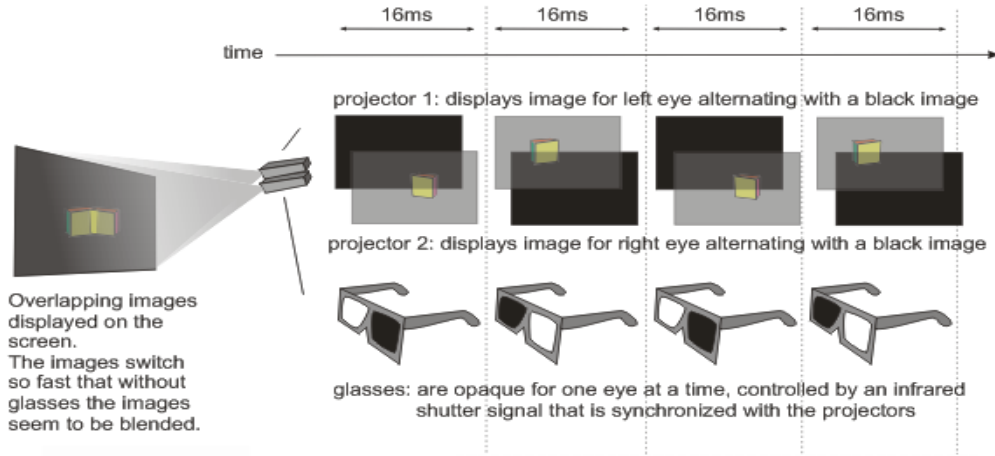
**See-through**  
(superimposes synthetic images onto real world)

**Spatially-multiplexed (field-concurrent)**  
(color filters, polarizers, etc.)

# Taxonomy of 3D Displays:

## Temporal Multiplexing (e.g., Shutter Glasses)

SIGGRAPH2012



**Glasses-bound Stereoscopic**

**Head-mounted**  
(eyepiece-objective and microdisplay)

**Multiplexed**  
(stereo pair with same display surface)

**Immersive**  
(blocks direct-viewing of real world)

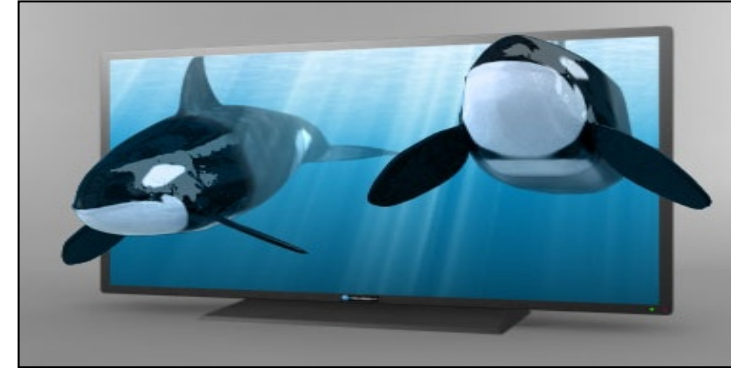
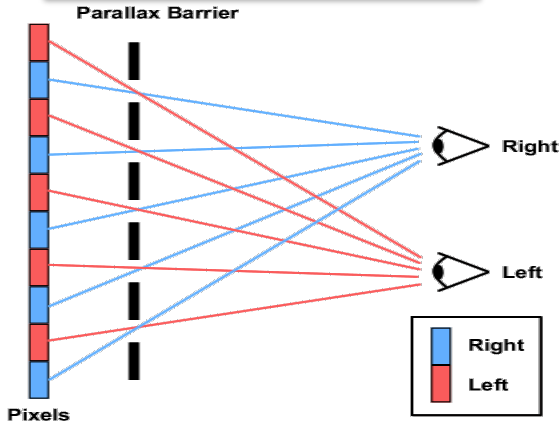
**See-through**  
(superimposes synthetic images onto real world)

**Spatially-multiplexed (field-concurrent)**  
(color filters, polarizers, autostereograms, etc.)

**Temporally-multiplexed (field-sequential)**  
(LCD shutter glasses)

# Taxonomy of Direct 3D Displays:

## Parallax Barriers



**NewSight MV-42AD3 42"**  
(1920x1080, 1x8 views)

Parallax Barriers  
(uniform array of 1D slits or 2D pinhole arrays)

**Unencumbered  
Automultiscopic**

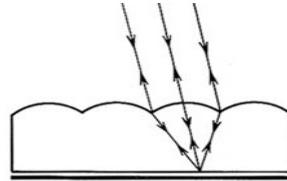
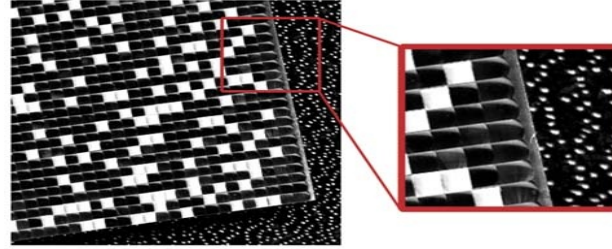
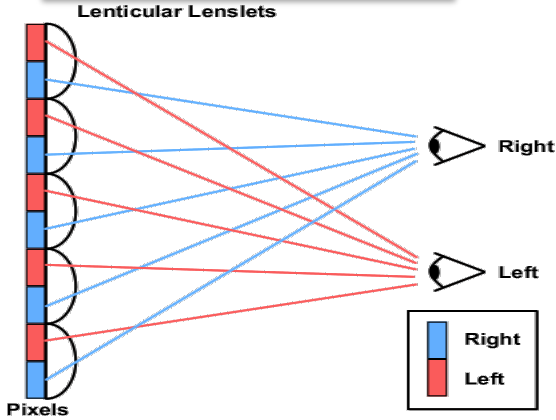
**Parallax-based**  
(2D display with light-directing elements)

**Volumetric**  
(directly illuminate points within a volume)

**Holographic**  
(reconstructs wavefront using 2D element)

# Taxonomy of Direct 3D Displays:

## Integral Imaging



**Alioscopy 3DHD 42''**  
(1920x1200, 1x8 views)

**Unencumbered  
Automultiscopic**

**Parallax-based**  
(2D display with light-directing elements)

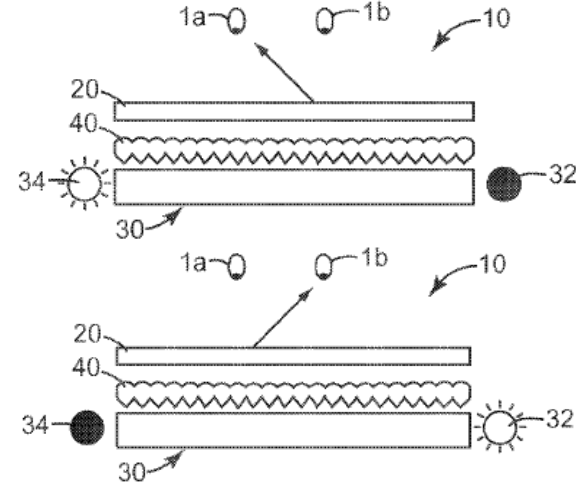
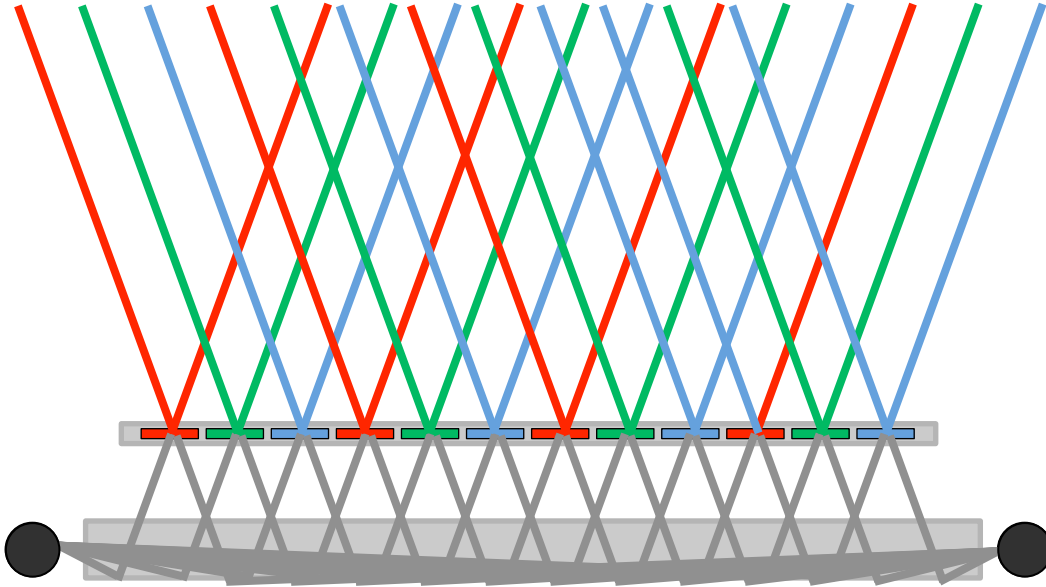
**Volumetric**  
(directly illuminate points within a volume)

**Holographic**  
(reconstructs wavefront using 2D element)

**Parallax Barriers**  
(uniform array of 1D slits or 2D pinhole arrays)

**Integral Imaging**  
(lenticular sheets or fly's eye lenslet arrays)

# Directional Backlighting

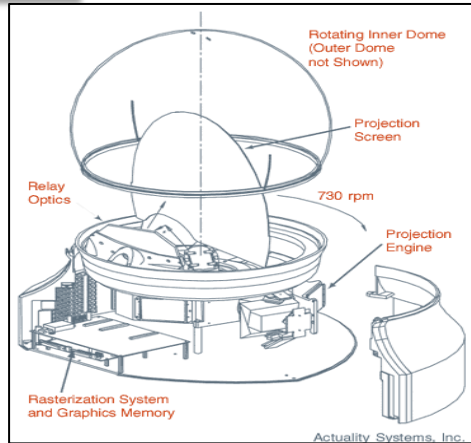
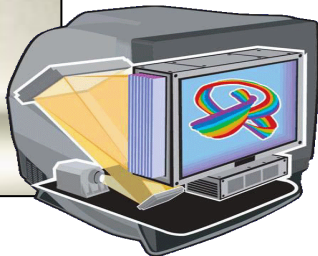


**Nelson and Brott, 2010**  
US Patent 7,847,869

- Currently promoted by 3M
- Requires a high-speed (120 Hz) LCD panel, an additional double-sided prism film, and a pair of LEDs
- Allows multi-view display, but requires higher-speed LCD and additional light sources for each view

# Taxonomy of Direct 3D Displays:

## Multi-planar Volumetric Displays



**Unencumbered  
Automultiscopic**

**Parallax-based**  
(2D display with light-directing elements)

**Volumetric**  
(directly illuminate points within a volume)

**Holographic**  
(reconstructs wavefront using 2D element)

**Parallax Barriers**  
(uniform array of 1D slits or 2D pinhole arrays)

**Integral Imaging**  
(lenticular sheets or fly's eye lenslet arrays)

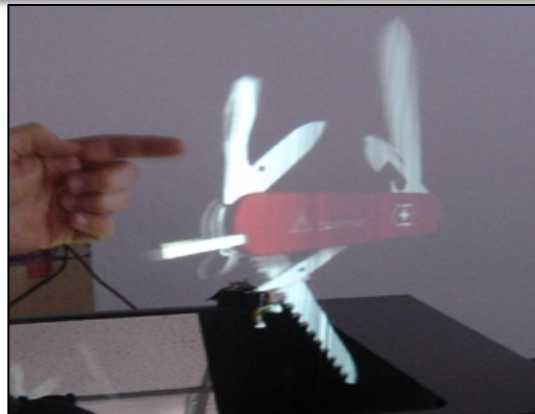
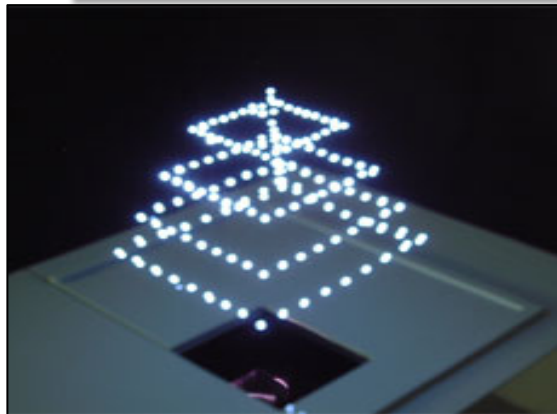
**Multi-planar**  
(time-sequential projection onto swept surfaces)

# Taxonomy of Direct 3D Displays:

SIGGRAPH2012



## Transparent-substrate Volumetric Displays



**Unencumbered  
Automultiscopic**

**Parallax-based**

(2D display with light-directing elements)

**Volumetric**

(directly illuminate points within a volume)

**Holographic**

(reconstructs wavefront using 2D element)

**Parallax Barriers**

(uniform array of 1D slits or 2D pinhole arrays)

**Integral Imaging**

(lenticular sheets or fly's eye lenslet arrays)

**Multi-planar**

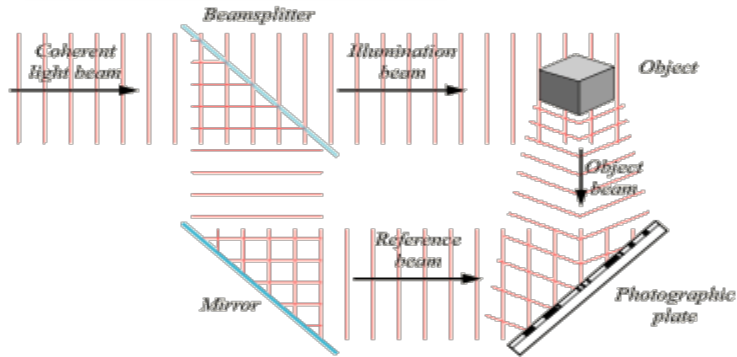
(time-sequential projection onto swept surfaces)

**Transparent Substrates**

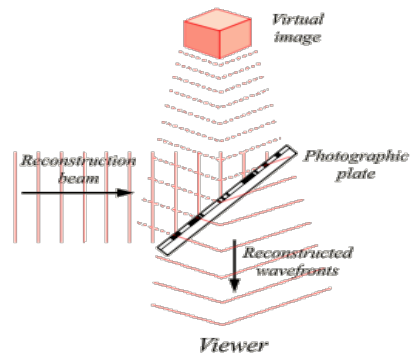
(intersecting laser beams, fog layers, etc.)

# Taxonomy of Direct 3D Displays:

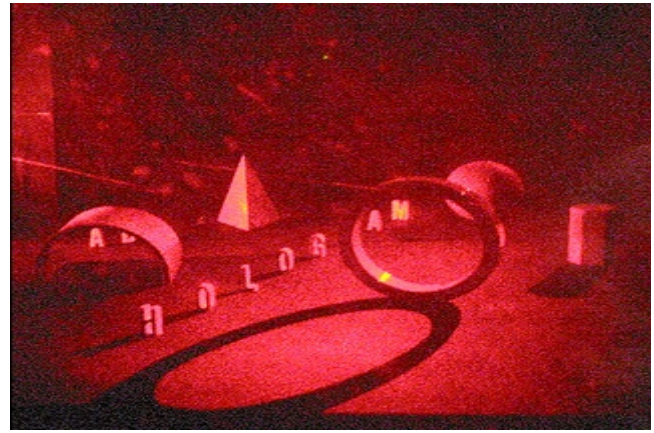
## Static Holograms



capture



reconstruction



Unencumbered  
Automultiscopic

**Parallax-based**  
(2D display with light-directing elements)

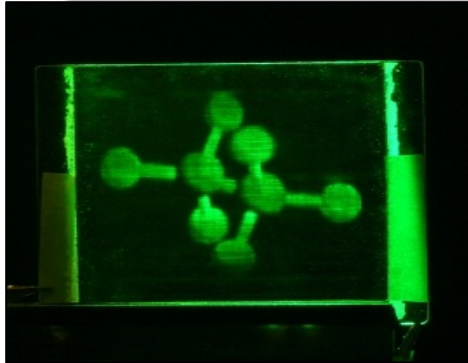
**Volumetric**  
(directly illuminate points within a volume)

**Holographic**  
(reconstructs wavefront using 2D element)

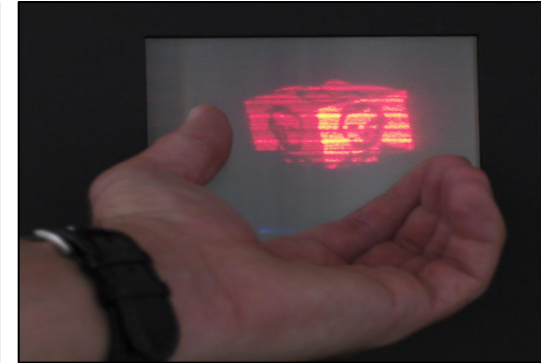
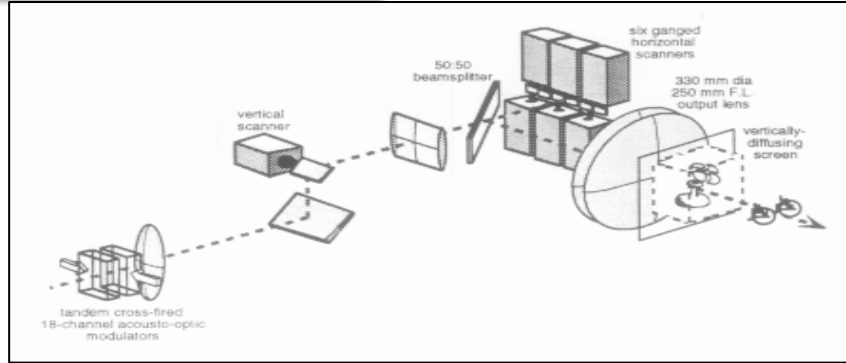
- Parallax Barriers**  
(uniform array of 1D slits or 2D pinhole arrays)
- Integral Imaging**  
(lenticular sheets or fly's eye lenslet arrays)
- Multi-planar**  
(time-sequential projection onto swept surfaces)
- Transparent Substrates**  
(intersecting laser beams, fog layers, etc.)
- Static**  
(holographic films)

# Taxonomy of Direct 3D Displays:

## Dynamic Holograms (Hologideo)



Tay et al.  
[Nature, 2008]



MIT Media Lab Spatial Imaging Group  
[Hologideo, 1989 – present]

Unencumbered  
Automultiscopic

**Parallax-based**  
(2D display with light-directing elements)

**Volumetric**  
(directly illuminate points within a volume)

**Holographic**  
(reconstructs wavefront using 2D element)

**Parallax Barriers**  
(uniform array of 1D slits or 2D pinhole arrays)

**Integral Imaging**  
(lenticular sheets or fly's eye lenslet arrays)

**Multi-planar**  
(time-sequential projection onto swept surfaces)

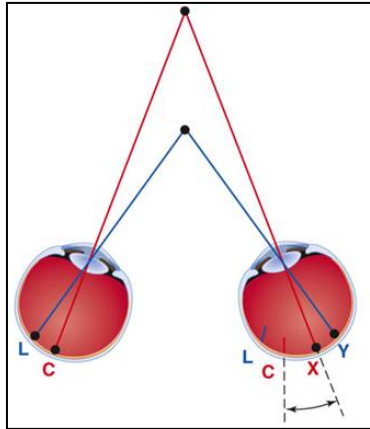
**Transparent Substrates**  
(intersecting laser beams, fog layers, etc.)

**Static**  
(holographic films)

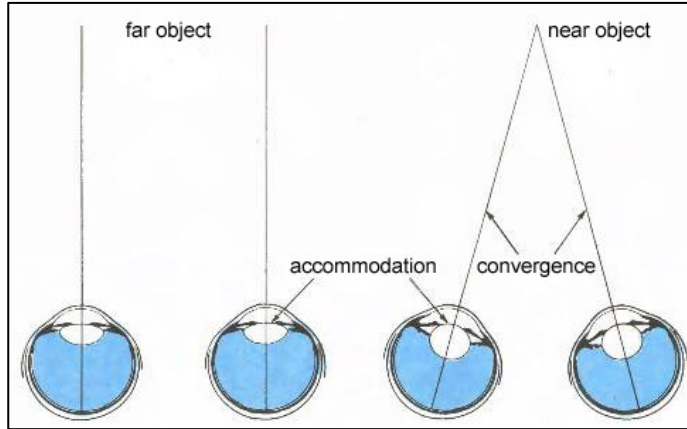
**Dynamic**  
(hologideo)

# What is meant by “glasses-free 3D”?

SIGGRAPH2012



binocular disparity



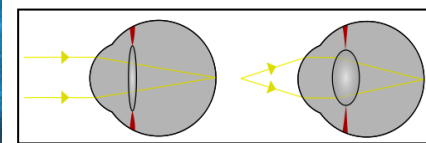
convergence



motion parallax



accommodation/blur

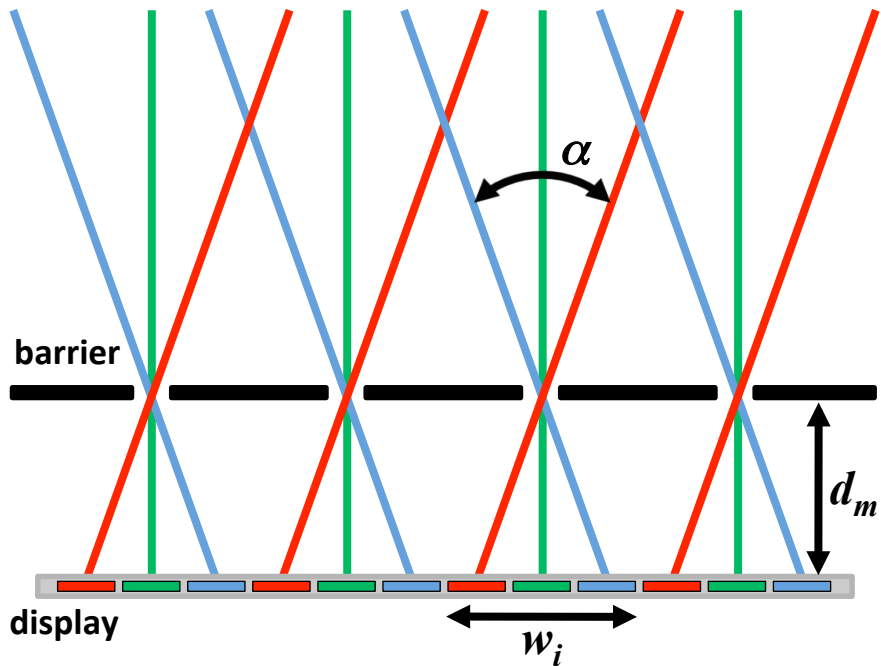


← current glasses-based (stereoscopic) displays →

← near-term glasses-free (automultiscopic) displays →

← longer-term volumetric and holographic displays →

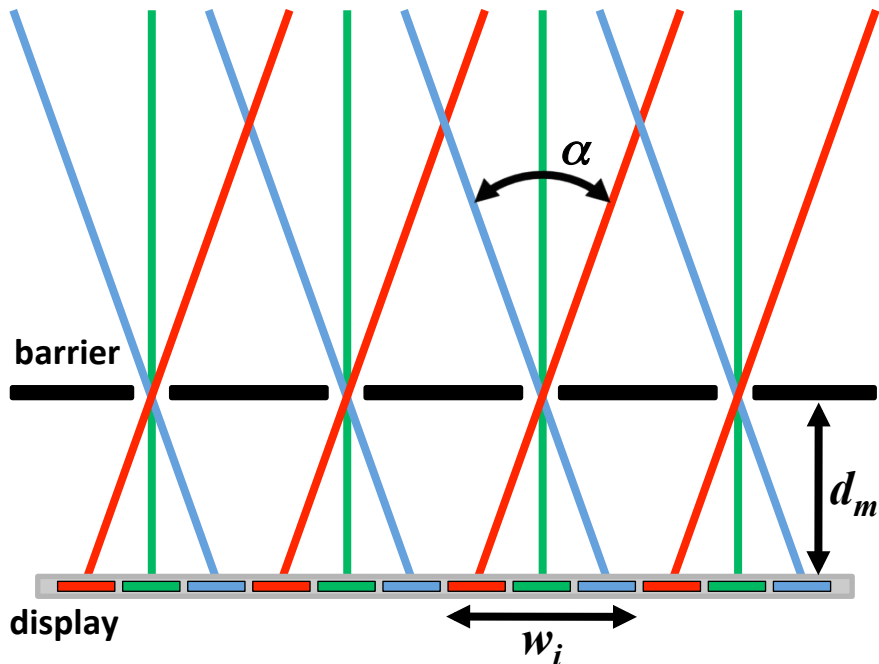
# Parallax Barriers



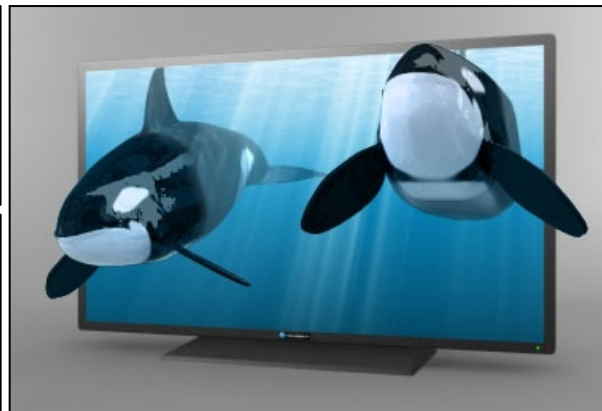
- Introduced by Frederic E. Ives in 1903
- Requires two light-attenuating layers (i.e., masks)
- Allows multi-view display, but results in dim images due to attenuation

# Parallax Barriers

SIGGRAPH2012



Range Rover 2010  
Dual-View Navigation

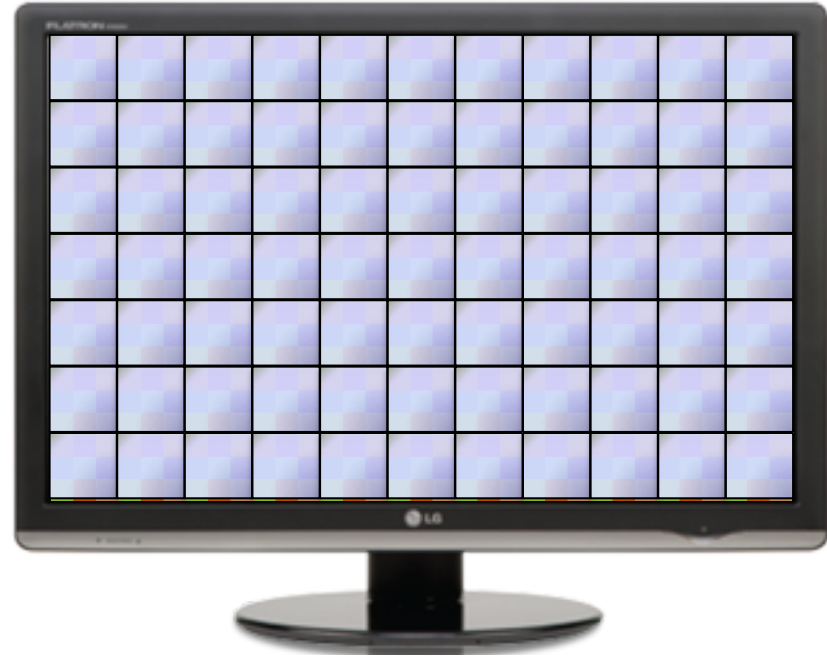
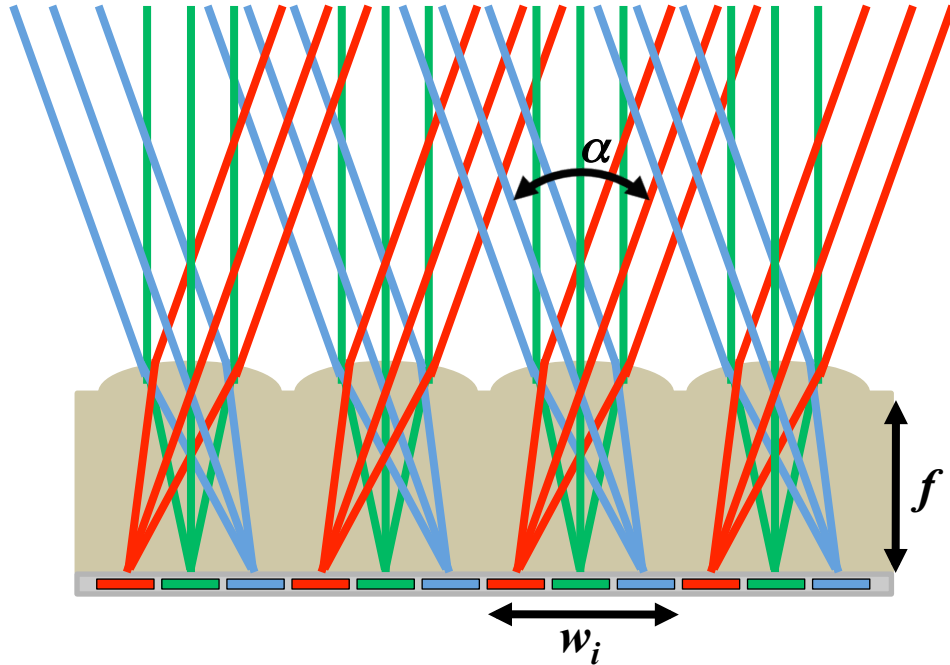


NewSight MV-42AD3 42"  
(1920x1080, 1x8 views)

- Introduced by Frederic E. Ives in 1903
- Requires two light-attenuating layers (i.e., masks)
- Allows multi-view display, but results in dim images due to attenuation

# Integral Imaging

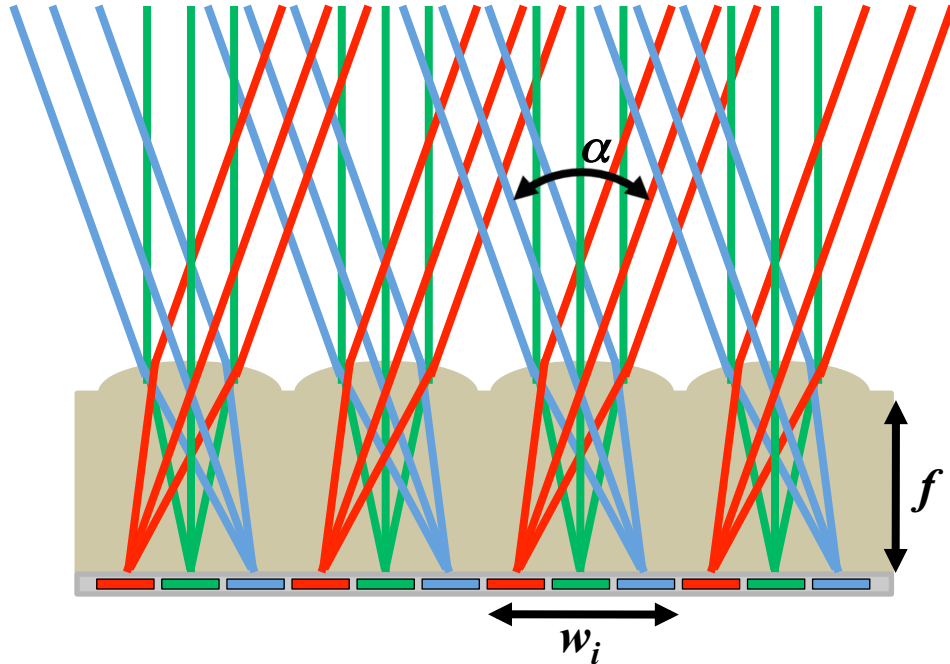
SIGGRAPH2012



- Introduced by Gabriel Lippmann in 1908
- Requires a refractive lenslet array to be affixed to a conventional display
- Allows multi-view display, but imposes fixed trade-off between spatial and angular resolution

# Integral Imaging

SIGGRAPH2012

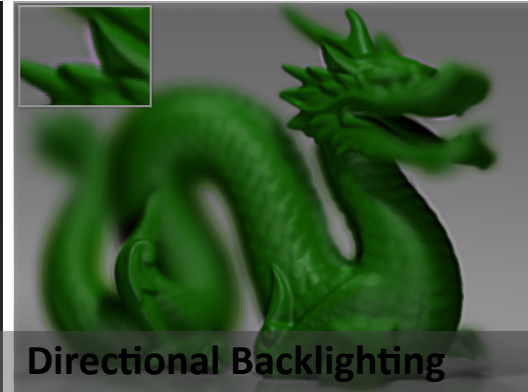
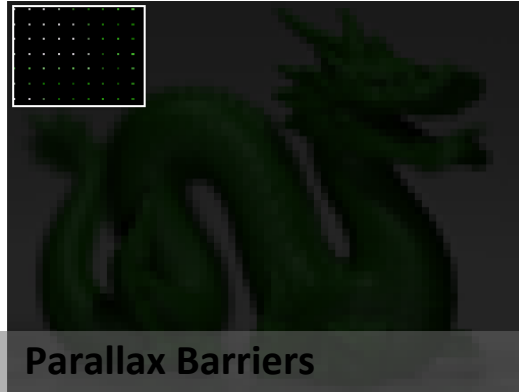
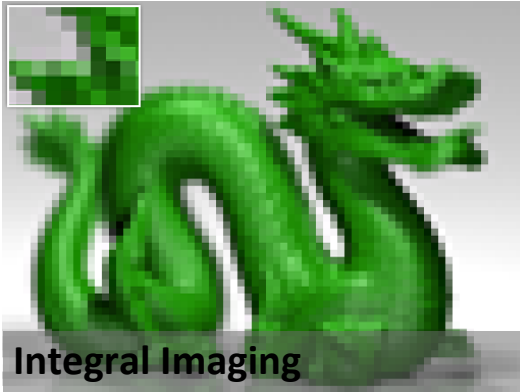


**Alioscopy 3DHD 42''**  
(1920x1200, 1x8 views)

- Introduced by Gabriel Lippmann in 1908
- Requires a refractive lenslet array to be affixed to a conventional display
- Allows multi-view display, but imposes fixed trade-off between spatial and angular resolution

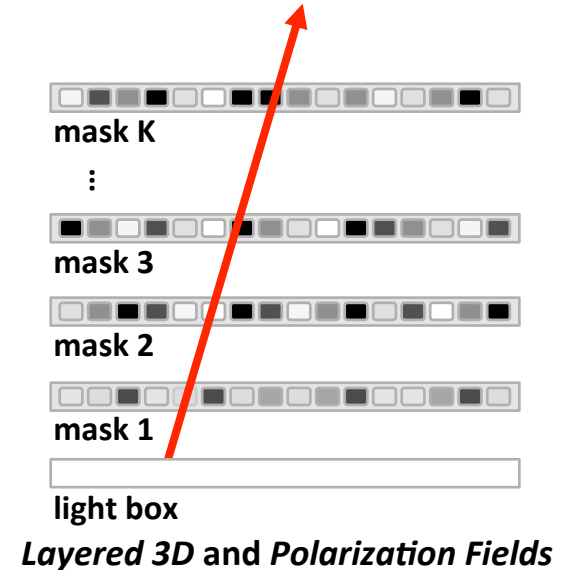
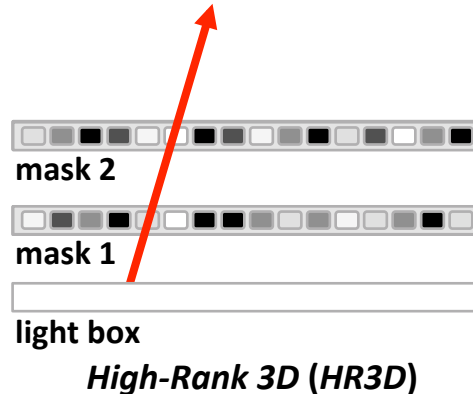
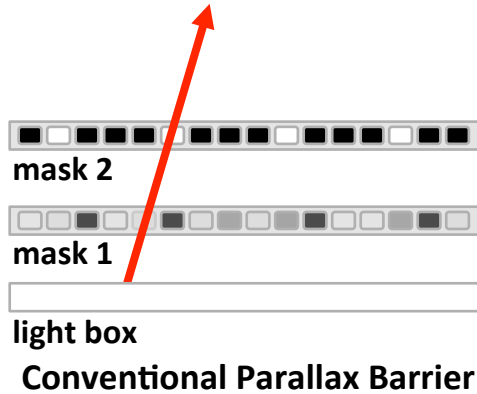
# Design Trade-offs

SIGGRAPH2012



	Integral Imaging	Parallax Barriers	Directional Backlighting
Spatial Resolution	low	low	high
Brightness	high	low	moderate
Cost	low	low – moderate	moderate – high
Full-resolution 2D	no	yes (dual-layer LCD)	yes
Motion Parallax	yes	yes	no

# Generalizing Parallax Barriers

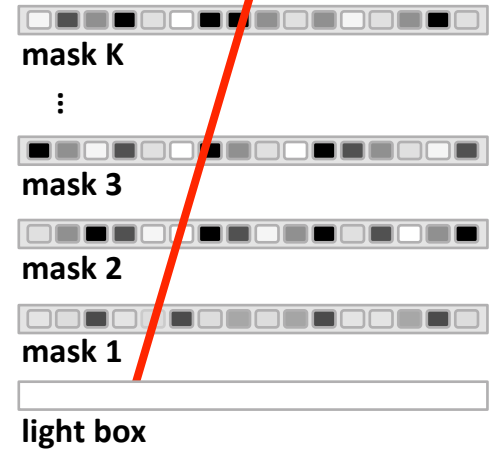
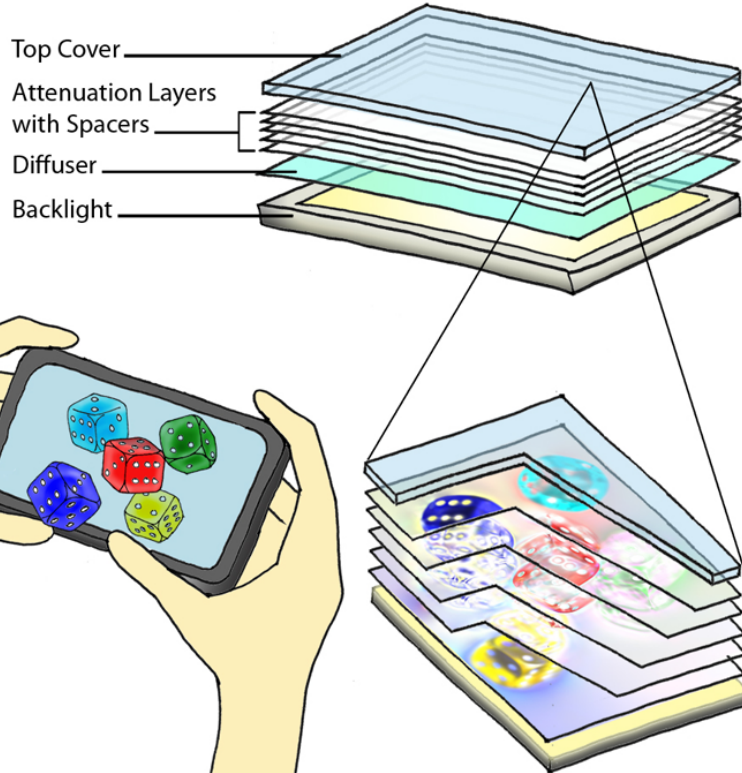


- Parallax barriers use *heuristic* design: front mask with slits/pinholes, rear mask with interlaced views
- *High-Rank 3D (HR3D)* considers **dual-layer design with arbitrary opacity and temporal multiplexing**
- *Layered 3D and Polarization Fields* considers **multi-layer design without temporal multiplexing**



- *Automultiscopic Displays*
  - ***Multi-Layer Displays***
    - **Layered 3D**
      - Polarization Fields
  - Dual-Layer Displays
    - High-Rank 3D (HR3D)

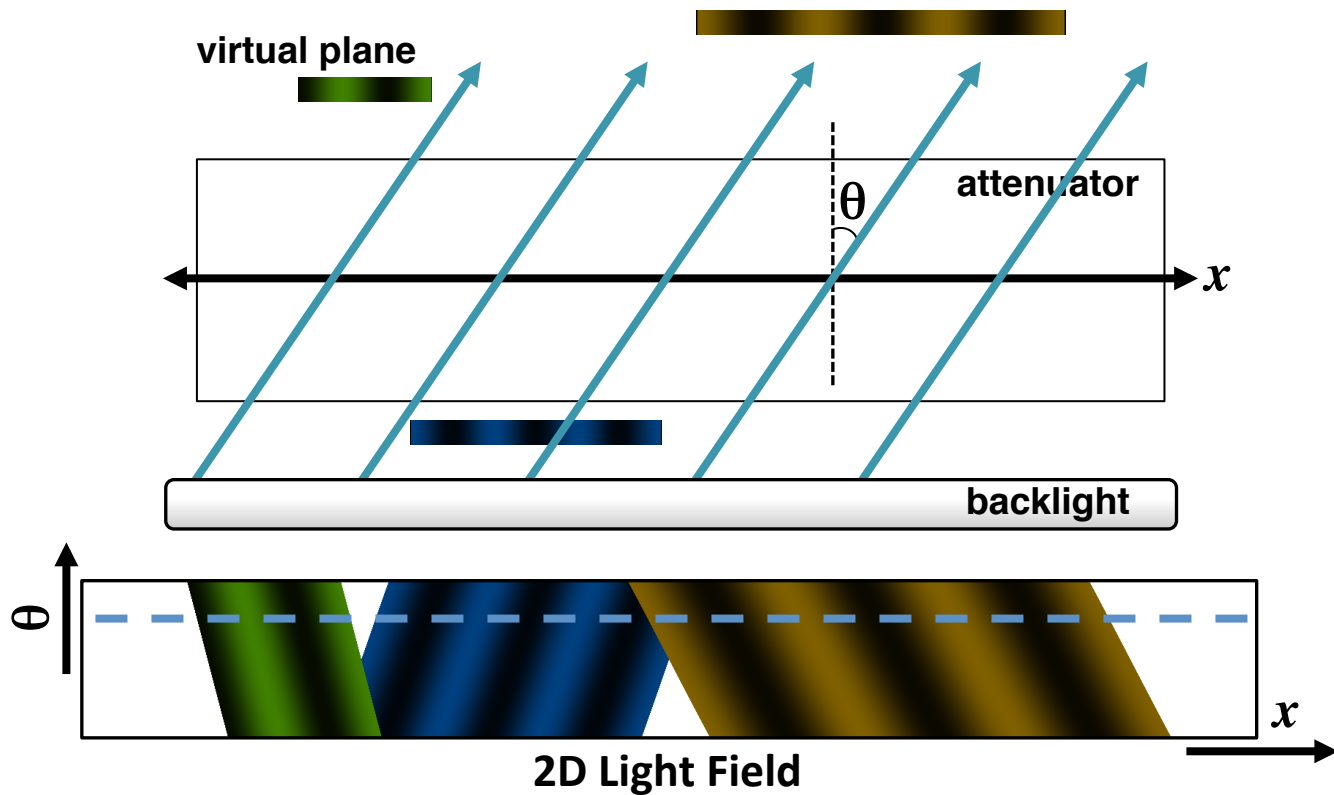
# Layered 3D: Multi-Layer Displays



*Layered 3D*

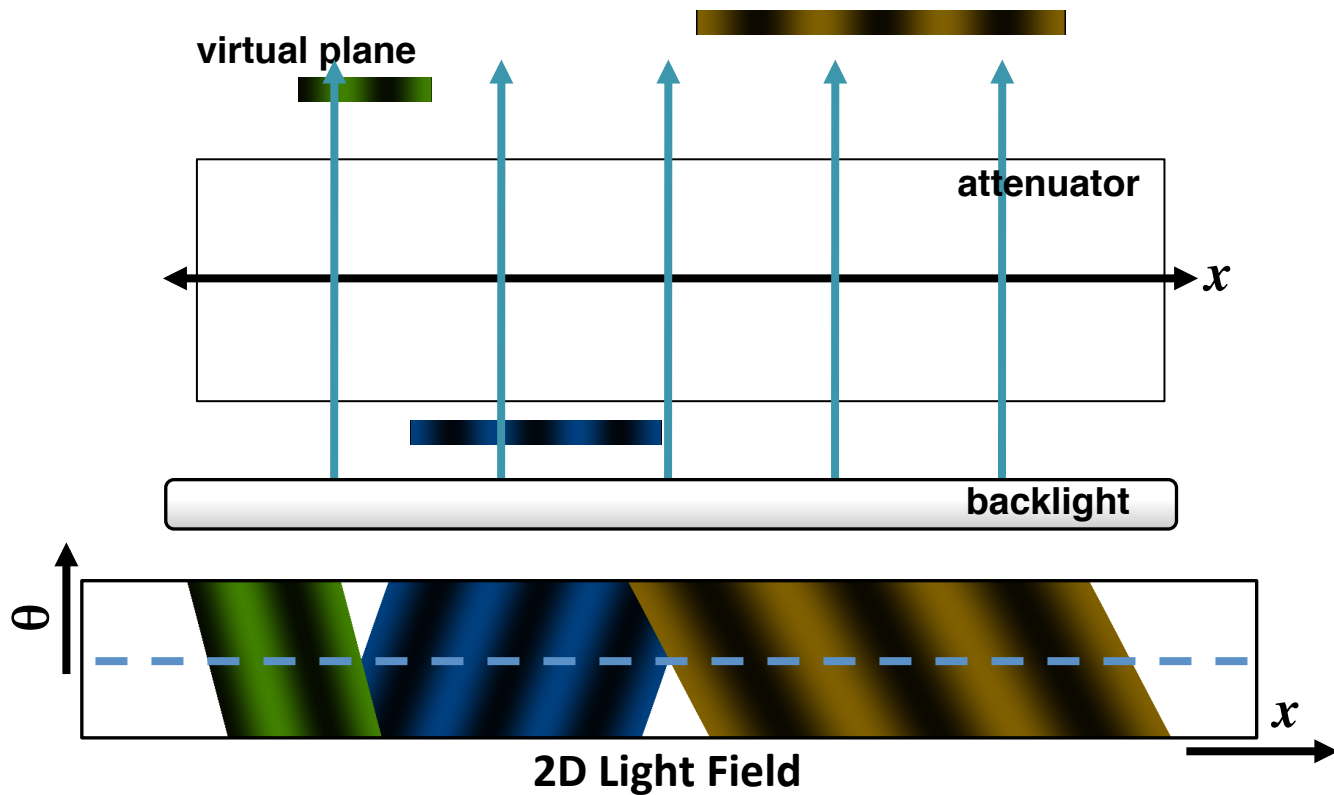
# Tomographic Light Field Synthesis

SIGGRAPH2012



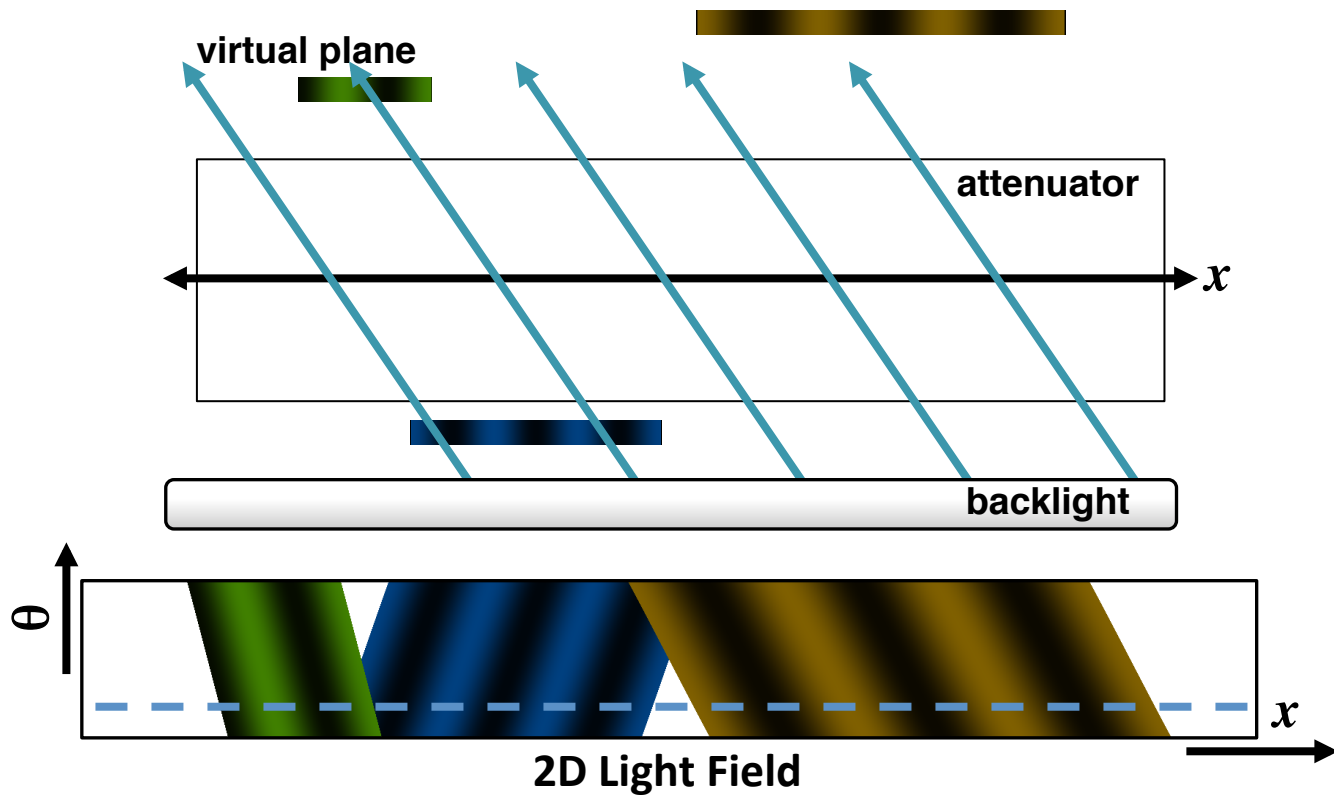
# Tomographic Light Field Synthesis

SIGGRAPH2012



# Tomographic Light Field Synthesis

SIGGRAPH2012



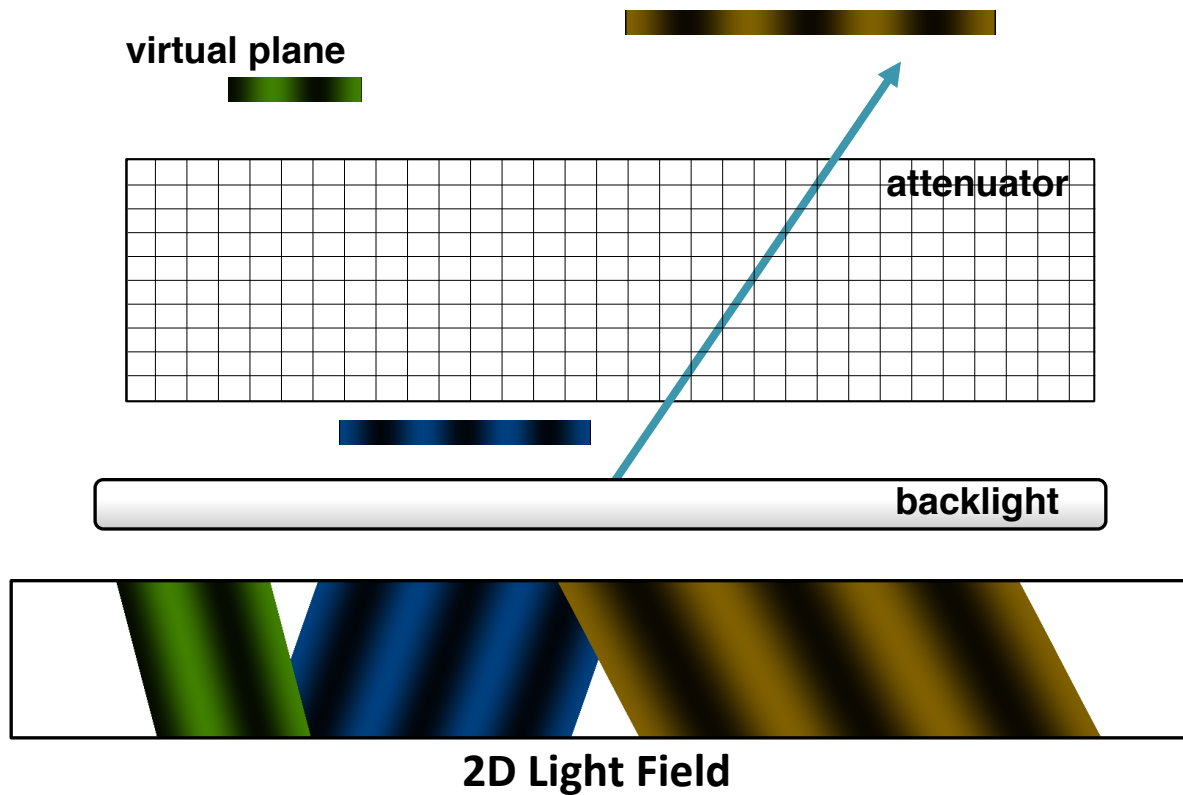


Image formation model:

$$L(x, \theta) = I_0 e^{-\int_c \mu(r) dr}$$

$$\bar{L}(x, \theta) = \ln \left( \frac{L(x, \theta)}{I_0} \right) = -\int_c \mu(r) dr$$

$$\bar{\mathbf{I}} = -\mathbf{P}\mathbf{a}$$

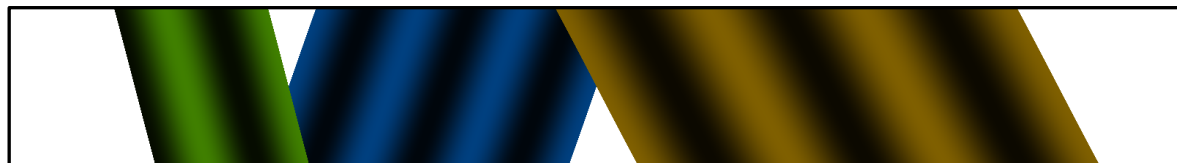
Tomographic synthesis:

$$\arg \min_{\mathbf{a}} \|\bar{\mathbf{I}} + \mathbf{P}\mathbf{a}\|^2, \text{ for } \mathbf{a} \geq 0$$

virtual plane



backlight



2D Light Field

Image formation model:

$$L(x, \theta) = I_0 e^{-\int_c \mu(r) dr}$$

$$\bar{L}(x, \theta) = \ln \left( \frac{L(x, \theta)}{I_0} \right) = -\int_c \mu(r) dr$$

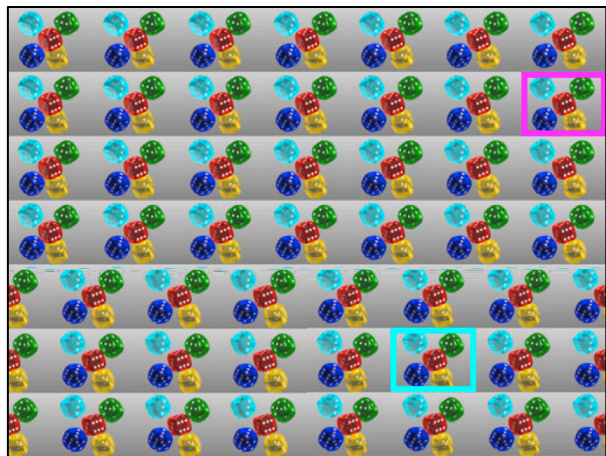
$$\bar{\mathbf{I}} = -\mathbf{P}\mathbf{a}$$

Tomographic synthesis:

$$\arg \min_{\mathbf{a}} \|\bar{\mathbf{I}} + \mathbf{P}\mathbf{a}\|^2, \text{ for } \mathbf{a} \geq 0$$

# Multi-Layer Light Field Decomposition

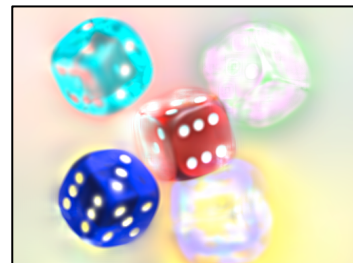
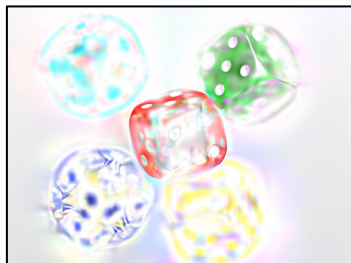
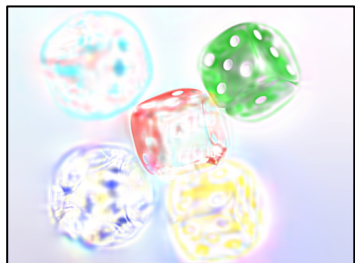
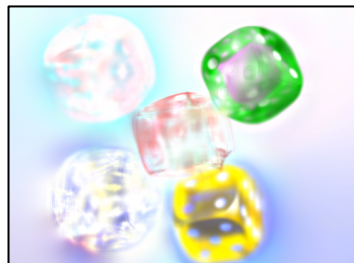
SIGGRAPH2012



Target 4D Light Field



Reconstructed Views



Multi-Layer Decomposition

# Prototype *Layered* 3D Display

SIGGRAPH2012



Transparency stack with acrylic spacers



Prototype in front of LCD (backlight source)

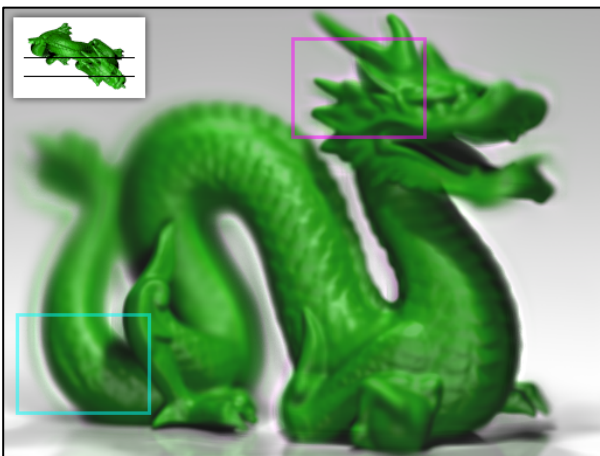
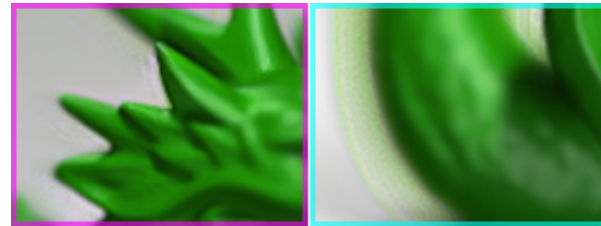
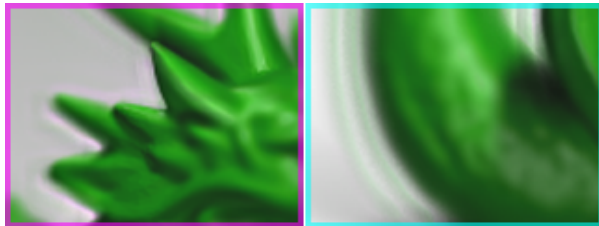
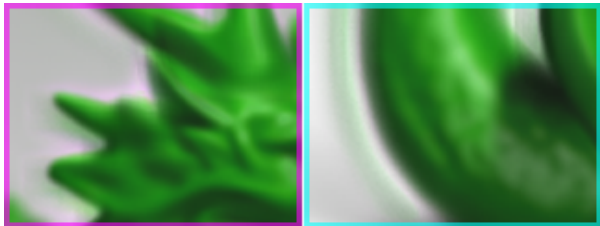
NEC

MultiSync LCD 1500

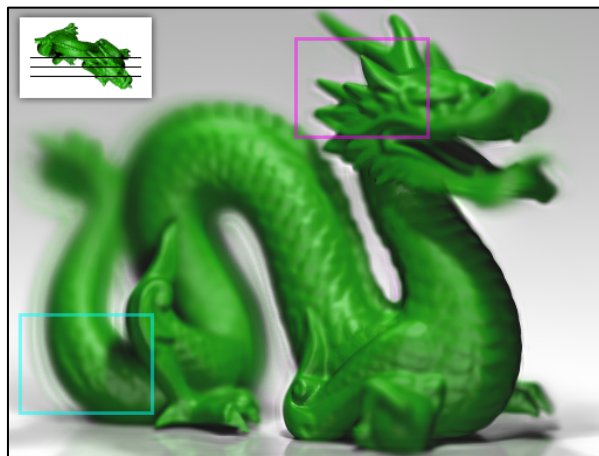


# Depth of Field

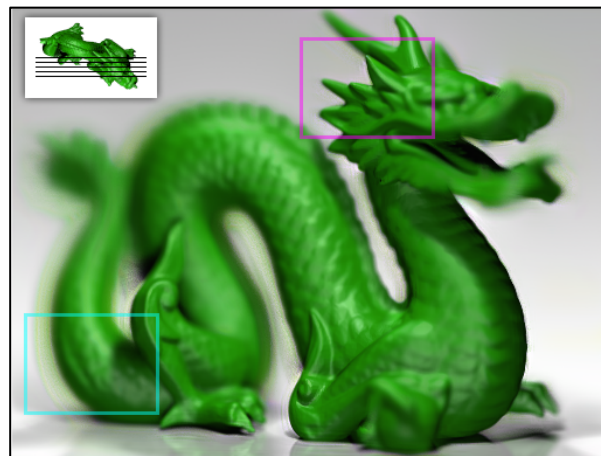
SIGGRAPH2012



Two Layers



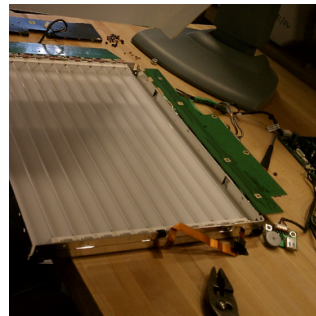
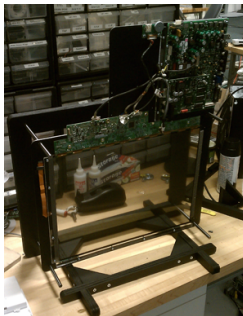
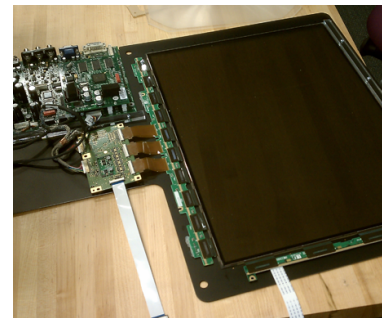
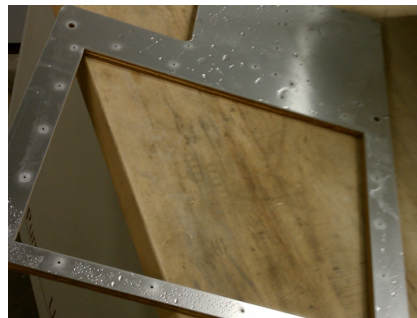
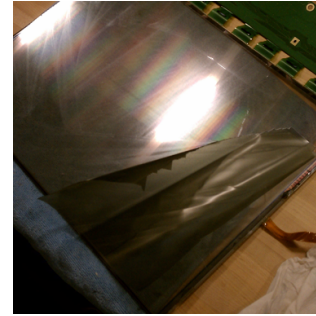
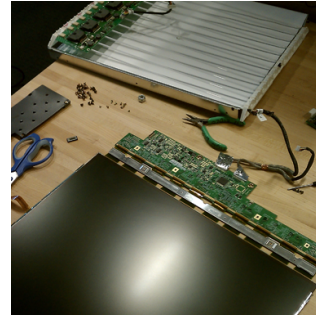
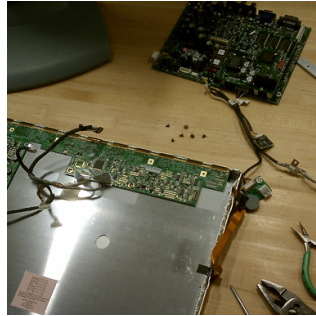
Three Layers



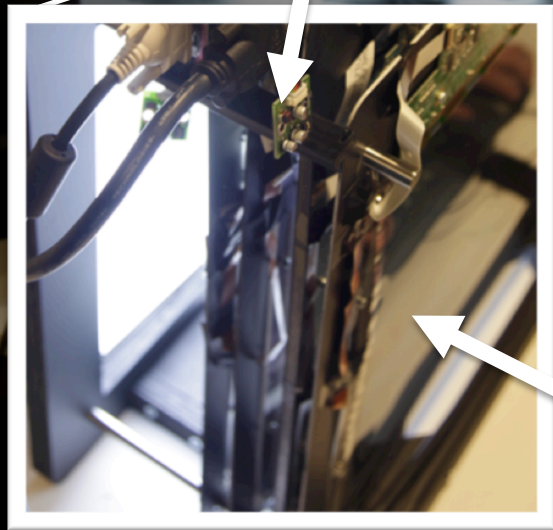
Five Layers



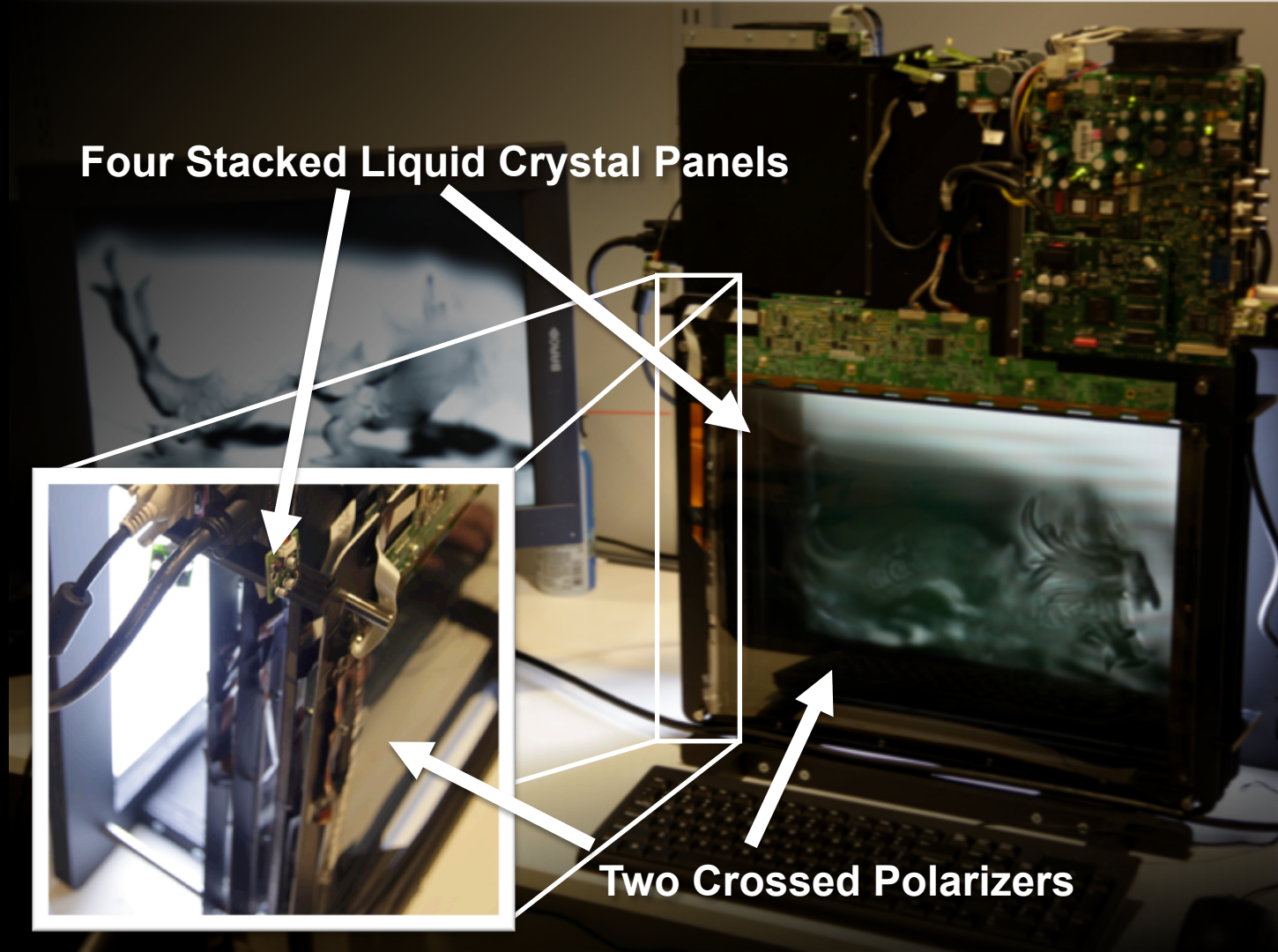
- *Automultiscopic Displays*
  - **Multi-Layer Displays**
    - Layered 3D
    - **Polarization Fields**
  - Dual-Layer Displays
    - High-Rank 3D (HR3D)



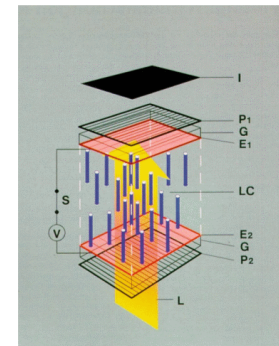
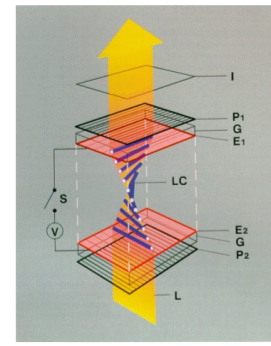
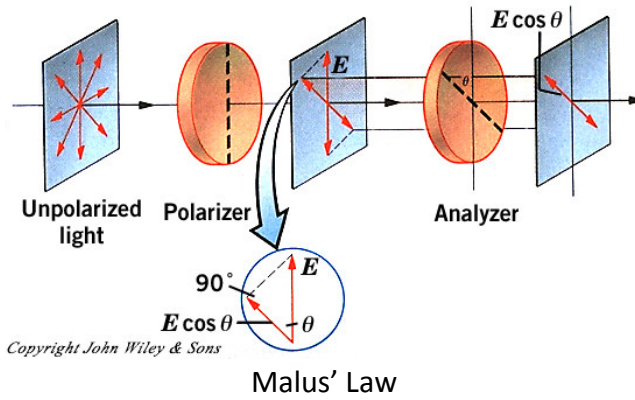
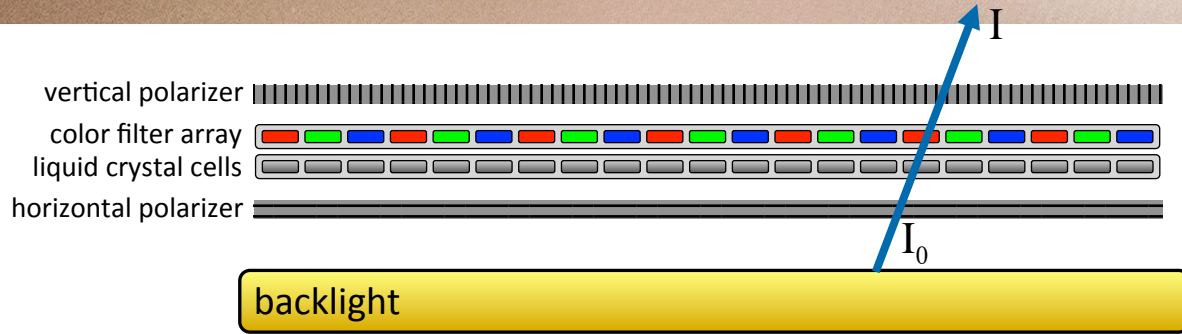
**Four Stacked Liquid Crystal Panels**



**Two Crossed Polarizers**



# Overview of LCDs

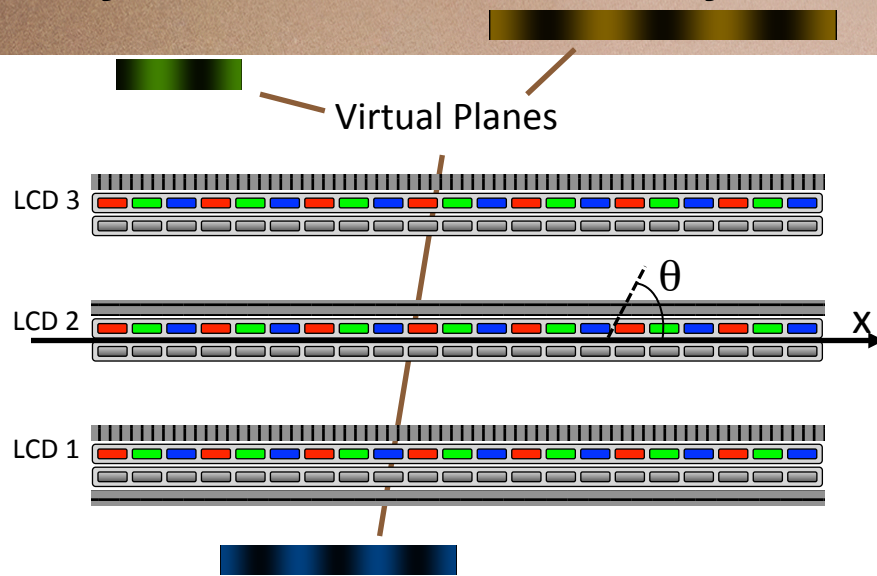


Intensity Modulation with Liquid Crystal Cells

$$I = I_0 \sin^2(\theta)$$

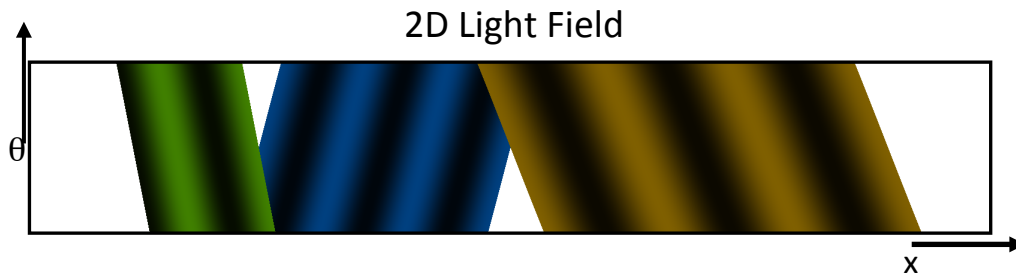
# Extending *Layered 3D* to Multi-Layer LCDs

SIGGRAPH2012



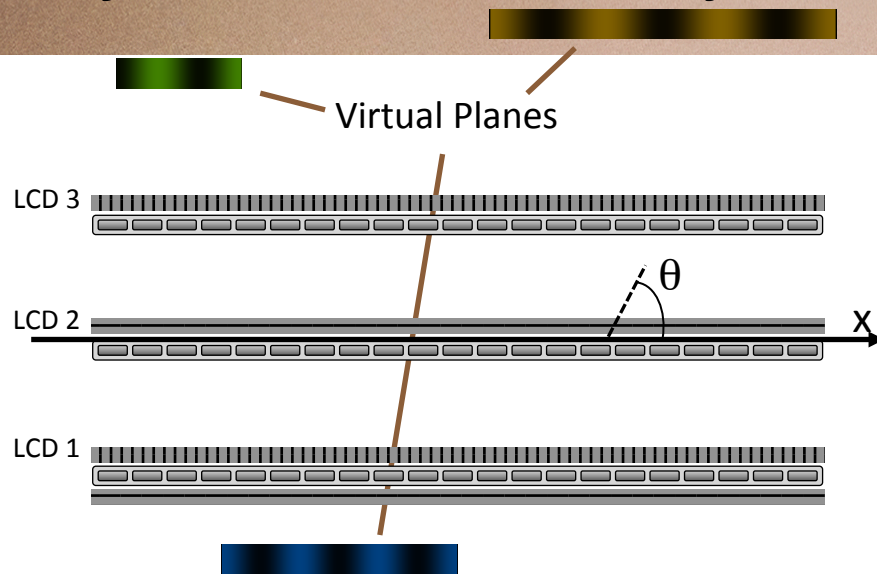
## Design Optimization

- Eliminate redundant polarizers
- Sequentially-crossed design



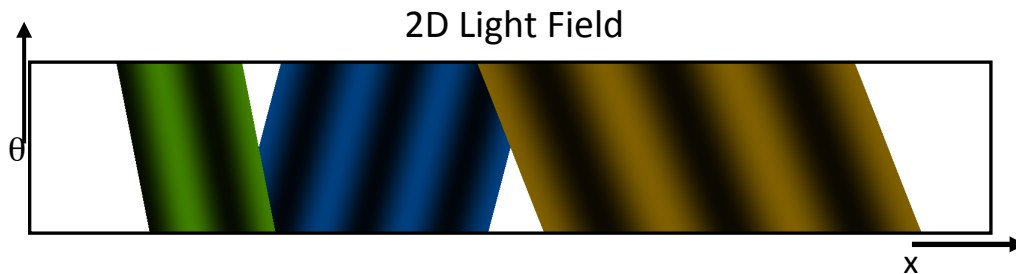
# Extending *Layered 3D* to Multi-Layer LCDs

SIGGRAPH2012



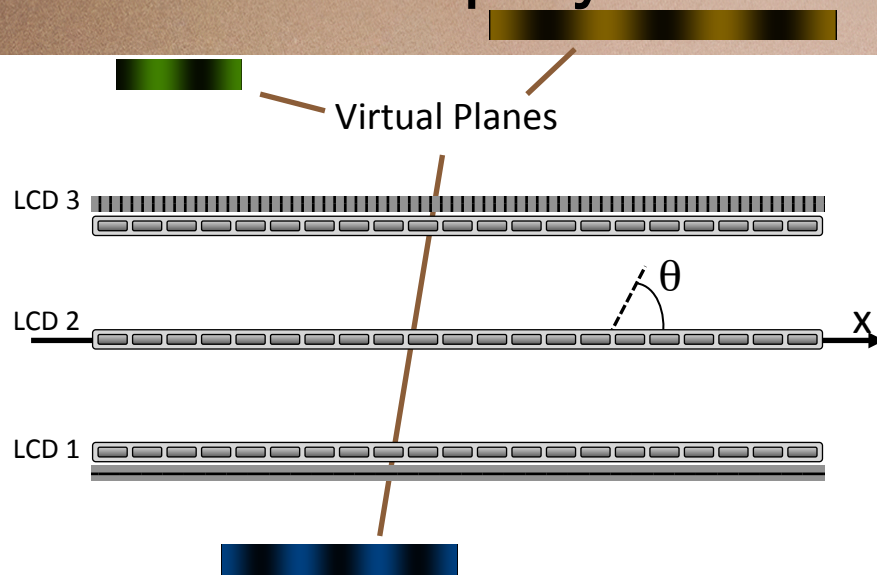
## Design Optimization

- Eliminate redundant polarizers  
→ Use sequentially-crossed
- Exploit field-sequential color  
→  $0.3^3 = 2.7\%$  brightness



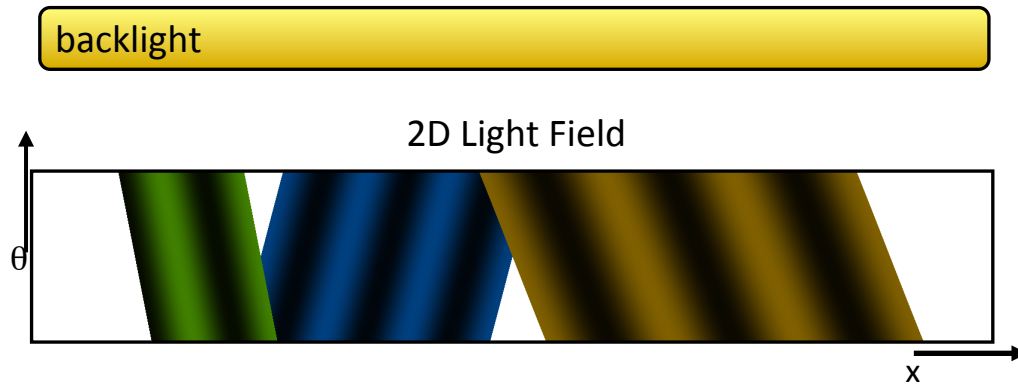
# Polarization Field Displays

SIGGRAPH2012



## Design Optimization

- Eliminate redundant polarizers  
→ Use sequentially-crossed
- Exploit field-sequential color  
→  $0.3^3 = 2.7\%$  brightness
- Further optimize polarizers  
→ Minimum is a crossed pair



# Polarization Field Displays

SIGGRAPH2012

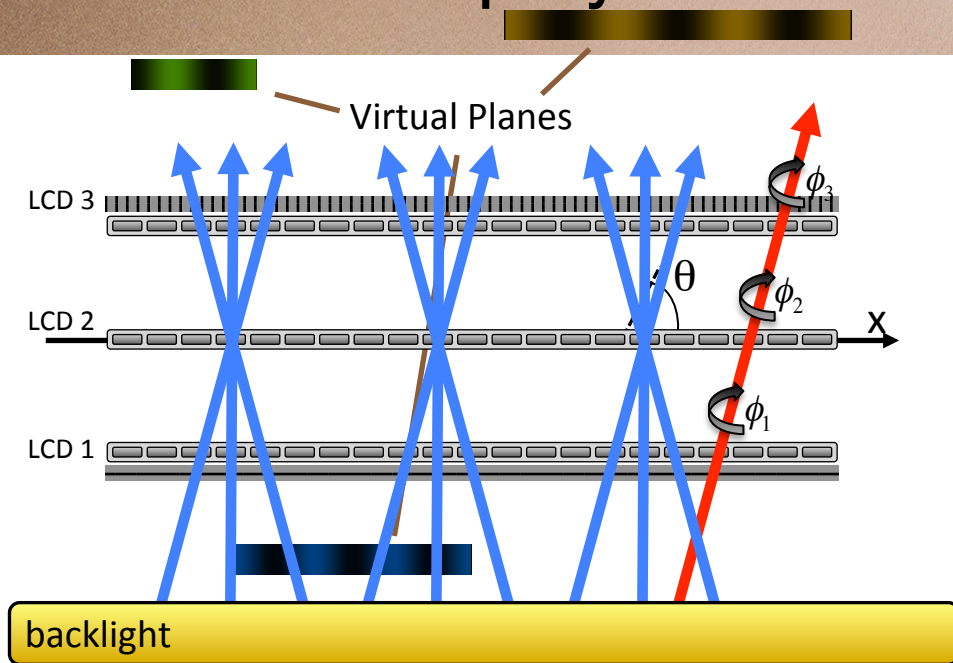


Image Formation

$$\Theta(x, \theta) = \sum_{k=1}^K \phi_k(x, \theta)$$

$$L(x, \theta) = \sin^2(\Theta(x, \theta))$$

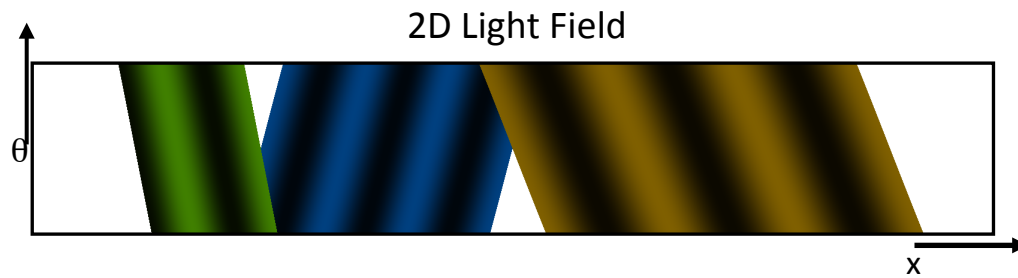
Tomographic Synthesis

$$\Theta(x, \theta) = \pm \sin^{-1}(\sqrt{L(x, \theta)}) \bmod \pi$$

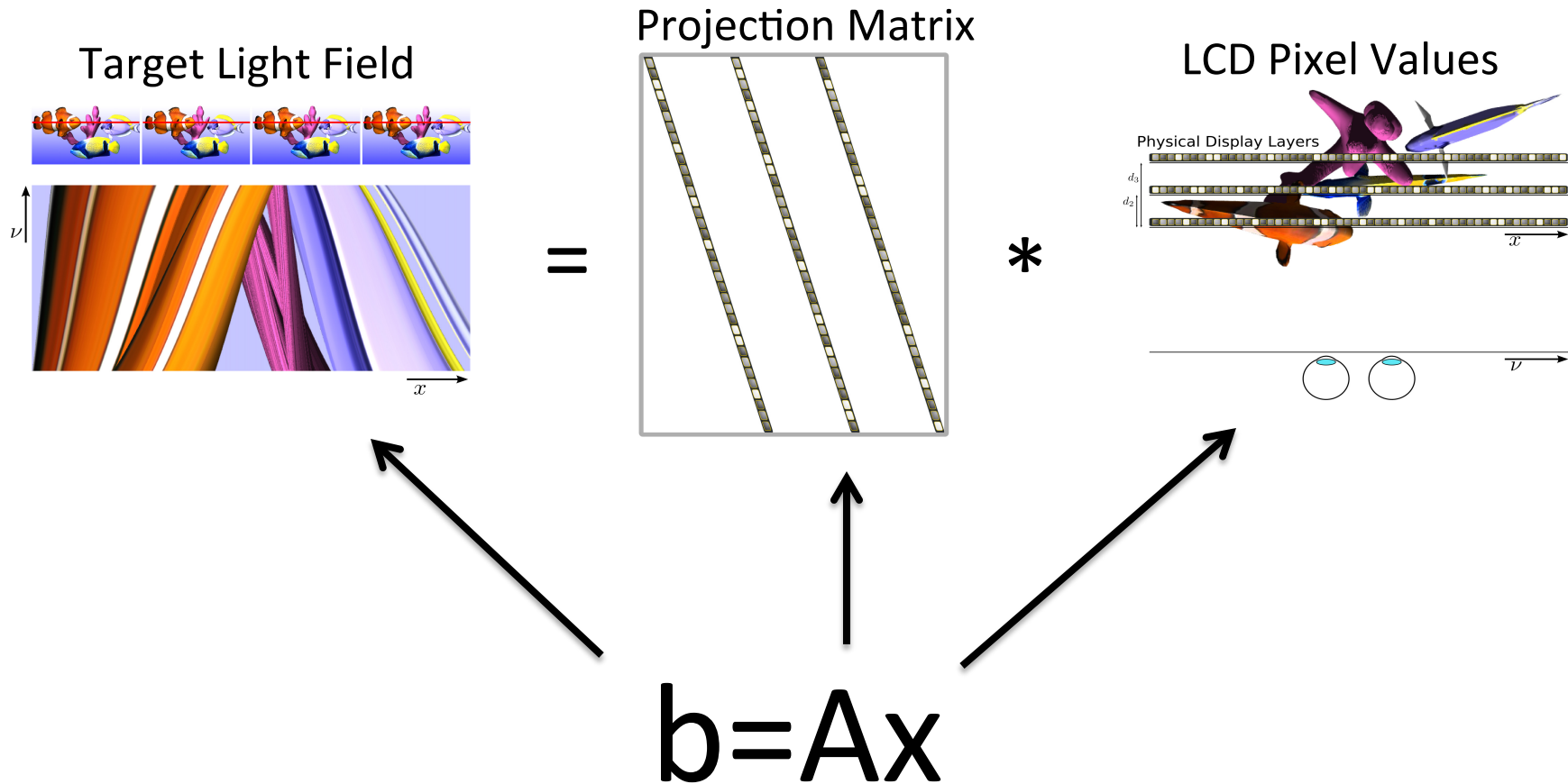
$$\Theta = P\phi$$

$$\operatorname{argmin} \|\Theta - P\phi\|_2^2$$

$$\phi_{\min} \leq \phi \leq \phi_{\max}$$



# Tomographic Image Synthesis





$$b = Ax$$

```

MATLAB
Editor - /Volumes/FreeAgent GoFLEX Drive/MIT/project/Layered3D/
File Edit Text Go Cell Tools Debug Desktop Window H
x [icons]
+ [1.0] + [1.1] x [icons]
1 % run a number of SART updates
2 function x = SART(Afun, b, lb, ub, x0, maxIters)
3
4 % compute weights
5 W = Afun( ones(size(x0)) , 1);
6 W(W~=0) = 1 ./ W(W~=0);
7
8 V = Afun( ones(size(W)) , -1);
9 V(V~=0) = 1 ./ V(V~=0);
10
11 % initialize result
12 x = x0;
13
14 % run SART iterations
15 for k=1:maxIters
16 % update x
17 x = x + V .* Afun( W .* (b - Afun(x,1)) , -1 );
18 % project back into feasible range
19 x(x<lb) = lb(x<lb);
20 x(x>ub) = ub(x>ub);
21 end
22
23 end
    
```

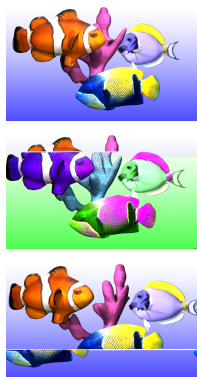
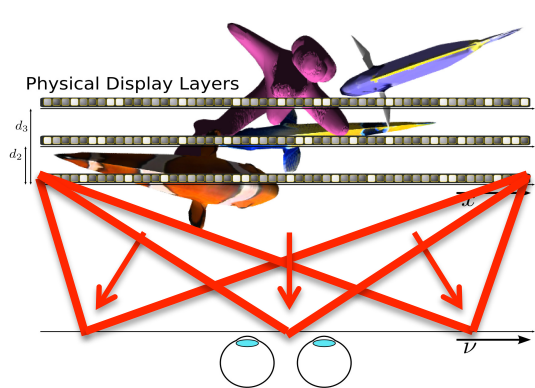
pre-compute some weights

initial guess

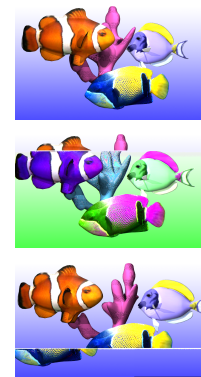
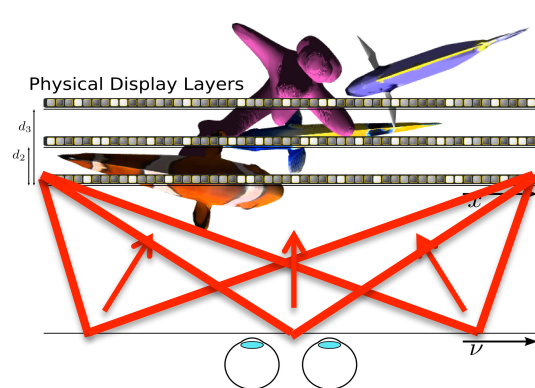
$A^T v$   $Ax$

update  
clamp

$$Ax$$



$$A^T v$$



Forward Projection (Multiview Rendering)

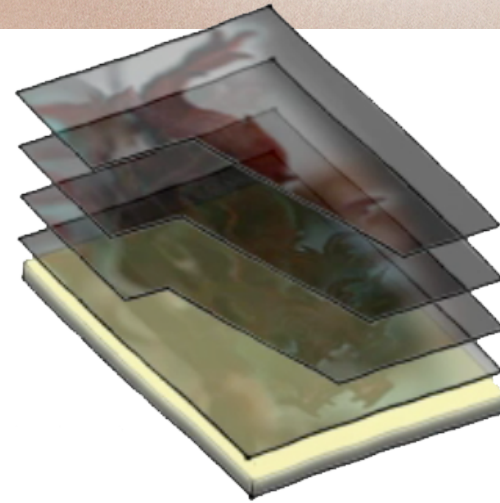
Back Projection (Projective Texture Mapping)

# Polarization Field Displays

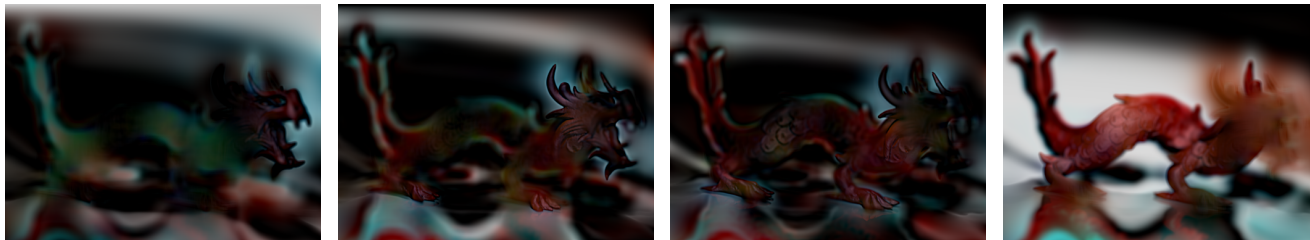
SIGGRAPH2012



**Input 4D Light Field**



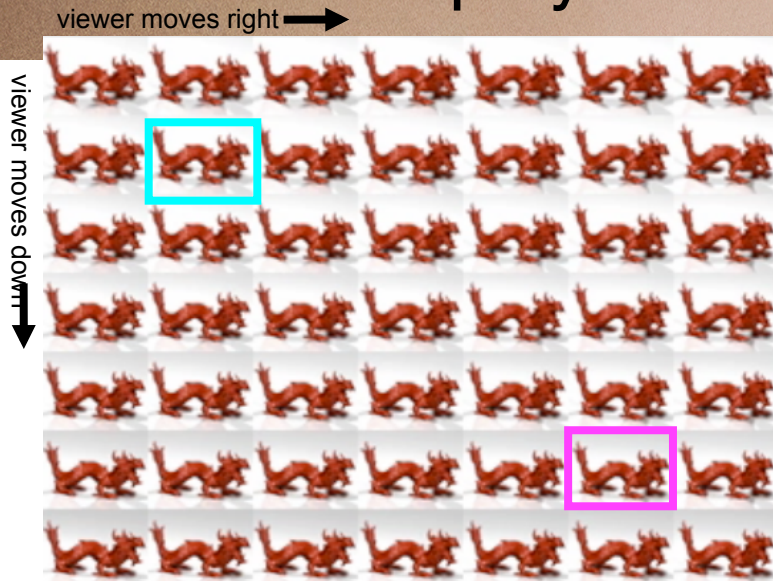
**Stacked Polarization Rotating Layers**



**Optimized Rotation Angles for Each Layer**

# Polarization Field Displays

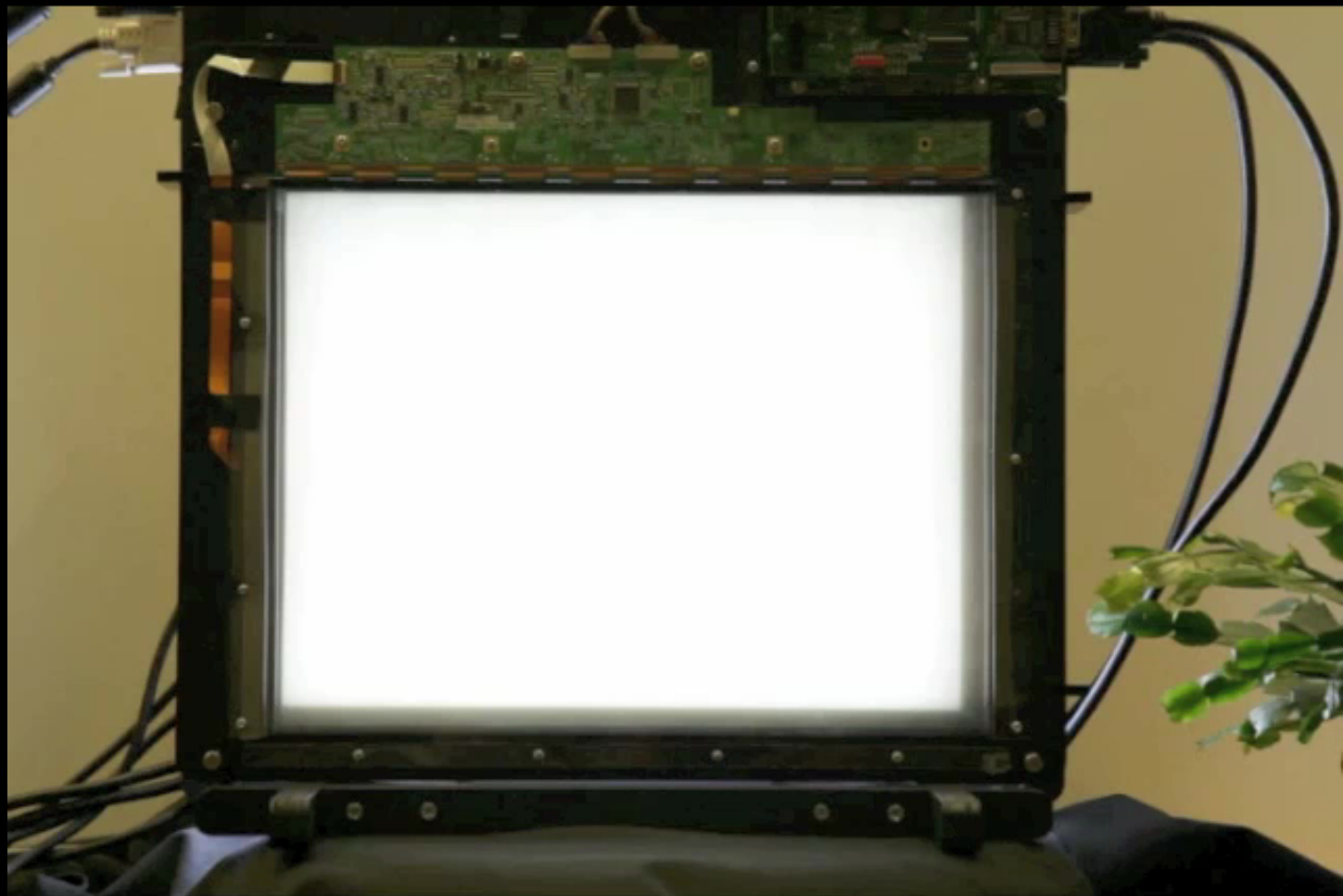
SIGGRAPH2012



Input 4D Light Field



Reconstruction Results

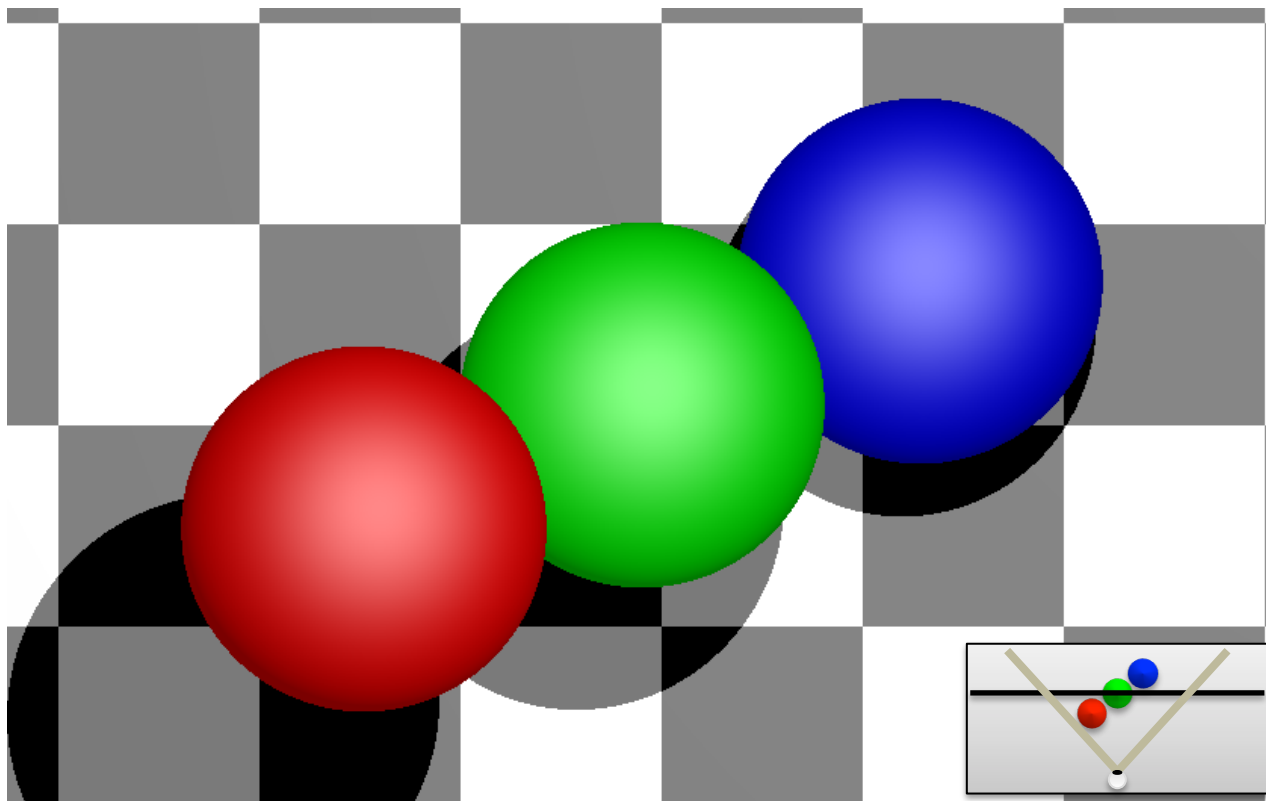




- *Automultiscopic Displays*
  - Multi-Layer Displays
    - Layered 3D
    - Polarization Fields
  - ***Dual-Layer Displays***
    - **High-Rank 3D (HR3D)**

# Input 4D Light Field

SIGGRAPH2012



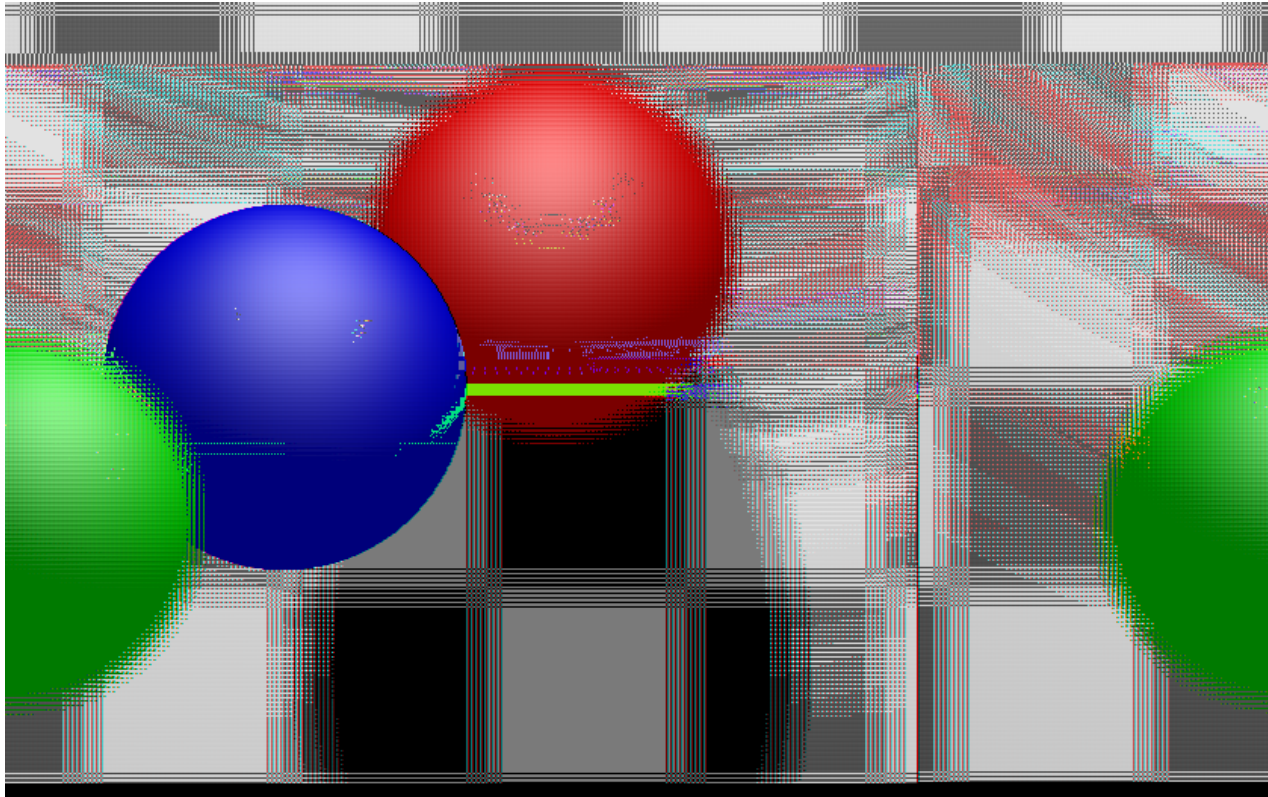
# Parallax Barrier: Front Layer

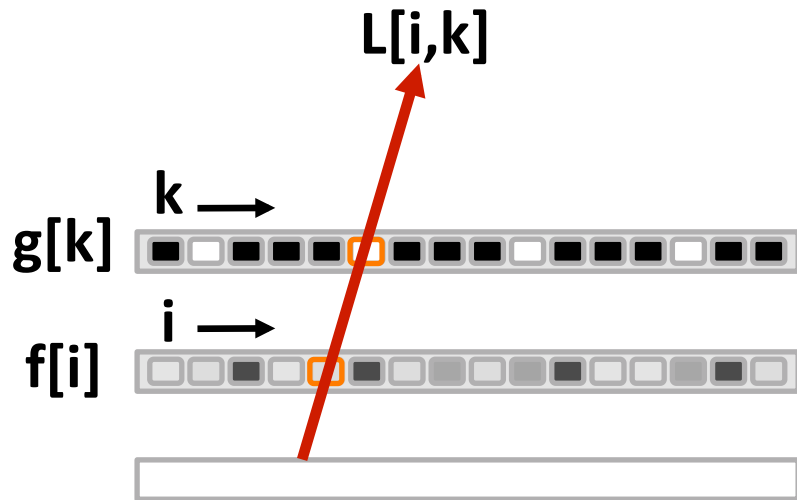
SIGGRAPH2012



# Parallax Barrier: Rear Layer

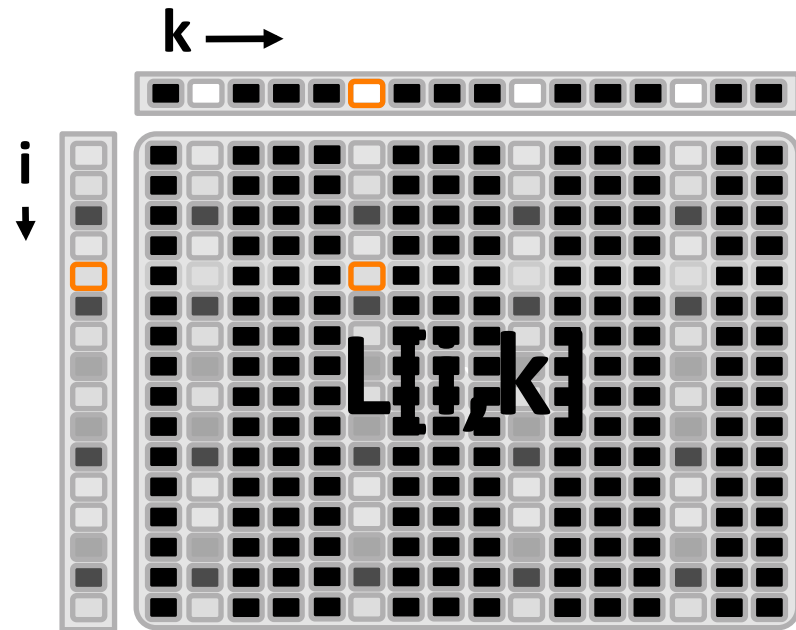
SIGGRAPH2012



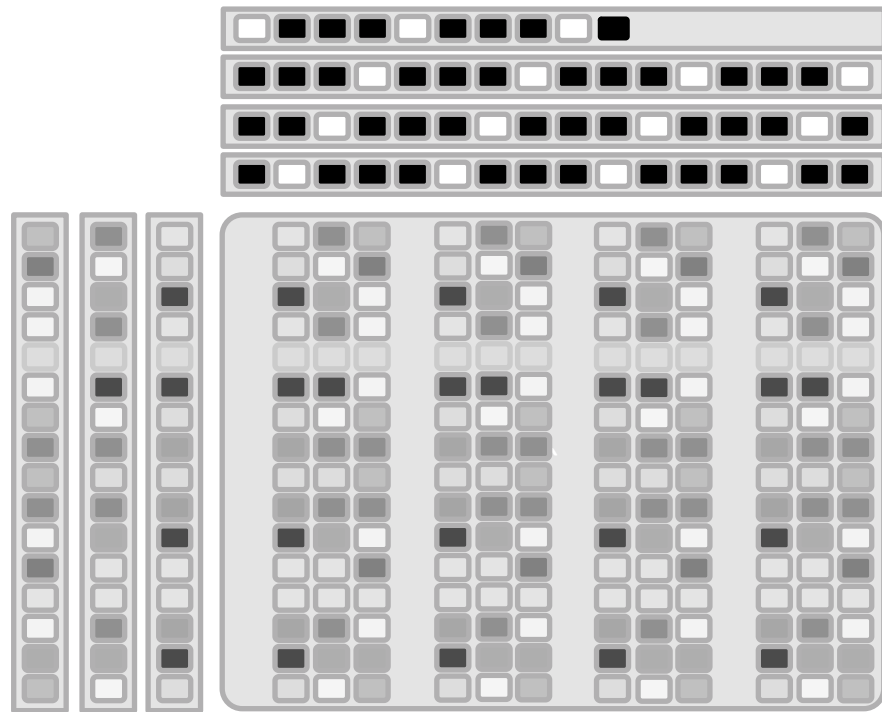


light box

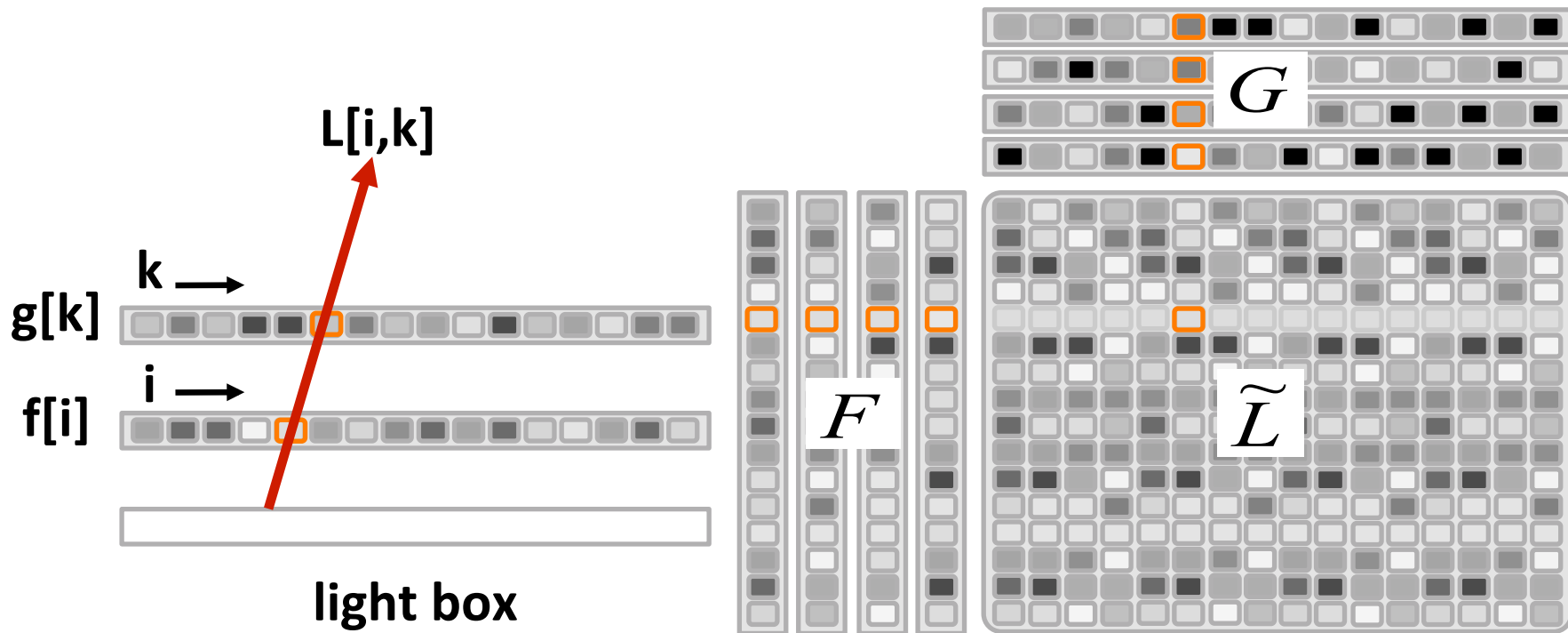
$$L[i,k] = f[i] \cdot g[k]$$



$$L[i,k] = f[i] \otimes g[k]$$

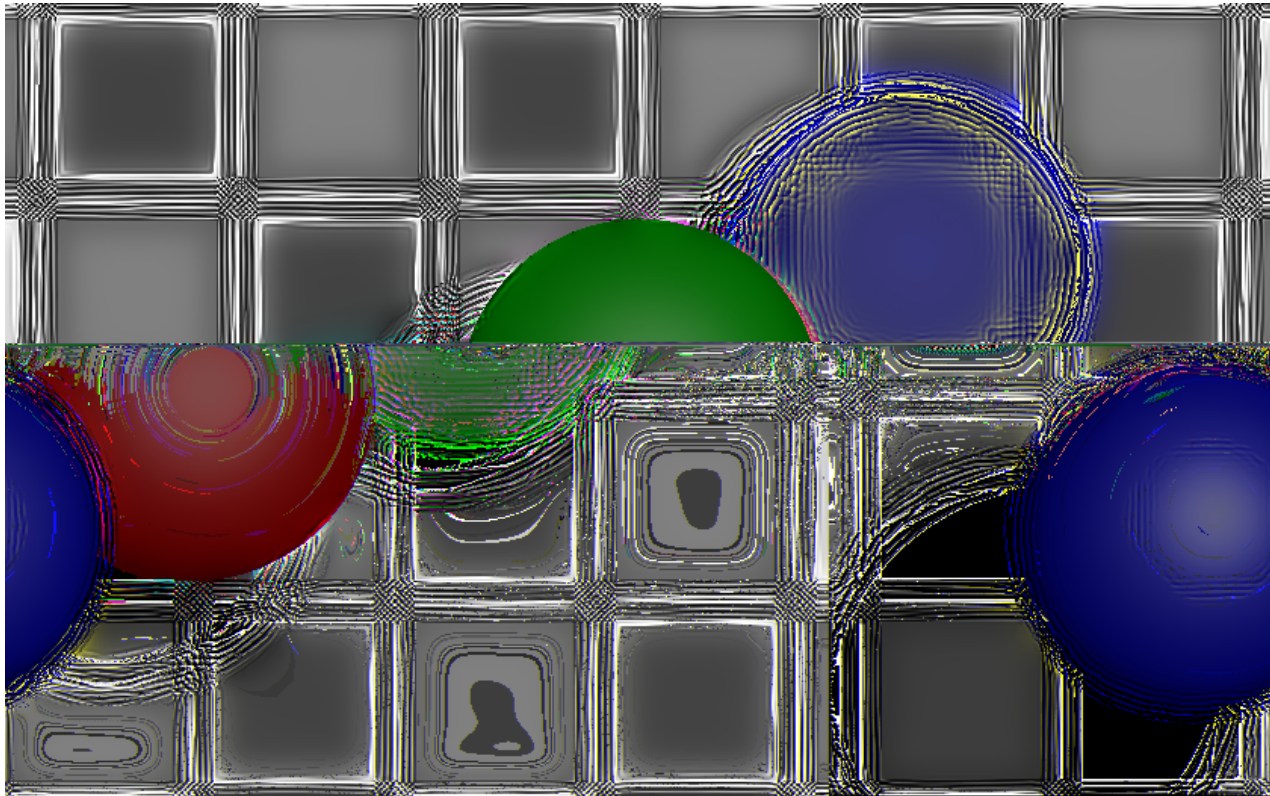


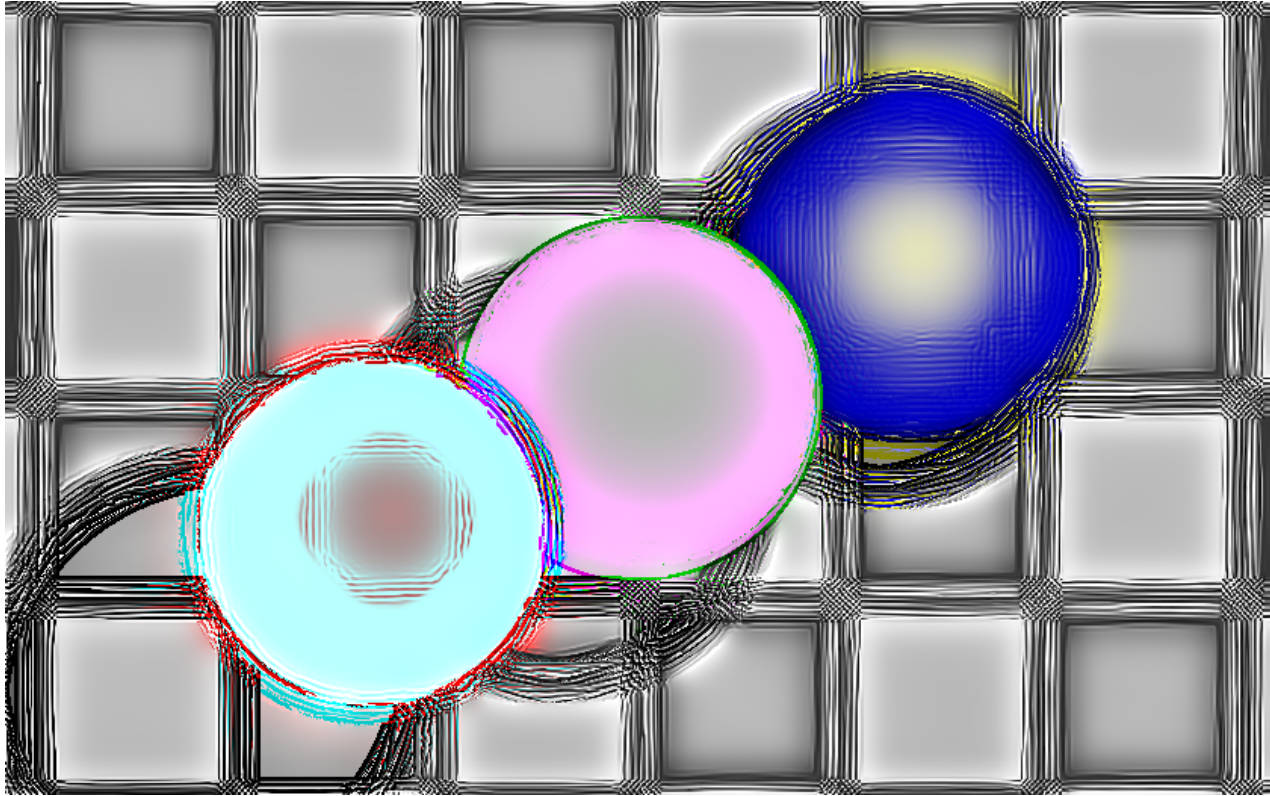
$$L[i,k] = \sum_{t=1}^T f_t[i] \otimes g_t[k]$$



$$\tilde{L} = FG$$

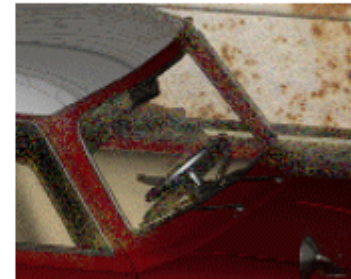
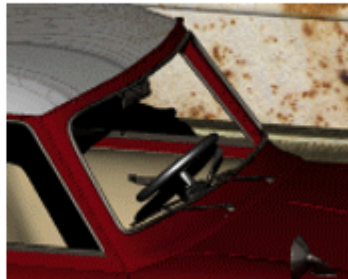
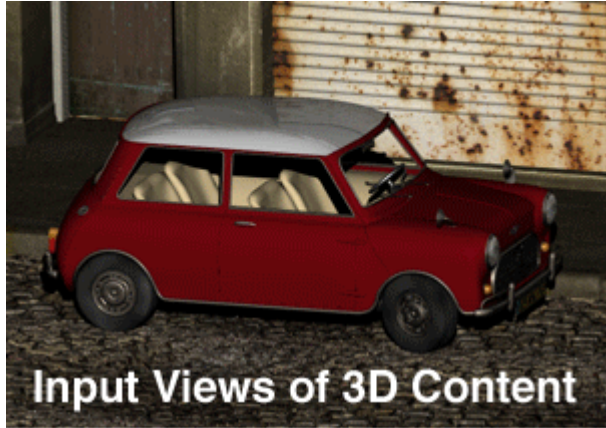






# Simulation Results

SIGGRAPH2012

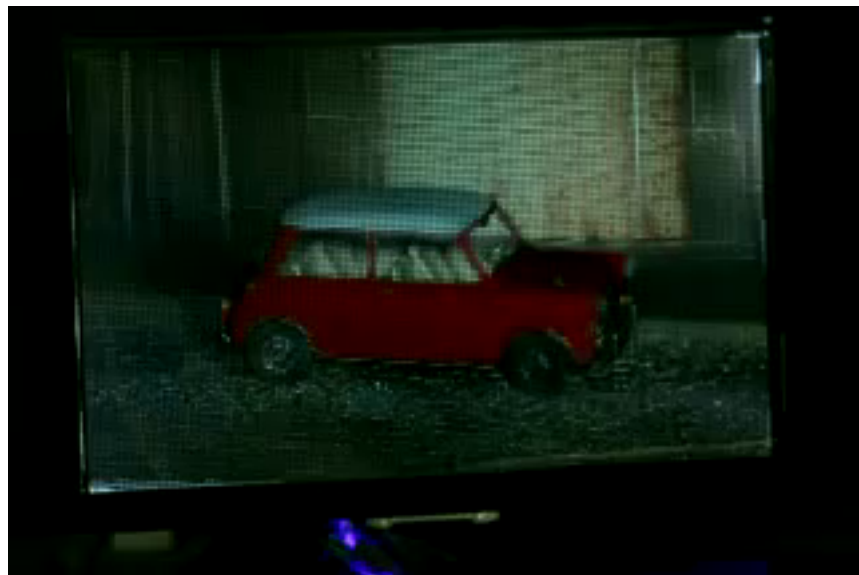


# Prototype *High-Rank 3D (HR3D)* Display

SIGGRAPH2012



<http://cameraculture.media.mit.edu/byo3d>



**Time-Multiplexed Parallax Barrier**

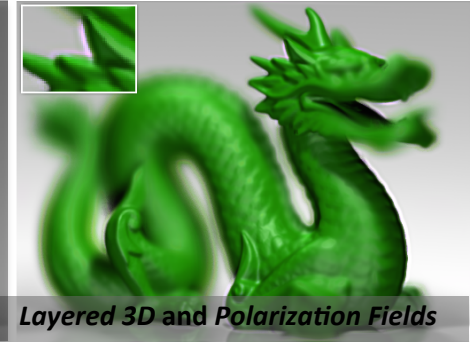
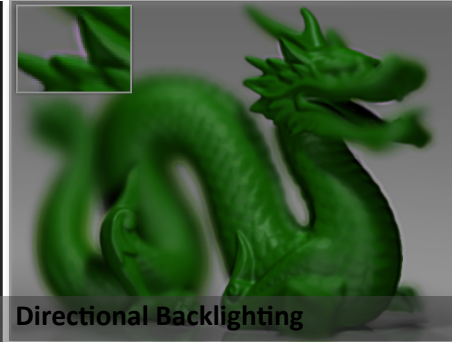
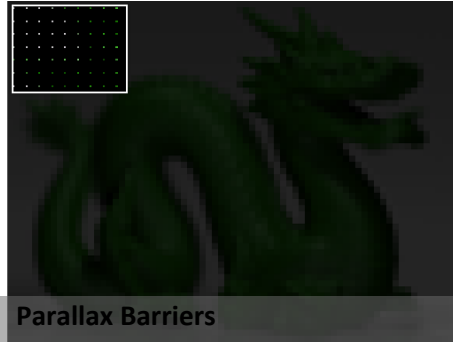
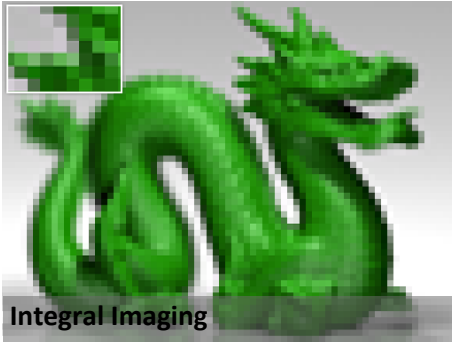


***High-Rank 3D (HR3D)***

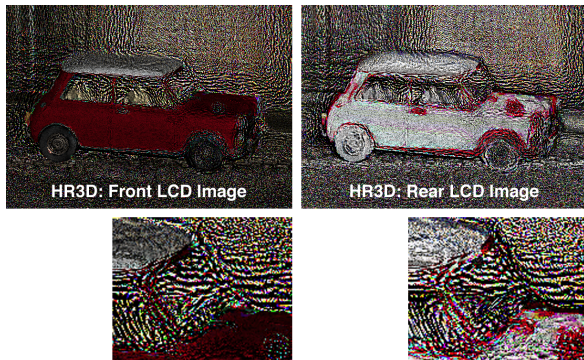


- *Automultiscopic Displays*
  - Multi-Layer Displays
    - Layered 3D
    - Polarization Fields
  - Dual-Layer Displays
    - High-Rank 3D (HR3D)

# Design Trade-offs

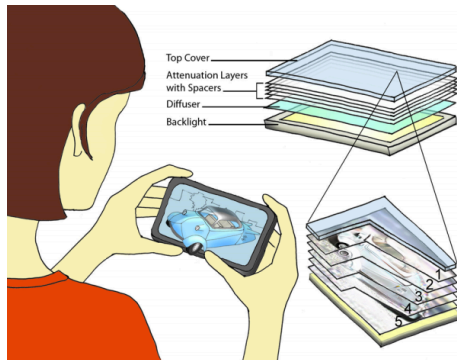


	Integral Imaging	Parallax Barriers	Directional Backlighting	<i>HR3D</i>	<i>Layered 3D and Polarization Fields</i>
<b>Spatial Resolution</b>	low	low	high	high	high
<b>Brightness</b>	high	low	moderate	moderate	high
<b>Cost</b>	low	low – moderate	moderate – high	moderate – high	low – high
<b>Full-resolution 2D</b>	no	yes	yes	yes	yes
<b>Motion Parallax</b>	yes	yes	no	yes	yes



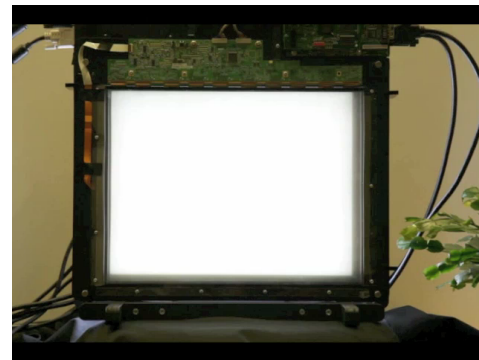
## ***High-Rank 3D (HR3D)***

[www.hr3d.info](http://www.hr3d.info)



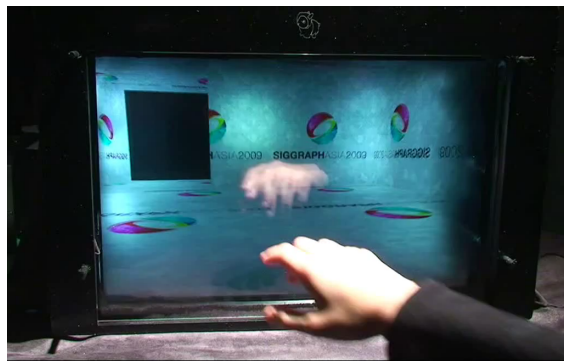
## ***Layered 3D***

[www.layered3d.info](http://www.layered3d.info)



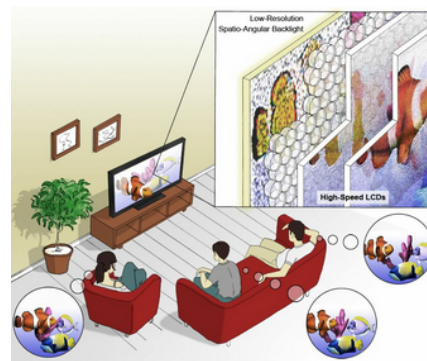
## ***Polarization Fields***

[tinyurl.com/polarization-fields](http://tinyurl.com/polarization-fields)



## ***BiDi Screen***

[www.bidiscreen.com](http://www.bidiscreen.com)



## ***Tensor Displays***

[tinyurl.com/tensordisplays](http://tinyurl.com/tensordisplays)

# Perceptually-Driven Computational Displays

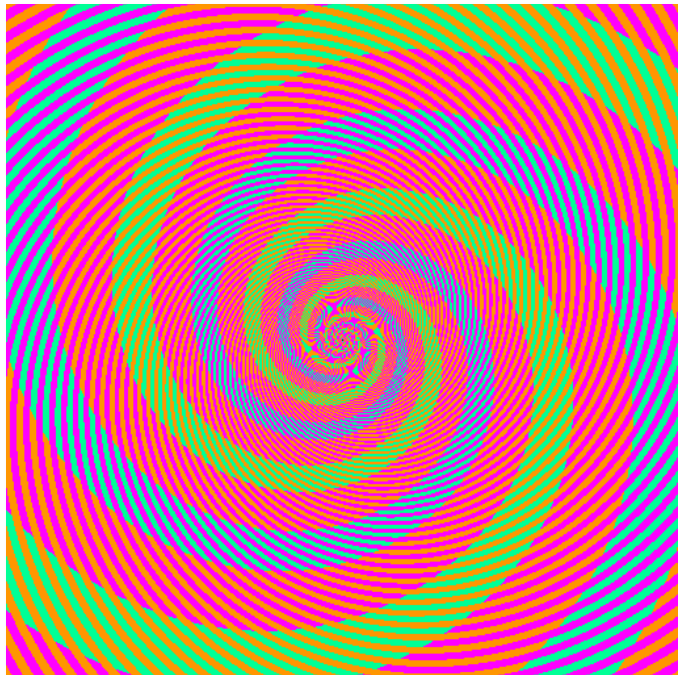
Slides by Diego Gutierrez  
Universidad de Zaragoza



- For the latest version of the slides, please go to:
  - <http://giga.cps.unizar.es/~diegog/pub.html>

# The HVS is not perfect...

SIGGRAPH2012

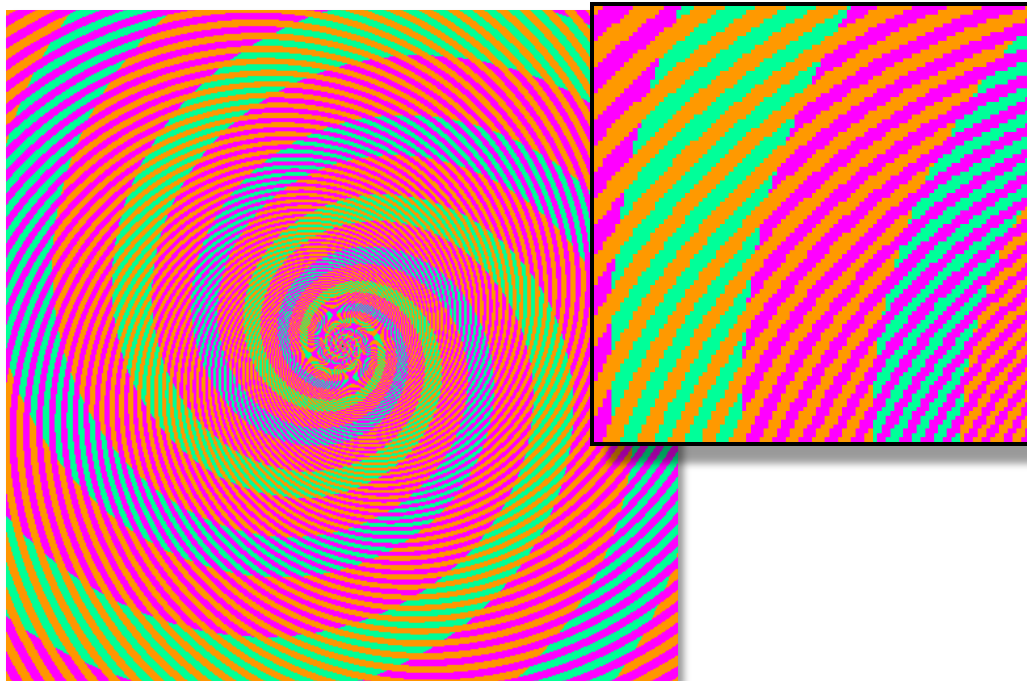


<http://blogs.discovermagazine.com/badastronomy/2009/06/24/the-blue-and-the-green/>

Slides by Diego Gutierrez

# The HVS is not perfect...

SIGGRAPH2012

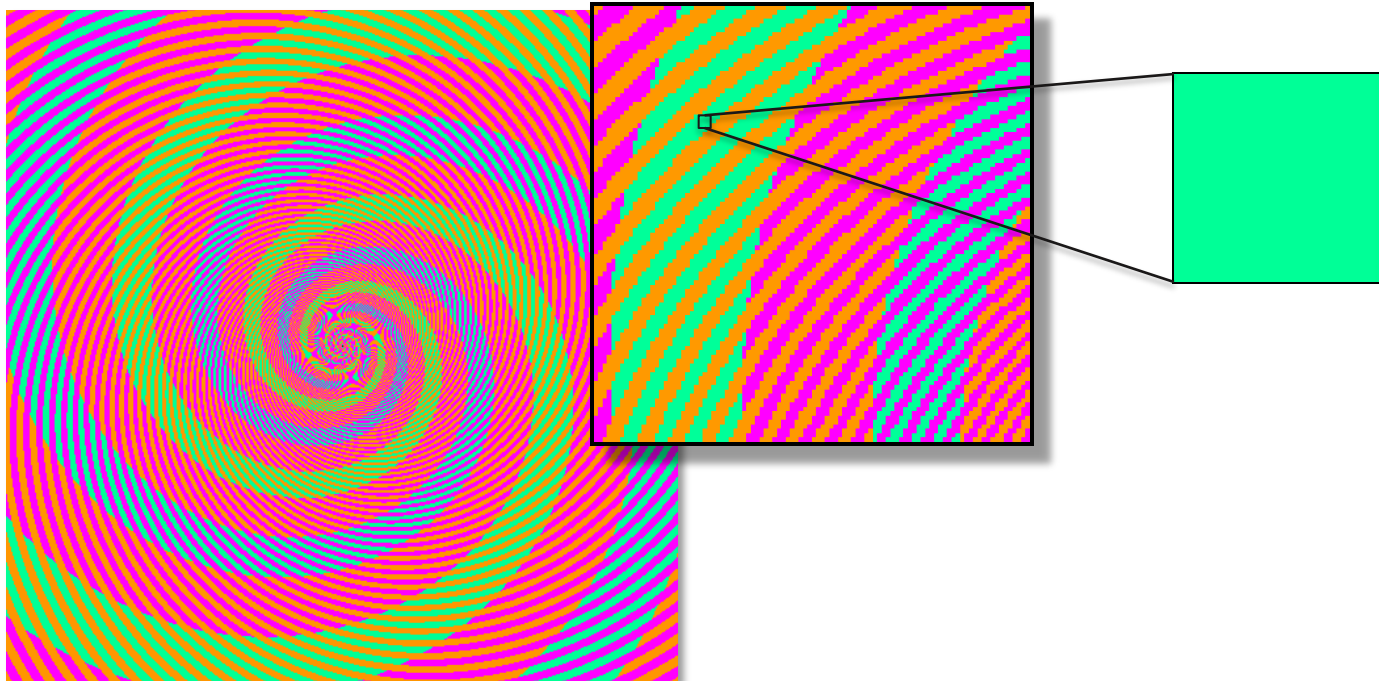


<http://blogs.discovermagazine.com/badastronomy/2009/06/24/the-blue-and-the-green/>

Slides by Diego Gutierrez

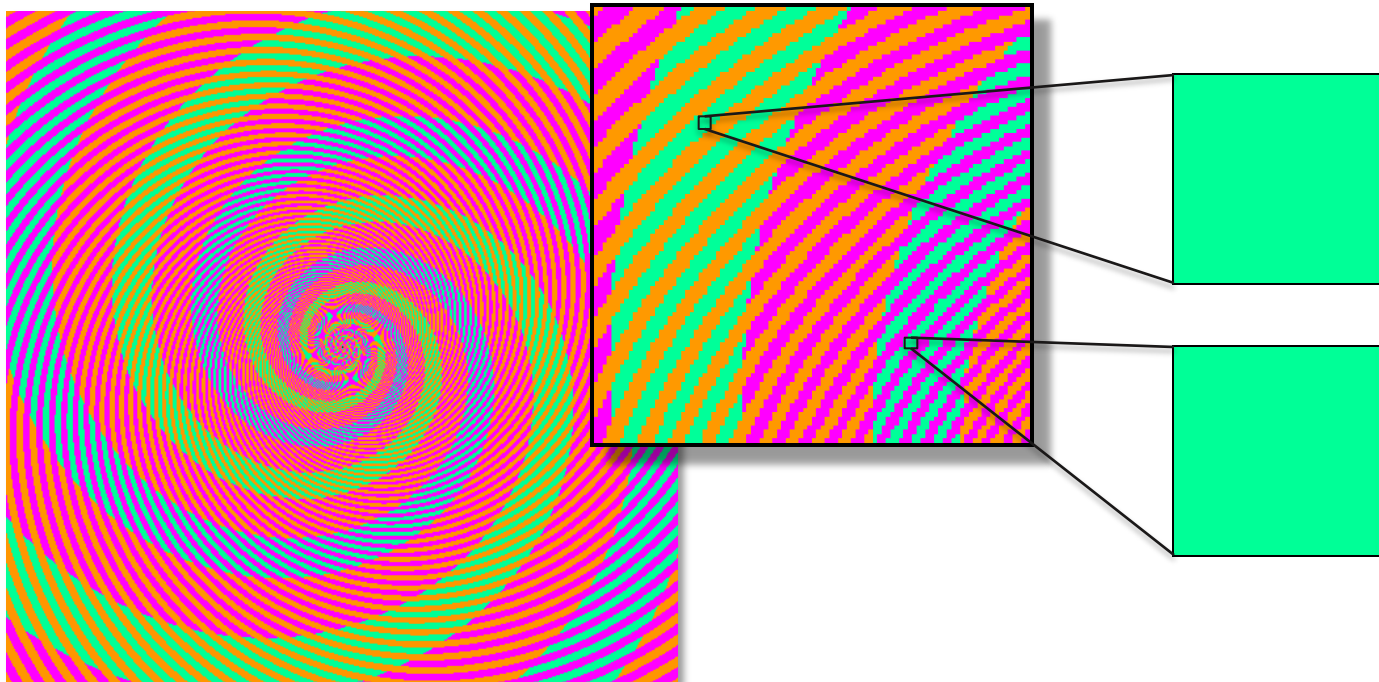
# The HVS is not perfect...

SIGGRAPH2012



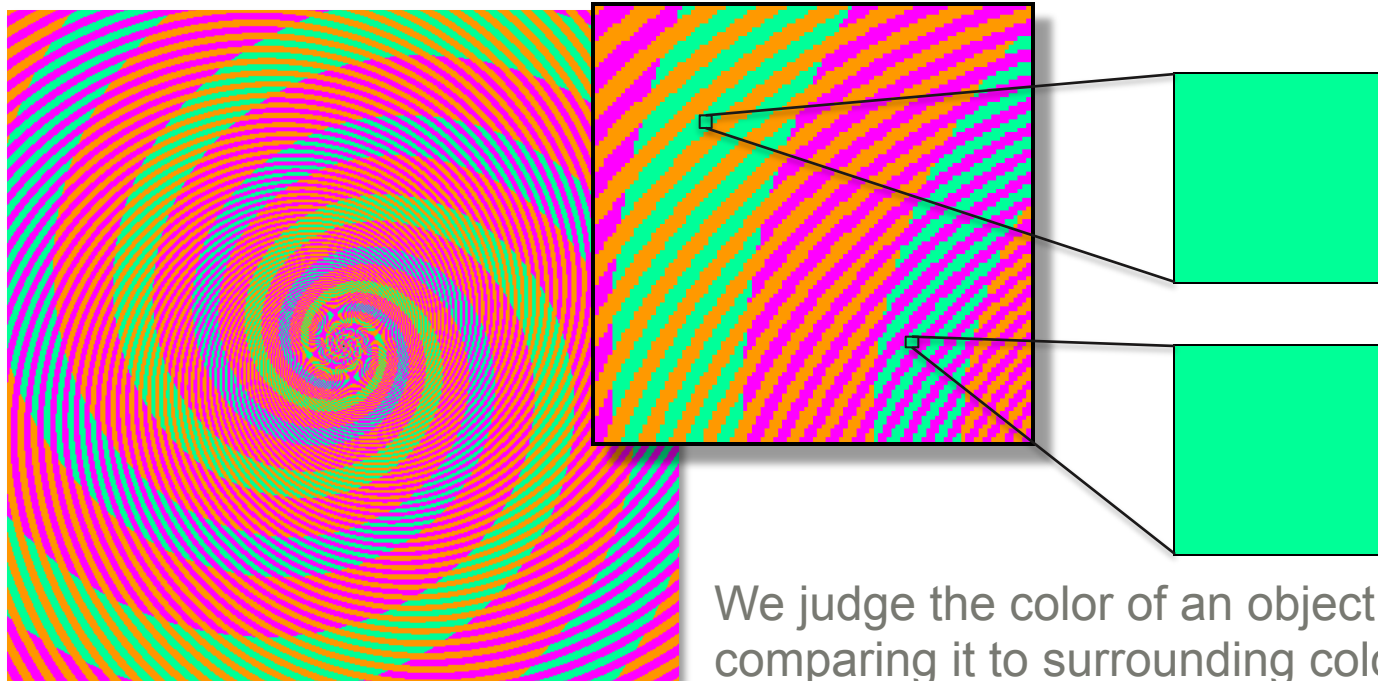
# The HVS is not perfect...

SIGGRAPH2012



# The HVS is not perfect...

SIGGRAPH2012



We judge the color of an object by comparing it to surrounding colors!

# The HVS is not perfect...



- Color versions of White's effect (mechanism unknown)



# The HVS is not perfect...



- The human visual system works in a specific way
  - Some aspects known, some are still open problems
- Sometimes what we *think* we see is different from the input signal

# The HVS is not perfect...



- The human visual system works in a specific way
  - Some aspects known, some are still open problems
- Sometimes what we *think* we see is different from the input signal
- **Let's take that into account when designing displays!**

# Displays are limited too

- Dynamic range
- Color
- Depth
- Spatial frequencies
- Temporal frequencies
- ...





- Dynamic range
- Color
- Depth
- Spatial frequencies
- Temporal frequencies
- ...



- Can we exploit the limitations/mechanisms of the HVS to enhance their **perceived** capabilities?

# A toy example: visual masking

SIGGRAPH2012



*Human visual system models in computer graphics* (Tunç Aydın, PhD Thesis 2010)

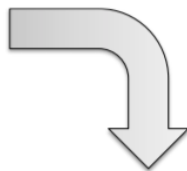
Slides by Diego Gutierrez

# Dynamic range and tone mapping

SIGGRAPH2012



Real-world

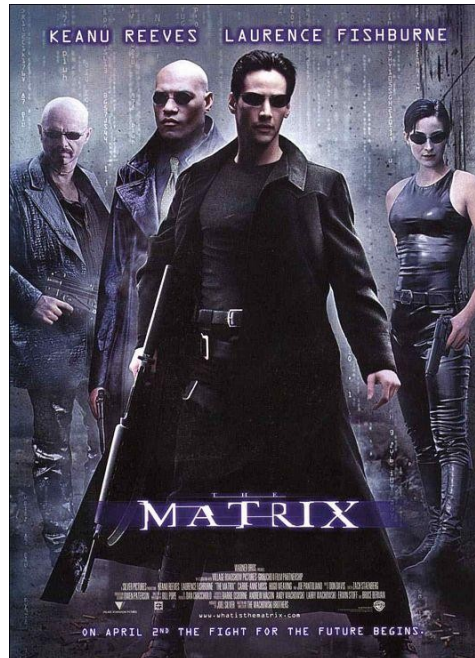


Display

Goal: map colors to a restricted color space

# Artists know this well: dynamic range

SIGGRAPH2012



*The art and science of depiction* (Fredo Durand)

Slides by Diego Gutierrez

# Artists know this well: dynamic range

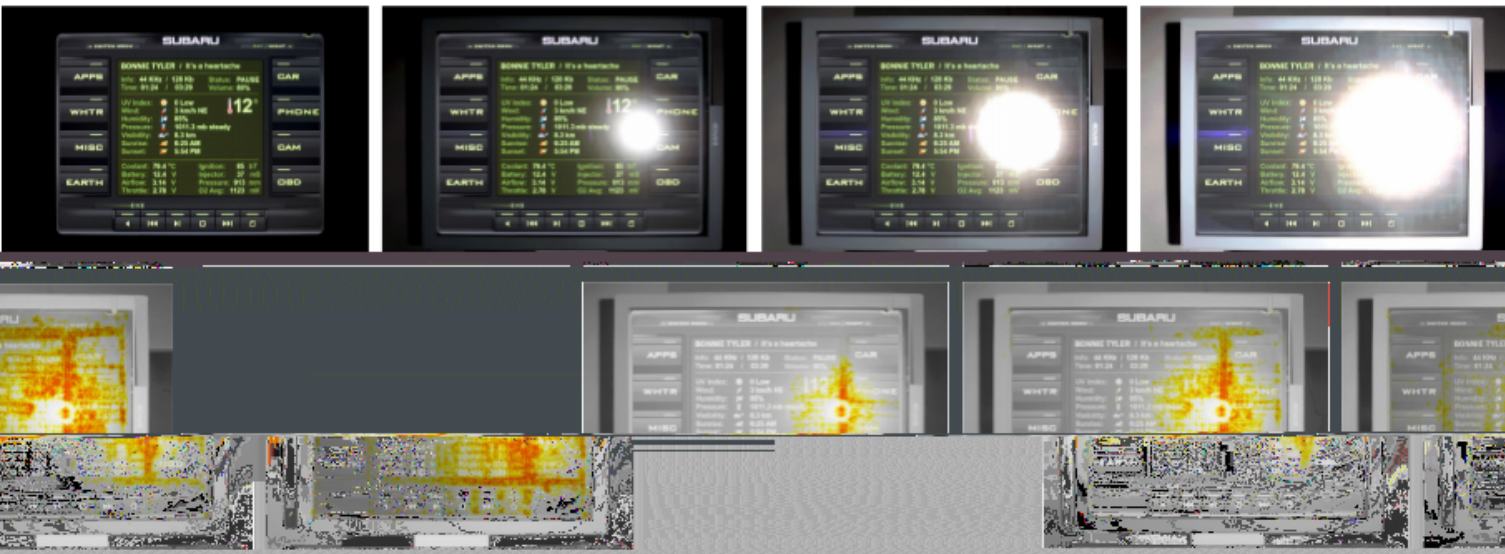


- Contrast is reinforced at the occlusion silhouette
- Tone modification / haze



# Another example: display visibility

SIGGRAPH2012

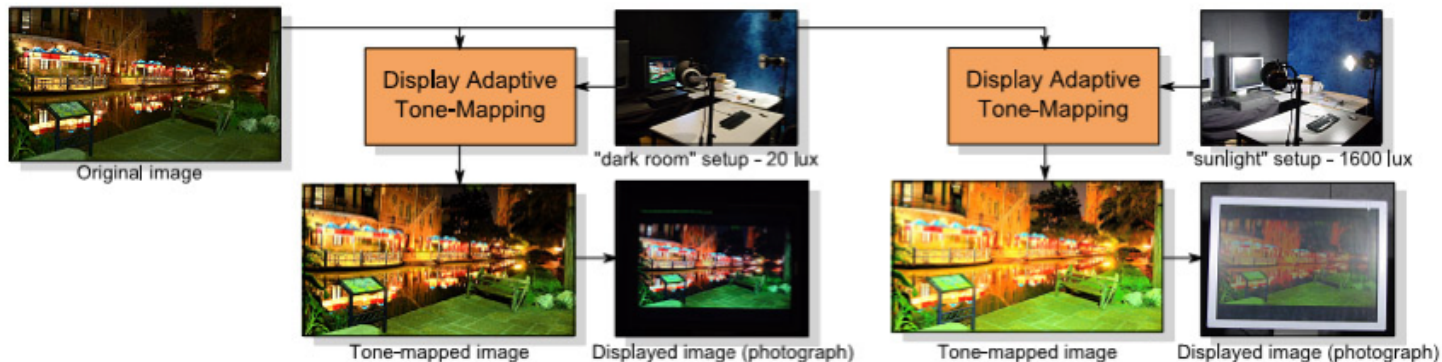


*Predicting display visibility under dynamically changing lighting conditions, Eurographics 2009 [Tunç Aydın et al.]*

Slides by Diego Gutierrez

# Different viewing conditions

SIGGRAPH2012



Predict the visibility of contrast distortions, and alter the input so that they are minimized

*Display adaptive tone mapping*, SIGGRAPH 2008 [Mantiuk et al.]

Slides by Diego Gutierrez

# Different viewing conditions

Dark room



*Display adaptive tone mapping, SIGGRAPH 2008 [Mantiuk et al.]*

# Different viewing conditions

Bright office



*Display adaptive tone mapping, SIGGRAPH 2008 [Mantiuk et al.]*

# Different viewing conditions

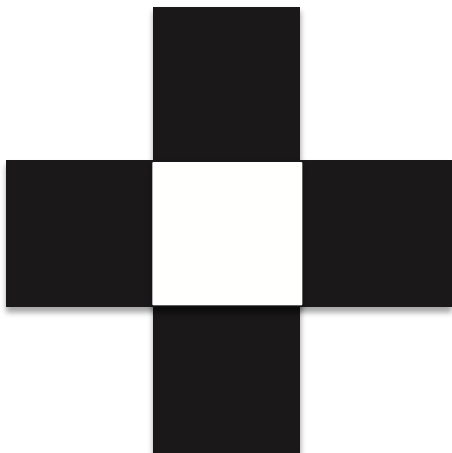
Outdoors



*Display adaptive tone mapping, SIGGRAPH 2008 [Mantiuk et al.]*

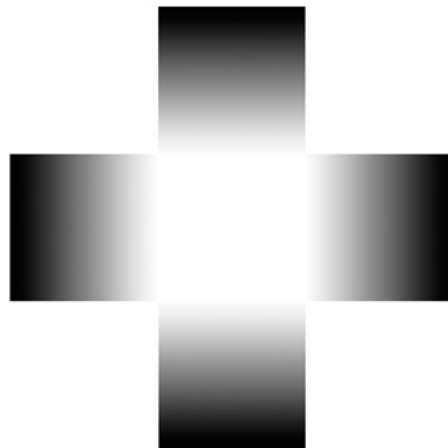
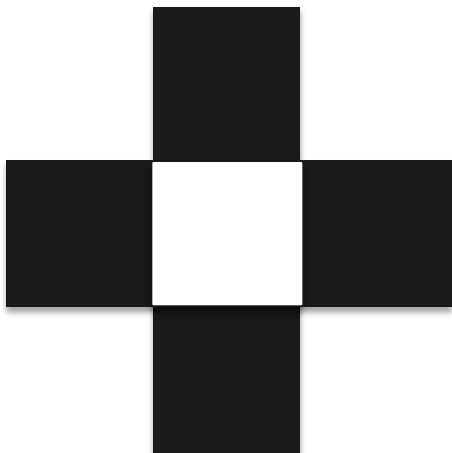
# Apparent brightness

SIGGRAPH2012



# Apparent brightness

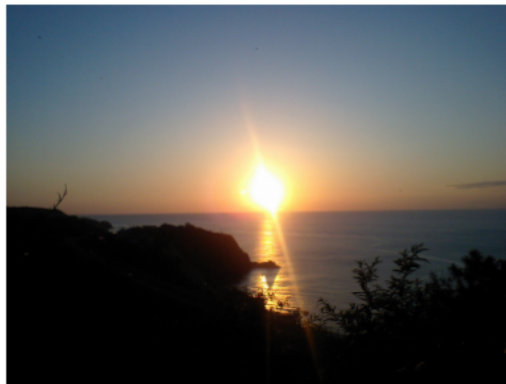
SIGGRAPH2012



<http://www.opticalillusion.net/optical-illusions/grey-glow-illusion-the-glare-effect/>

# Apparent brightness

SIGGRAPH2012

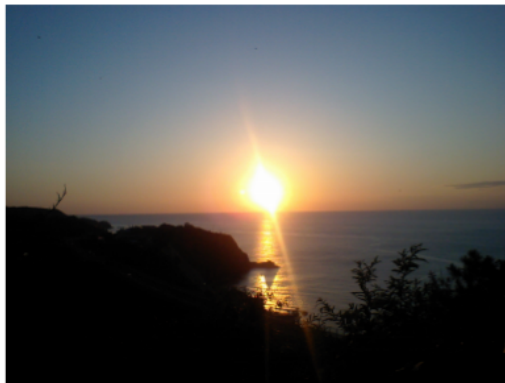


*Brightness of the glare illusion.* APGV 2008 [Yoshida et al.]

Slides by Diego Gutierrez

# Apparent brightness

SIGGRAPH2012

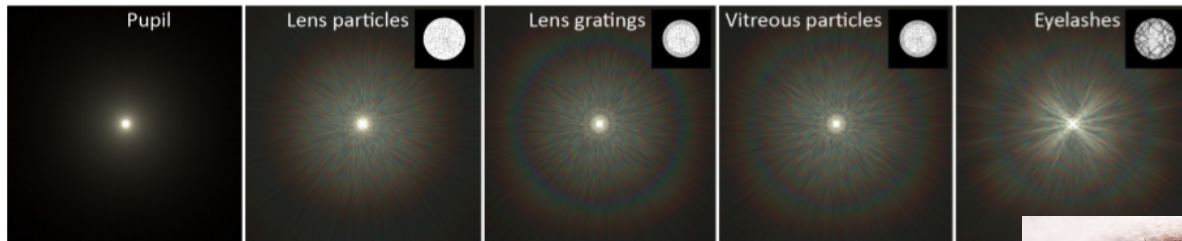


*Brightness of the glare illusion.* APGV 2008 [Yoshida et al.]

Slides by Diego Gutierrez

# Dynamic glare

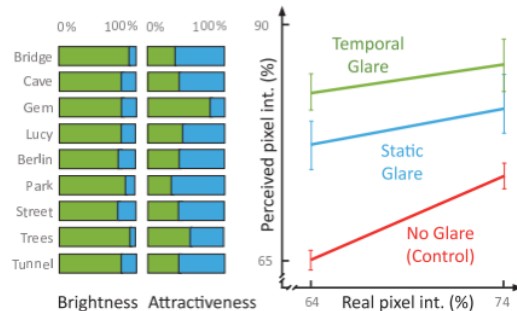
SIGGRAPH2012



*Temporal Glare: Real-Time Dynamic Simulation of the Scattering in the Human Eye*, Eurographics 2009 [Ritschel et al.]

Slides by Diego Gutierrez

# Dynamic glare



# Apparent brightness

SIGGRAPH2012



keep staring at the black dot.

*Perception-based rendering: eyes wide bleached*, Eurographics 2005 [Gutierrez et al.]

Slides by Diego Gutierrez

# Apparent brightness

SIGGRAPH2012



johnsadowski.com

*Perception-based rendering: eyes wide bleached*, Eurographics 2005 [Gutierrez et al.]

Slides by Diego Gutierrez

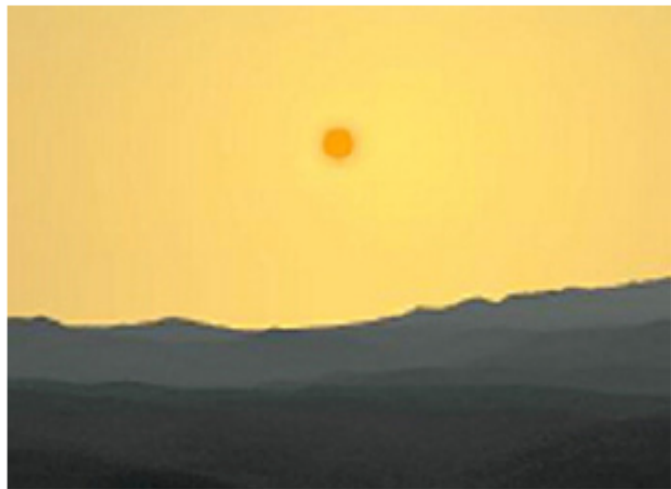
# Apparent brightness



- Neurons in the retina habituate (**adapt**) and stop responding to a fixed stimulus
- Once adapted, they need a little time to reset to their original, responsive state

# Apparent brightness

SIGGRAPH2012



bleaching of retinal photoreceptors

*Perception-based rendering: eyes wide bleached, Eurographics 2005 [Gutierrez et al.]*

Slides by Diego Gutierrez

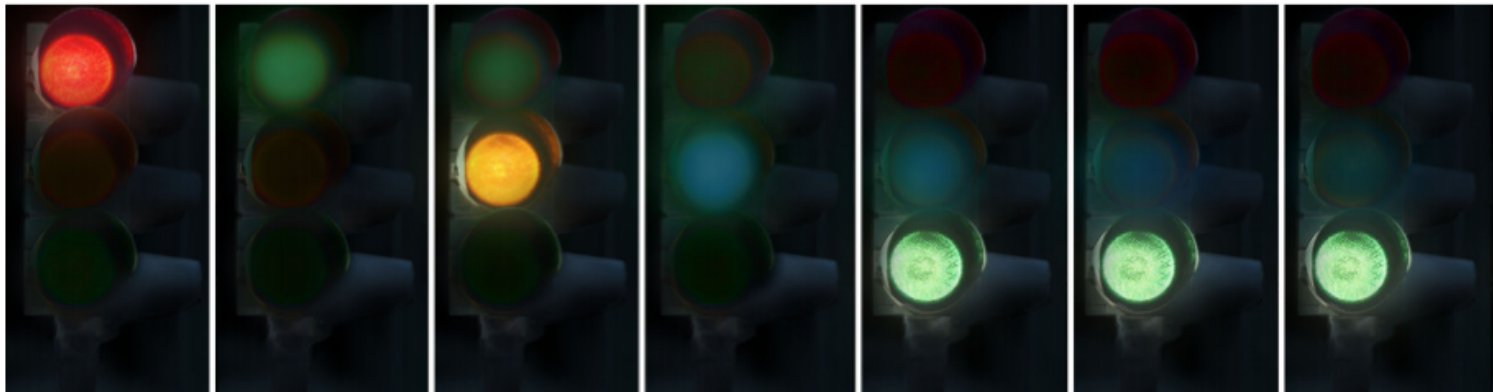
# Apparent brightness



- Neurons in the retina habituate (adapt) and stop responding to a fixed stimulus
- Once adapted, they need a **little time** to reset to their original, responsive state

# Apparent brightness

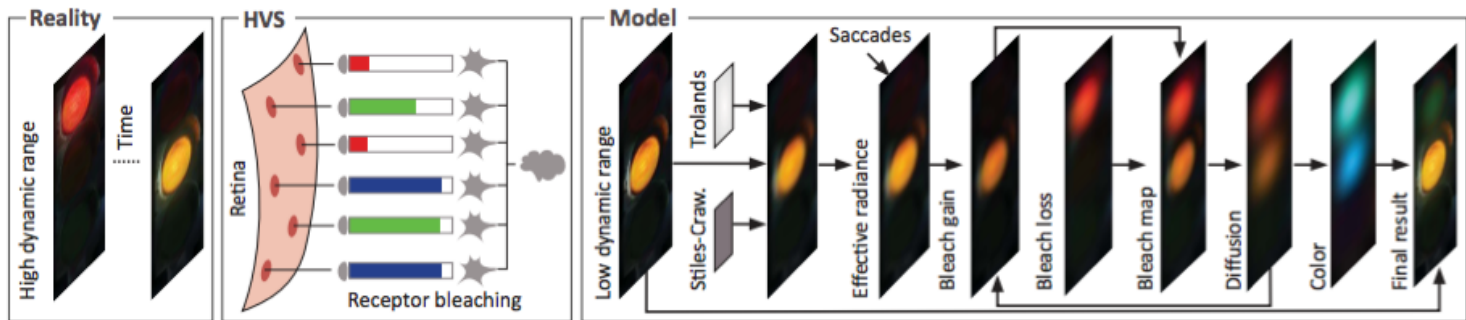
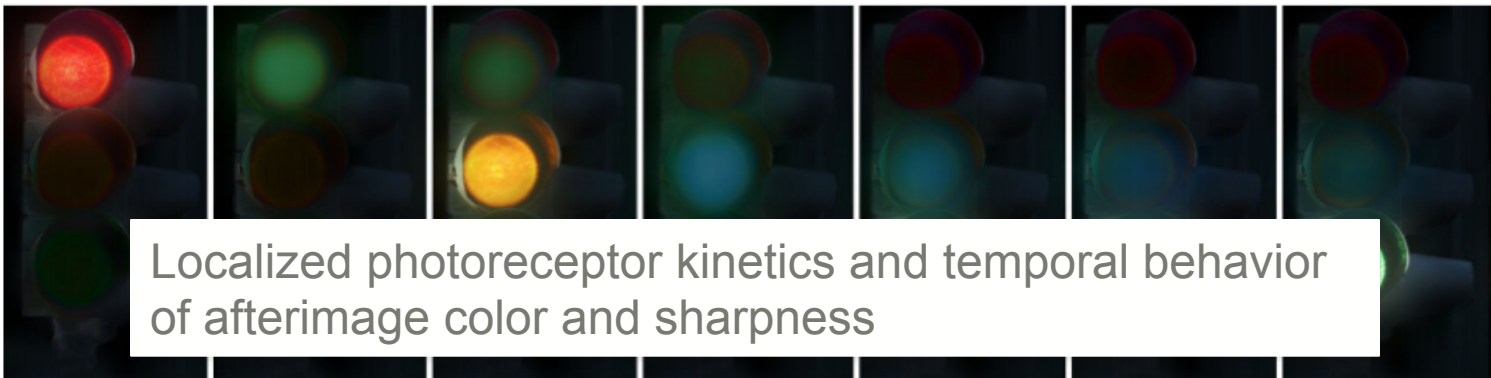
SIGGRAPH2012



*A computational model of afterimages*, Eurographics 2012 [Ritschel and Eisemann]

Slides by Diego Gutierrez

# Apparent brightness



# Apparent brightness

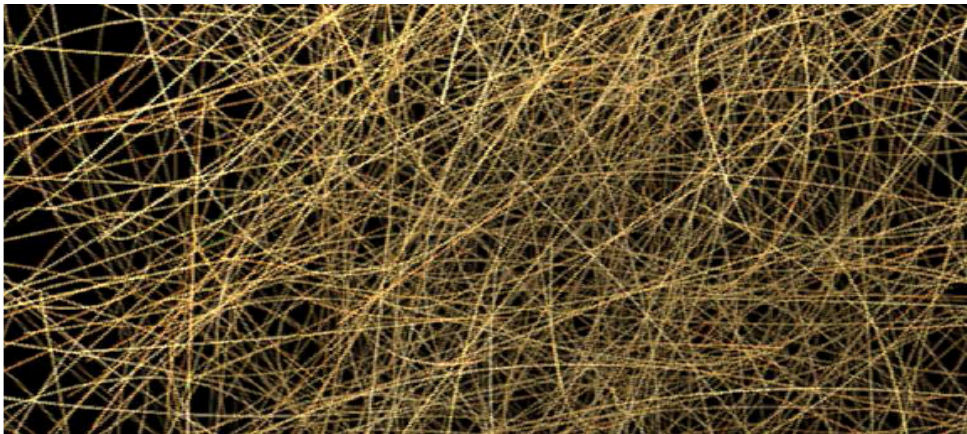
SIGGRAPH2012



*"Unsharp masking, countershading and halos: enhancements or artifacts?"* by Trentacoste et al. 2012  
Slides by Diego Gutierrez



- Limited spatial resolution of displays makes showing very fine details impossible

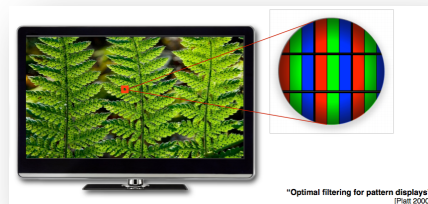




- HVS to the rescue!

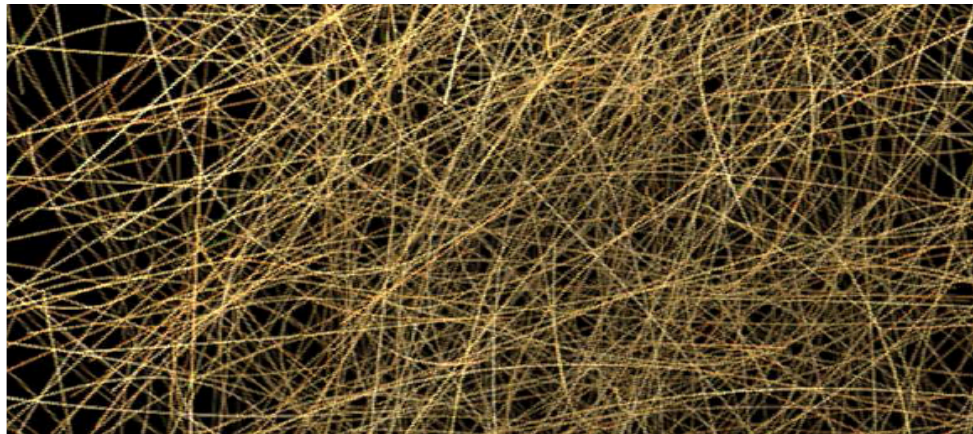


- **Smooth pursuit eye motion**
  - Eye caught on an interesting moving feature
  - Eye tracks feature (matching velocity)
- The image will be constantly projected on predictable locations of the fovea with high density of photoreceptors
- Interesting integration effect!



# Resolution enhancement

SIGGRAPH2012

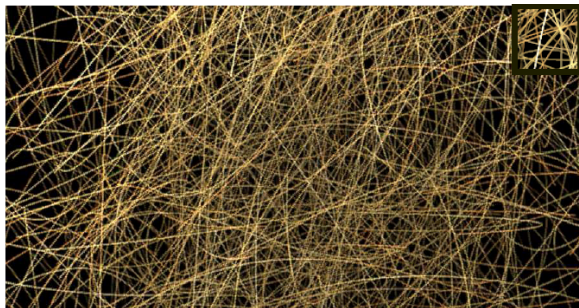


*Apparent display resolution enhancement for moving images, SIGGRAPH 2010 [Didyk et al.]*

Slides by Diego Gutierrez

# Resolution enhancement

SIGGRAPH2012

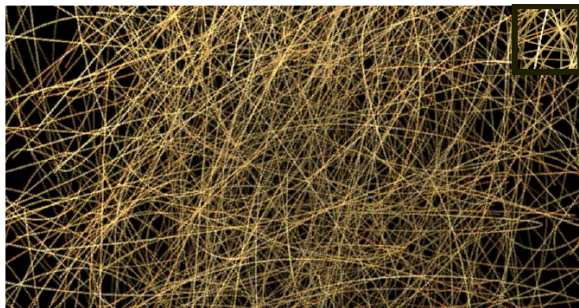


*Apparent display resolution enhancement for moving images, SIGGRAPH 2010 [Didyk et al.]*

Slides by Diego Gutierrez

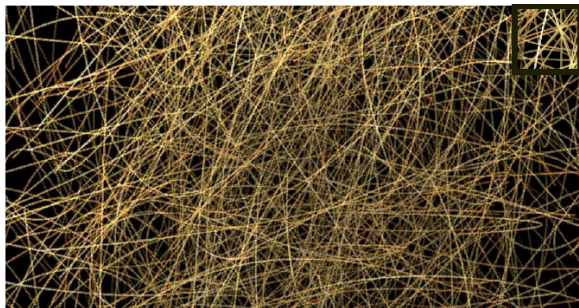
# Resolution enhancement

SIGGRAPH2012



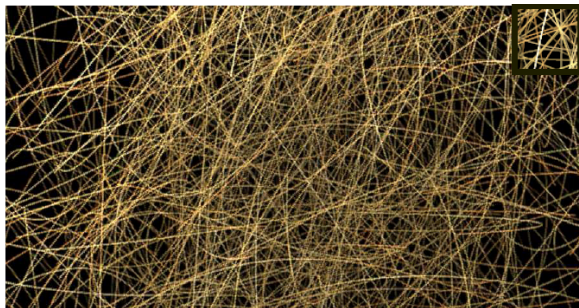
# Resolution enhancement

SIGGRAPH2012



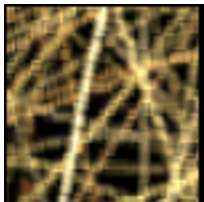
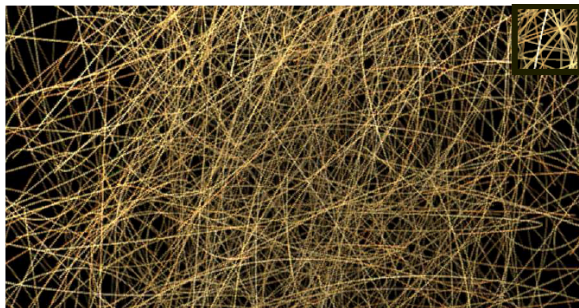
# Resolution enhancement

SIGGRAPH2012



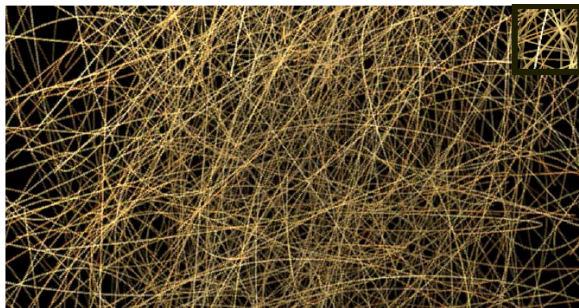
# Resolution enhancement

SIGGRAPH2012



# Resolution enhancement

SIGGRAPH2012

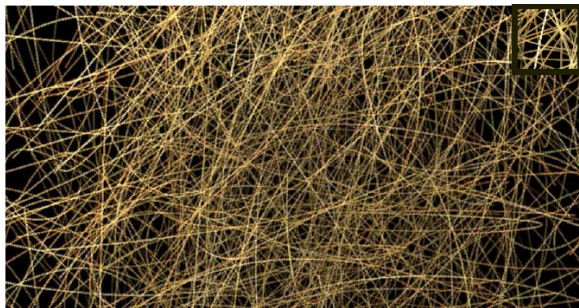


*Apparent display resolution enhancement for moving images, SIGGRAPH 2010 [Didyk et al.]*

Slides by Diego Gutierrez

# Resolution enhancement

SIGGRAPH2012

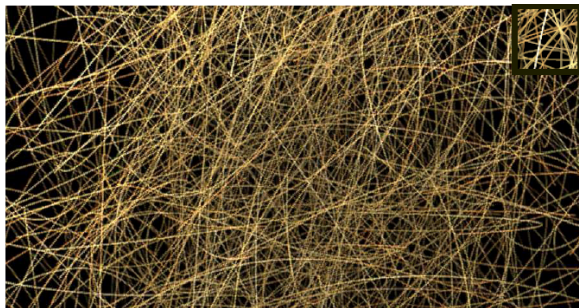


*Apparent display resolution enhancement for moving images*, SIGGRAPH 2010 [Didyk et al.]

Slides by Diego Gutierrez

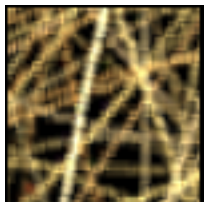
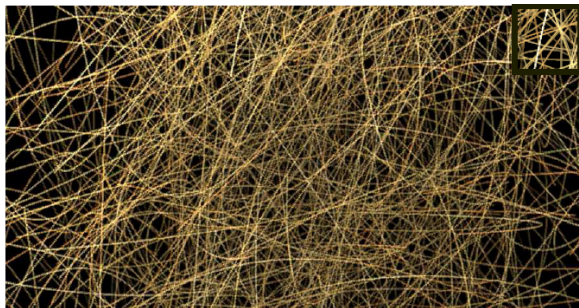
# Resolution enhancement

SIGGRAPH2012



# Resolution enhancement

SIGGRAPH2012



# Our goal



**mpii**

max planck institute  
informatik



Slide by P. Didyk

*Apparent display resolution enhancement for moving images*, SIGGRAPH 2010 [Didyk et al.]

Slides by Diego Gutierrez



# Stereo Retargeting

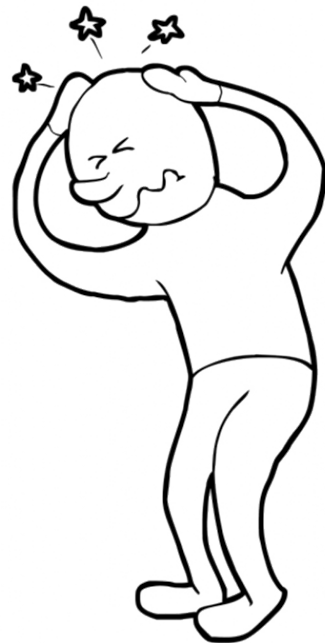
SIGGRAPH2012



Slides by Diego Gutierrez

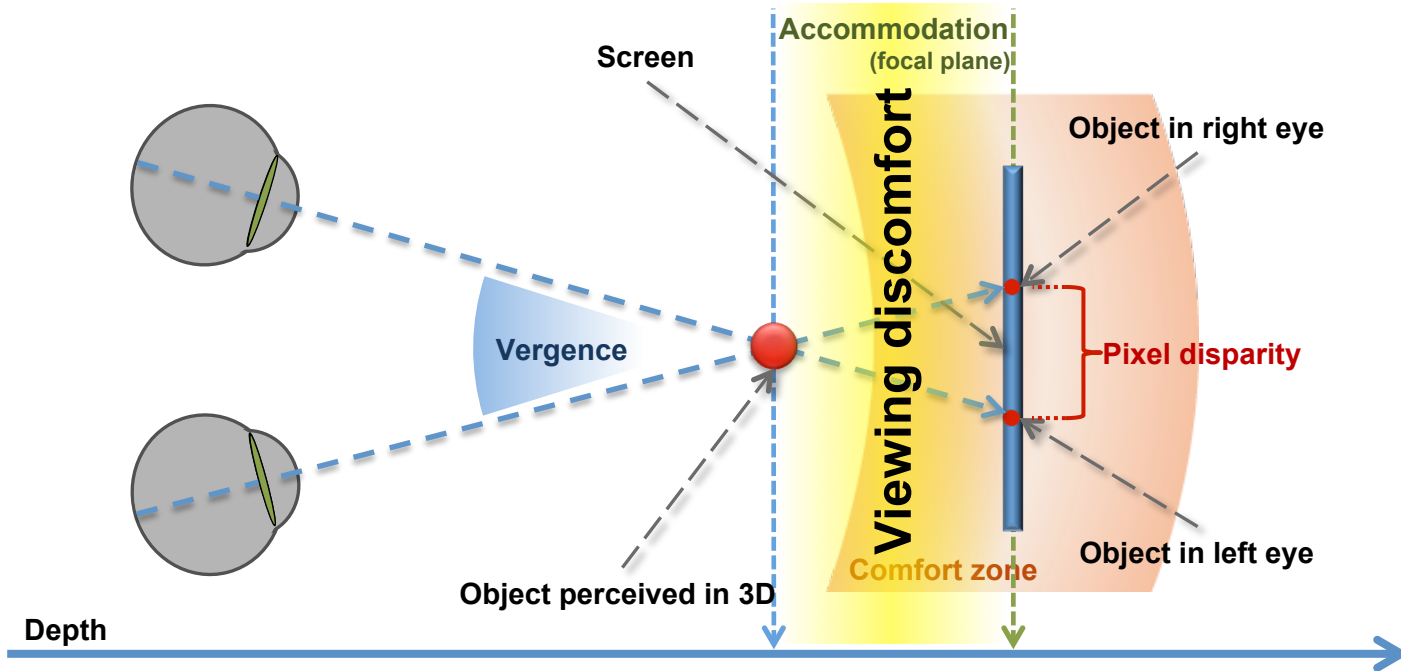
# Stereo Retargeting

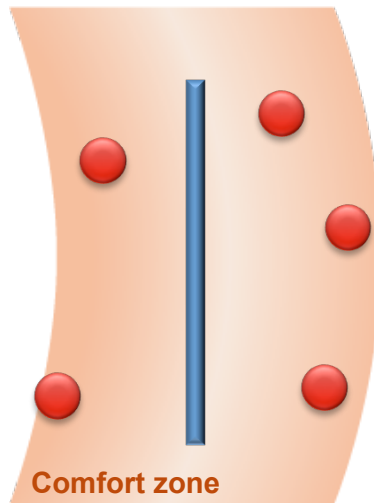
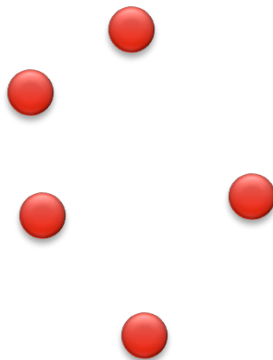
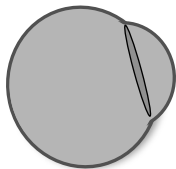
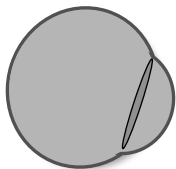
SIGGRAPH2012



Slides by Diego Gutierrez

# Visual Discomfort





Scene manipulation  
**Viewing discomfort** → **Viewing comfort**

# Disparity Remapping

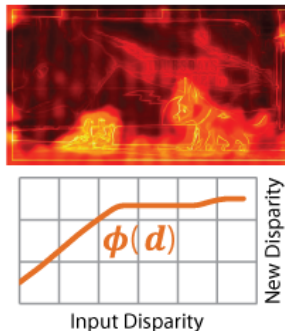
SIGGRAPH2012



A perceptual model for disparity, SIGGRAPH 2011 [Didyk et al.]

Slides by Diego Gutierrez

# Disparity Remapping

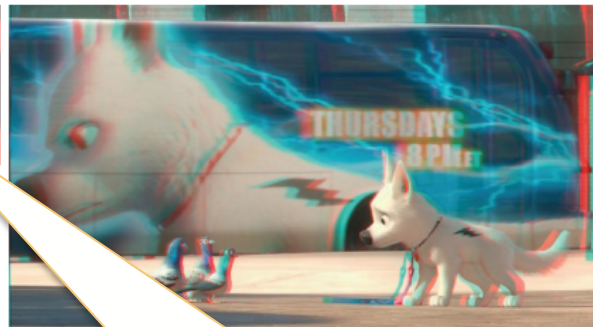
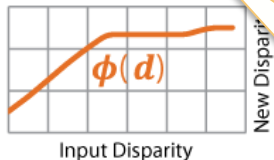
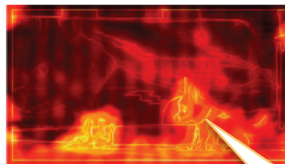


© 2010 Disney Enterprises

Nonlinear disparity retargeting

Introduce more distortions where they will be less perceived

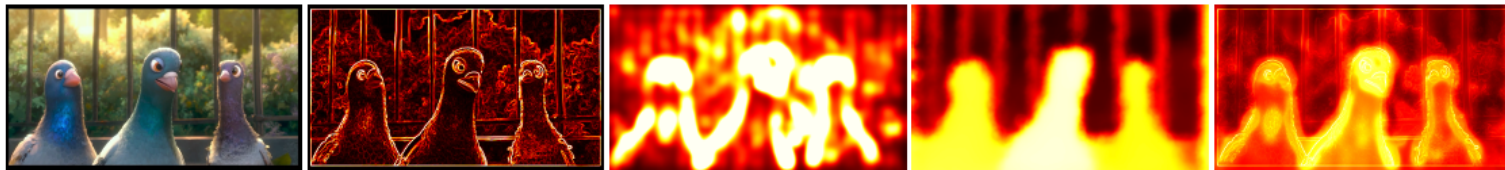
# Disparity Remapping



© 2010 Disney Enterprises

Visual Importance  
based on saliency

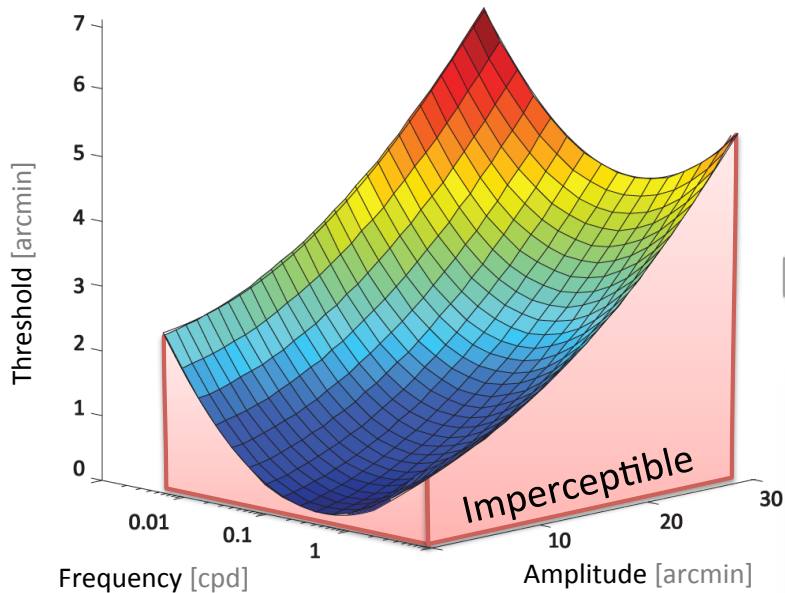
# Disparity Remapping



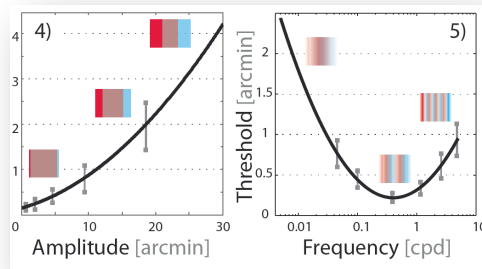
©2010 Disney Enterprises

Edge saliency + global texture saliency + disparity-based saliency

# Disparity discrimination threshold function



**Can be removed**  
Without reducing quality



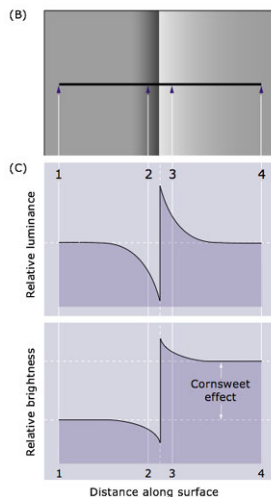


# Perceptual linear space

- Scaling is performed in a **linear perceptual space**
- Different applications, including:
  - Compression: remove disparity below 1 JND (or more)
  - Non-linear disparity scaling: more predictable in linear space
  - “Backward compatible stereo”



- Relies on the *Craik-O'Brien-Cornsweet* illusion
  - Apparent depth is **induced** at the disparity continuity, and **propagated** by the HVS

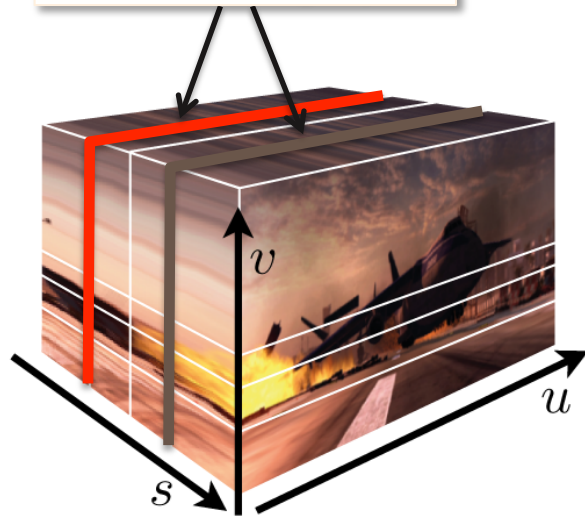
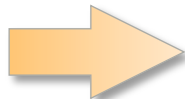


# Disparity Remapping (light fields)

SIGGRAPH 2012



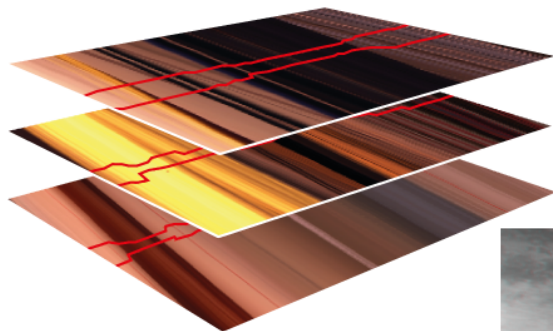
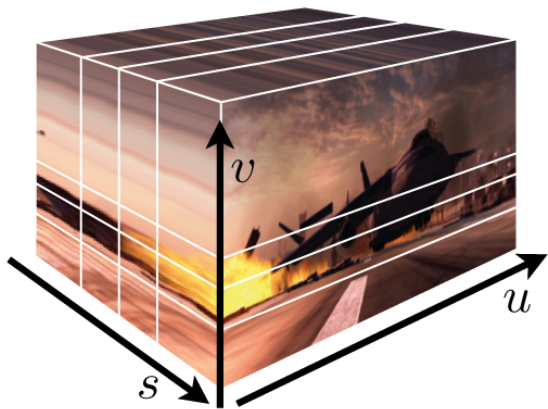
Stereo image pair



## Light Field

# Disparity Remapping (light fields)

SIGGRAPH2012

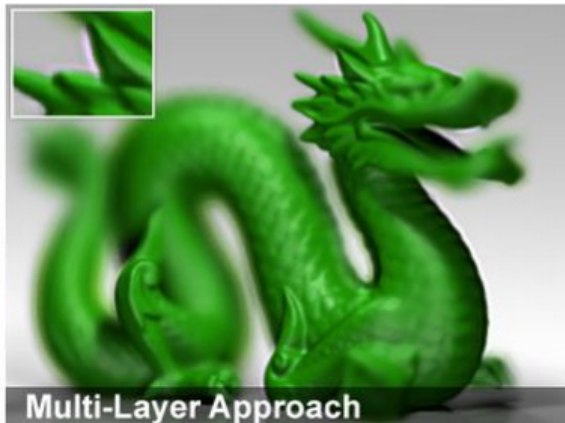


# Automultiscopic displays

SIGGRAPH2012



- Similar to DOF in photography, automultiscopic displays can only reproduce a limited depth range at full spatial resolution



**Multi-Layer Approach**

Dragon from *Layered 3D: tomographic image synthesis for attenuation-based light field and high dynamic range displays*, SIGGRAPH 2011 [Wetzstein et al.]

*Antialiasing for automultiscopic 3D displays*, EGSR 2006 [Zwicker et al.]

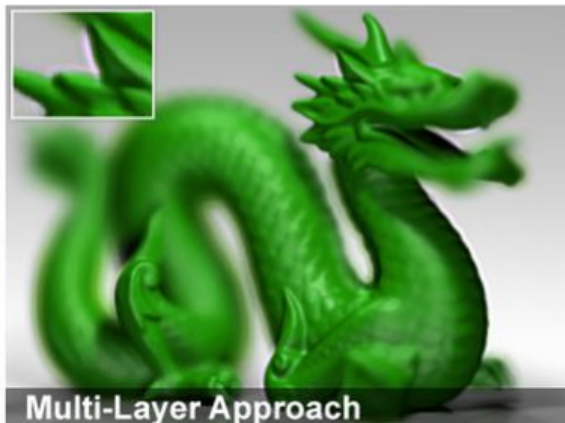
*Perceptually-based content remapping for automultiscopic displays*, SIGGRAPH 2012 (poster) [Masia et al.]

Slides by Diego Gutierrez

# Automultiscopic displays

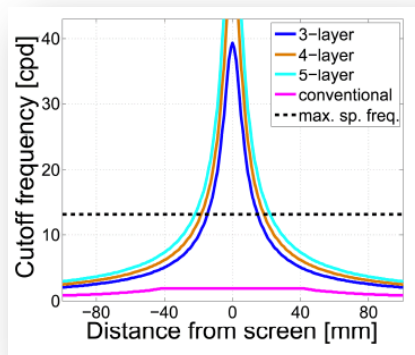


- Similar to DOF in photography, automultiscopic displays can only reproduce a limited depth range at full spatial resolution



Dragon from Layered 3D: tomographic image synthesis for attenuation-based light field and high dynamic range displays, SIGGRAPH 2011 [Wetzstein et al.]

Antialiasing for automultiscopic 3D displays, EGSR 2006 [Zwicker et al.]



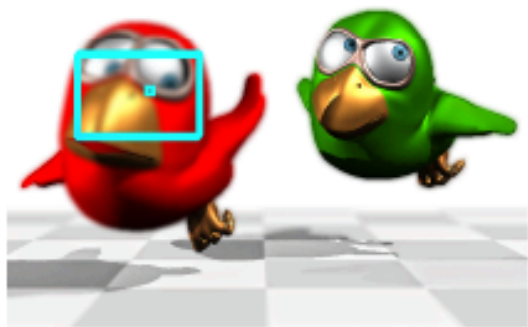
Perceptually-based content remapping for automultiscopic displays, SIGGRAPH 2012 (poster) [Masia et al.]

# Automultiscopic displays

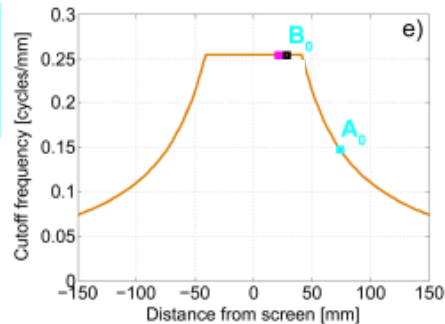
SIGGRAPH2012



Predicted View



a) Original



# Automultiscopic displays

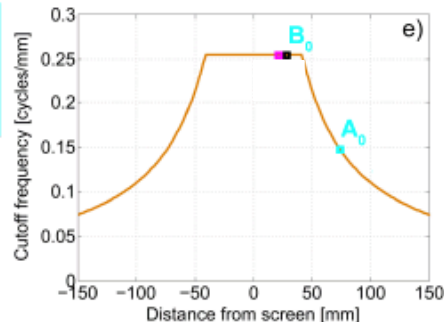
SIGGRAPH2012



Predicted View



a) Original



$$\arg \min_d \left[ \mu_{DOF} \|\omega_{CSF}(\rho(L_{orig}) - \rho(\phi_b(L_{orig}, d)))\|_2^2 + \mu_{BD} \|\omega_{BD} \rho(\Delta_\nu(d))\|_2^2 + \mu_{MP} \|\omega_{MP} \rho(\Delta_\nu(d))\|_2^2 \right]$$

Depth-of-field blur

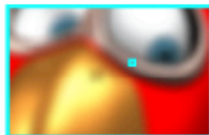
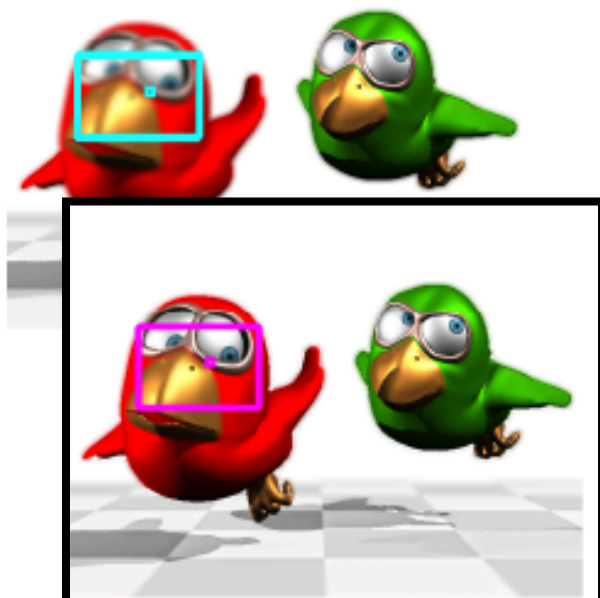
Binocular Disparity

Motion Parallax

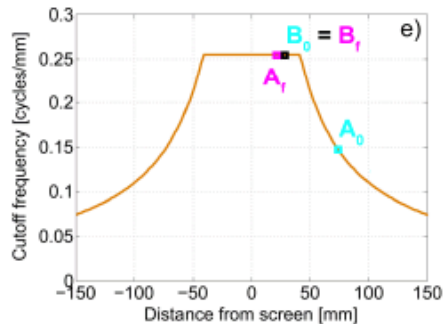
# Automultiscopic displays



Predicted View



c) Close up

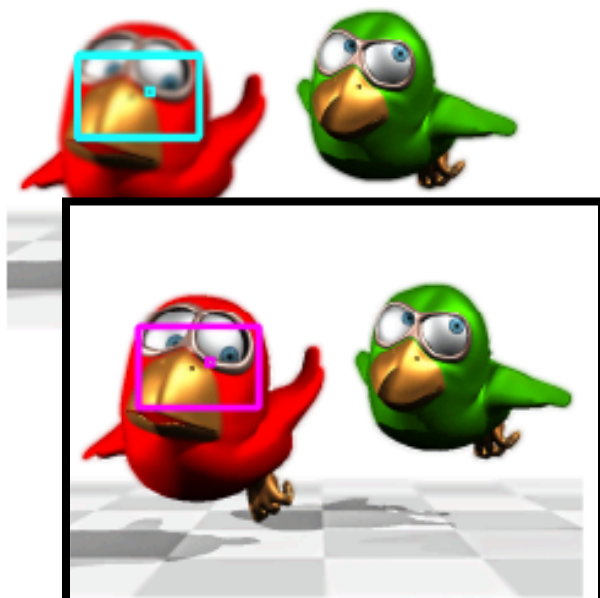


b) Retargeted

# Automultiscopic displays



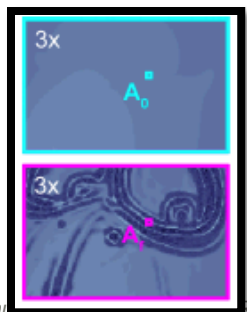
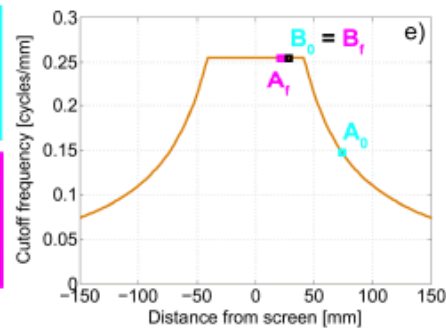
Predicted View



b) Retargeted



c) Close up

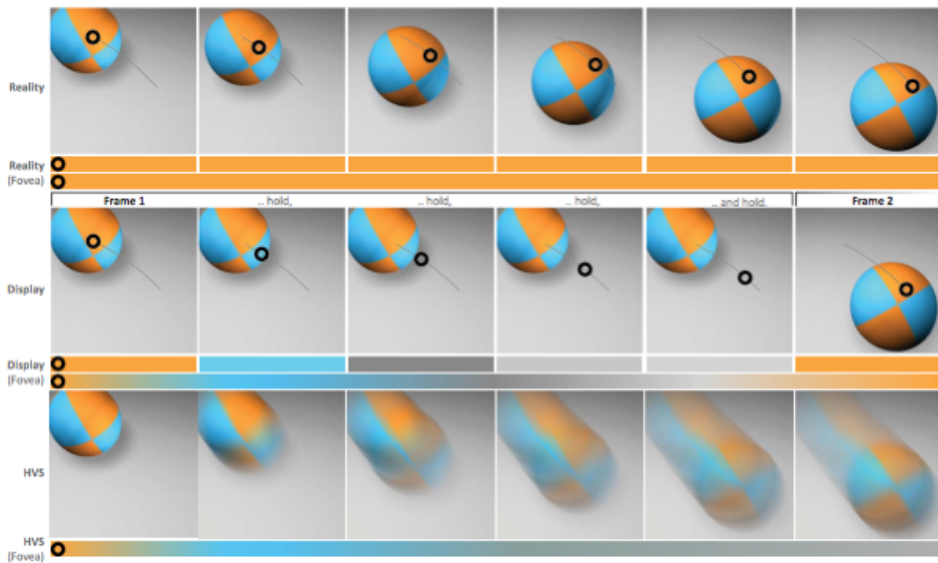


# Automultiscopic displays

SIGGRAPH2012



# Temporal upsampling



*"Perceptually-motivated real-time temporal upsampling of 3D content for high-refresh-rate displays"* by Didyk et al. 2010

*"Perceptual considerations for motion blur rendering"* by Navarro et al. 2011

Slides by Diego Gutierrez



- The HVs can play an important role in designing future displays and overcome current limitations
- The list of examples is very extensive
  - Only a small set of examples shown here
- Some fields have seen a lot of action already (tone mapping, color...)
- Others are hot today (stereo...)
- Others are quite revolutionary

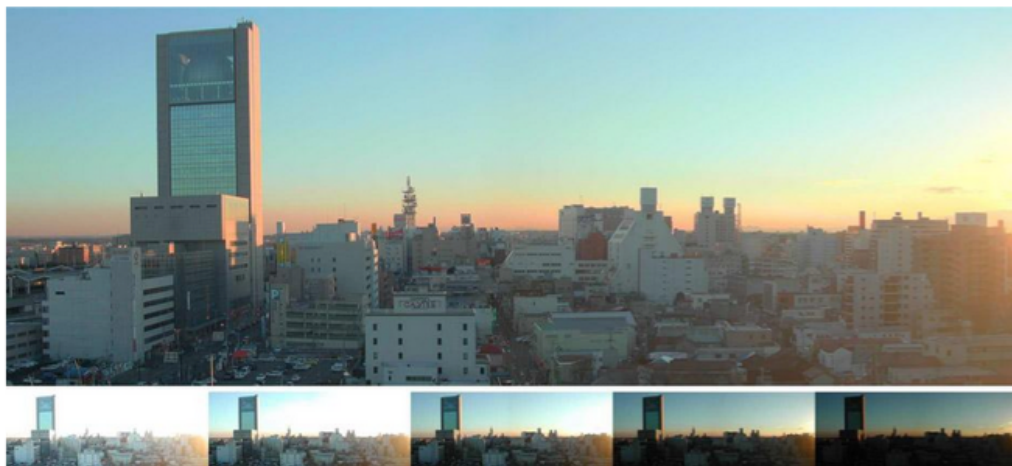
# Perceptual Digital Imaging: Methods and Applications

---

**Piotr Didyk, Tobias Ritschel, Elmar Eisemann, Karol Myszkowski**  
*Exceeding Physical Limitations: Apparent Display Qualities*

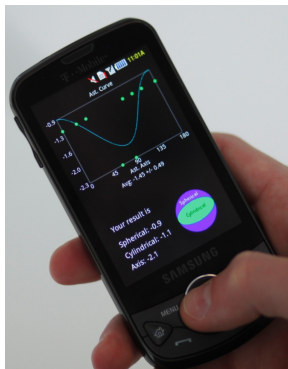
*CRC Press*

---



# Turning things around...

- Displays that can diagnose?
  - NETRA: Near Eye Tool for Refractive Assessment
  - CATRA: Cataract Screening Tool





- So what awaits for us in the future?
- Vibrating displays will further exploit the temporal integration in the retina
- Future displays will free the viewer from needing optical corrections (glasses)
  - A light field will be split into multiple instances focused at different distances

# Conclusions



- So when will this occur?



- So when will this occur?

**This Wednesday**



- So when will this occur?

## This Wednesday

Technical Papers Session: **Displays**

Wednesday, 8 August, 0900-1030

Room 408A



# Thanks for your attention!

(and thanks a lot to the authors of the original papers and slides!)

For the latest version of the slides, please go to:

<http://giga.cps.unizar.es/~diegog/pub.html>