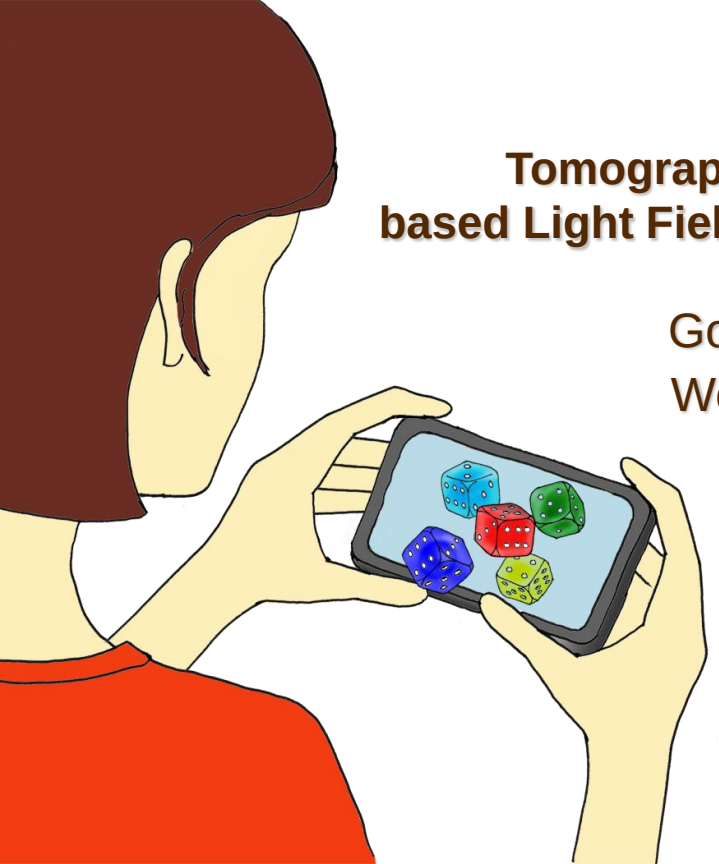
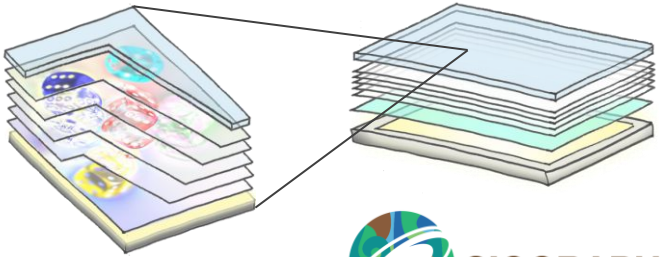


Layered 3D

Tomographic Image Synthesis for Attenuation-based Light Field and High Dynamic Range Displays

Gordon Wetzstein
Wolfgang Heidrich
UBC

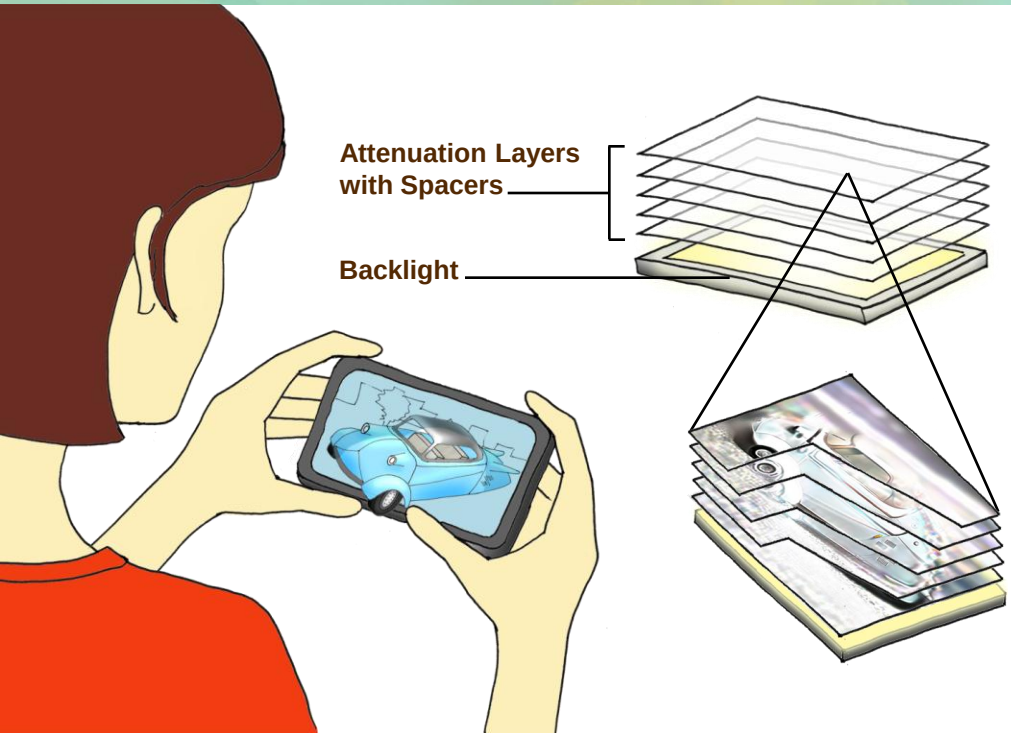
Douglas Lanman
Ramesh Raskar
MIT Media Lab



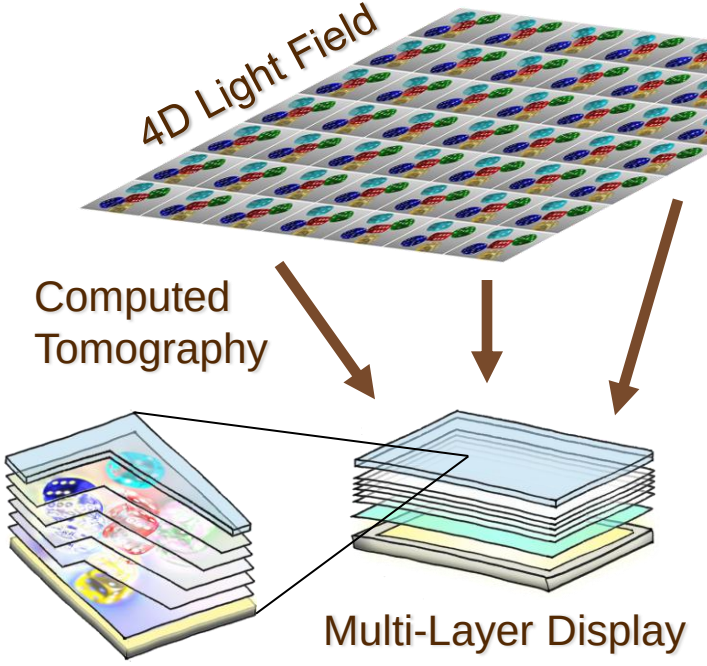
SIGGRAPH2011


NEC

Overview



Key Insights

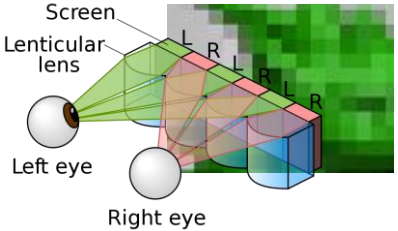


Glasses-Free 3D Display

Lenslet Arrays

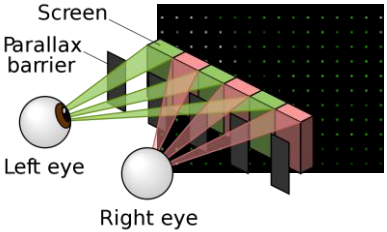
Lippmann 1908

source: wikipedia

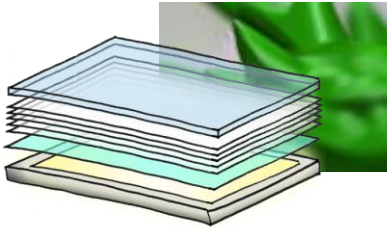


Parallax Barriers

Ives 1903

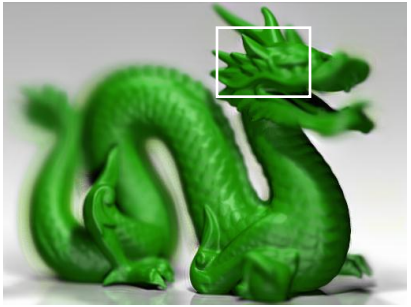


Layered 3D



Alioscopy 3DHD 42”

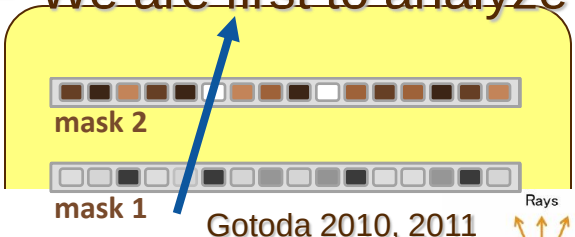
Nintendo 3DS



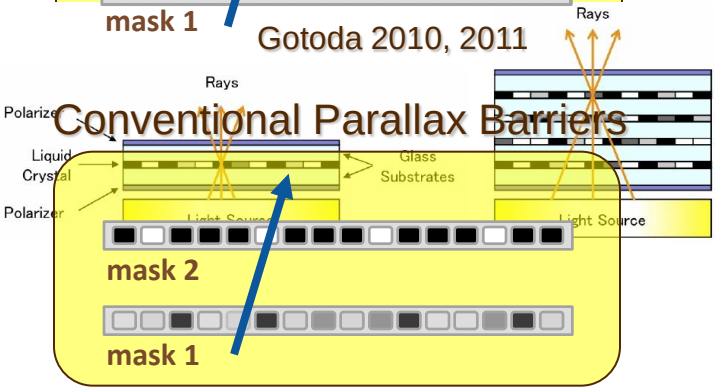
Generalizing Parallax Barriers

- We are first to analyze problem and build prototypes

Lanman et al. 2010

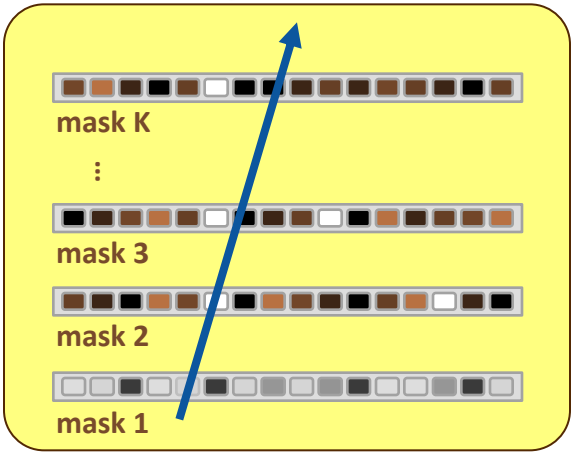


Gotoda 2010, 2011



Conventional Parallax Barriers

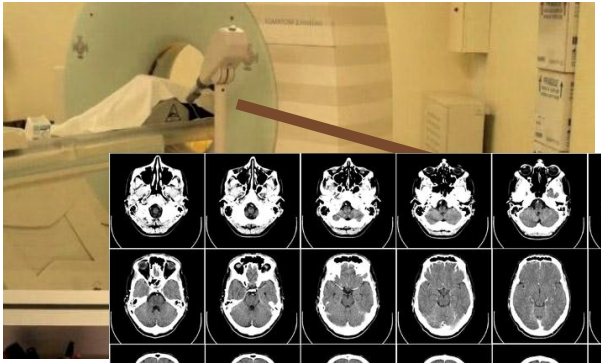
Layered 3D



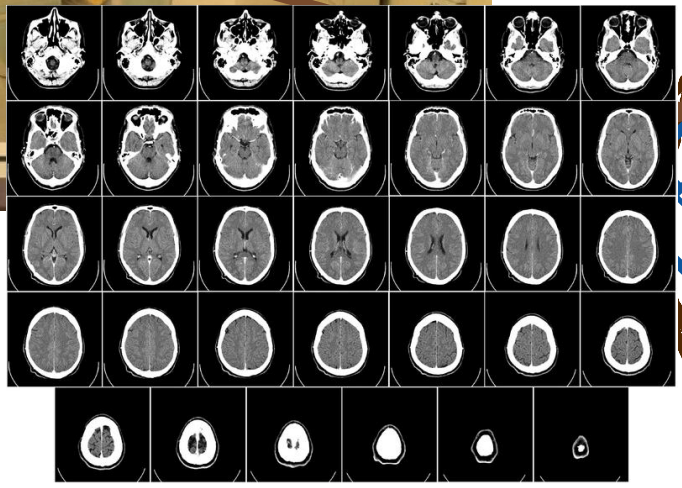
Temporal Multiplexing

Multiple Layers

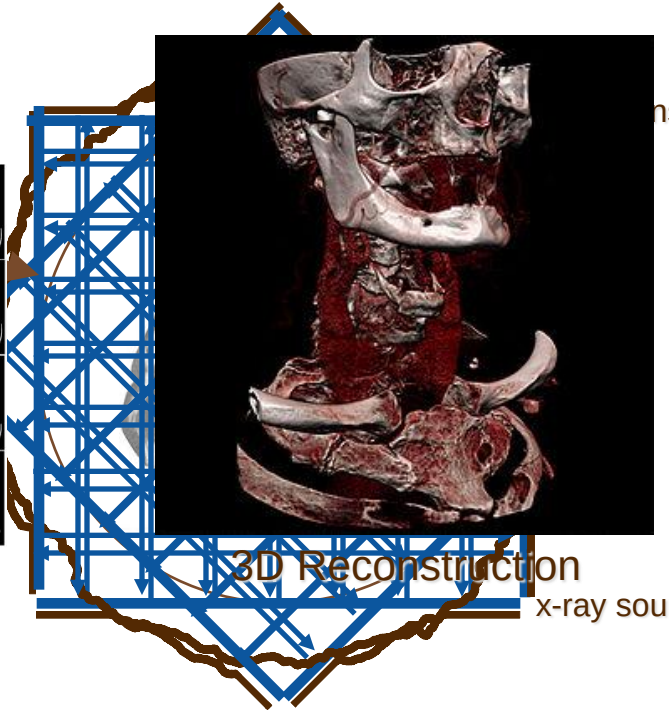
Computed Tomography (CT)



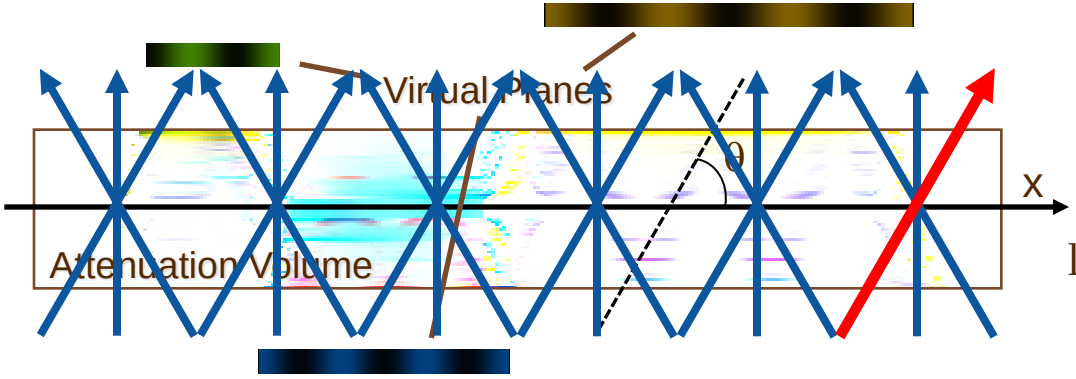
source: wikipedia



Reconstructed 2D Slices



Tomographic Light Field Synthesis



Backlight

2D Light Field

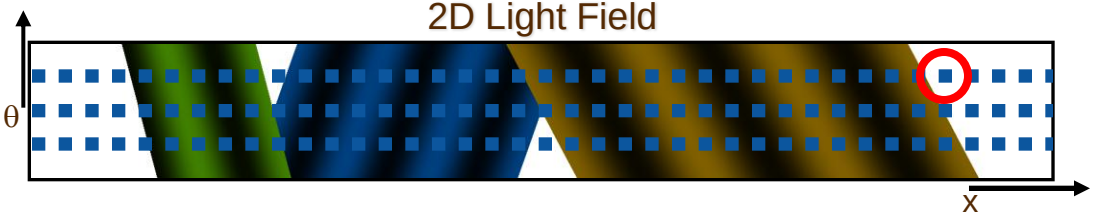


Image Formation

$$L(x,q) = e^{-\int_0 m(r)dr}$$

$$\log\left(L(x,\theta)\right) = -\int_c \mu(r)dr$$

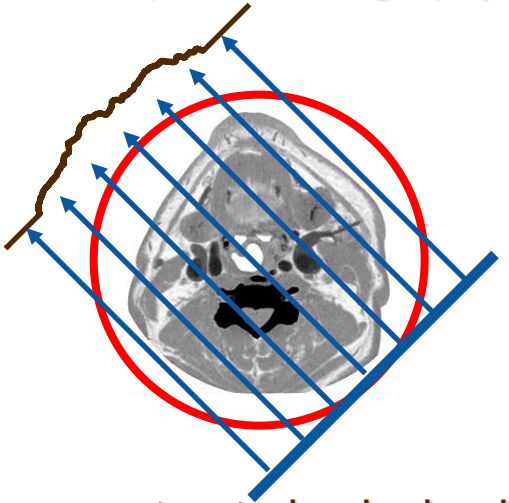
Tomographic Synthesis

$$\log(L) = -\mathrm{P}\mu$$

$$\underset{\mu \geq 0}{\operatorname{argmin}} \left\| \log(L) - \mathrm{P}\mu \right\|_2^2$$

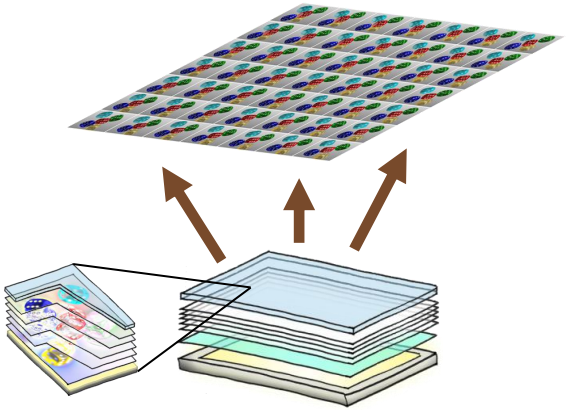
CT vs. Layered 3D

Computed Tomography



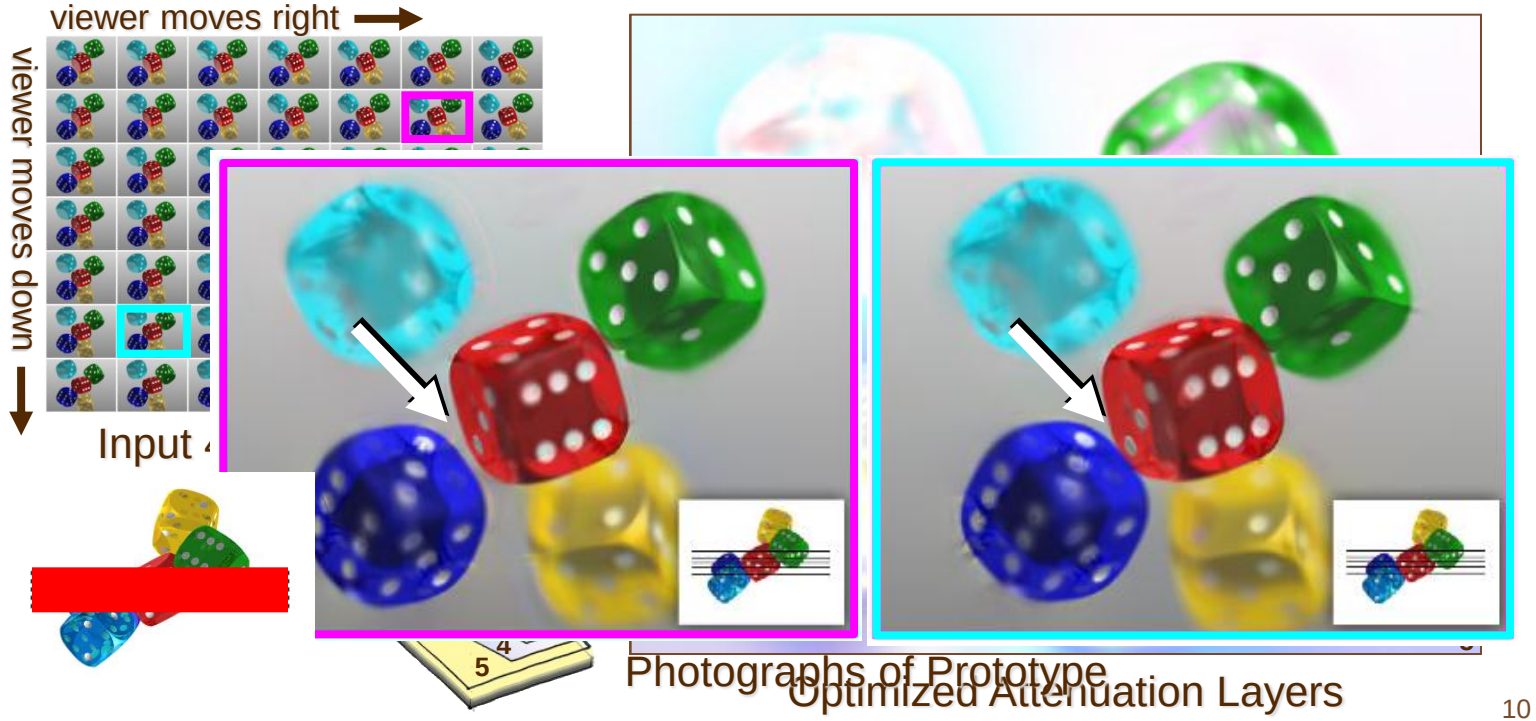
- reconstruct physical volume
- sensor noise

Layered 3D



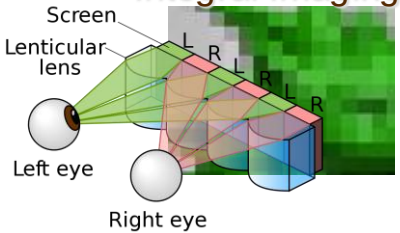
- thin stack of optimized layers
- no noise

Multi-Layer Decomposition

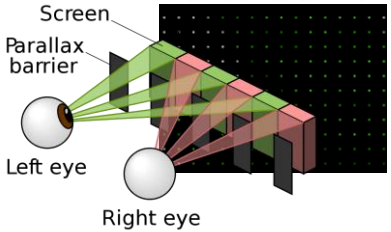


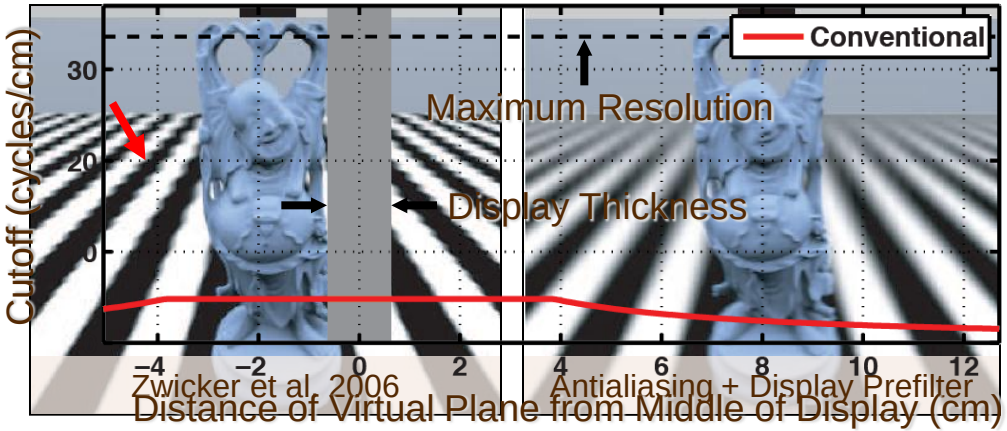
Depth of Field for 3D Displays

Integral Imaging



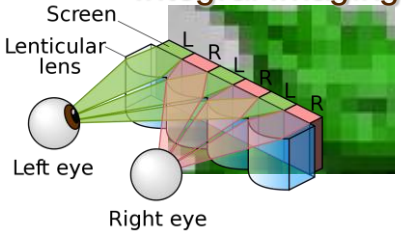
Parallax Barriers



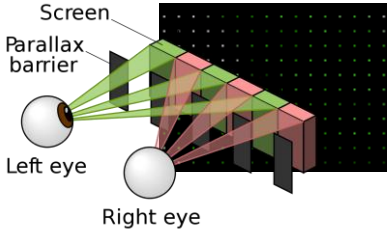


How Do Layers Increase Depth of Field?

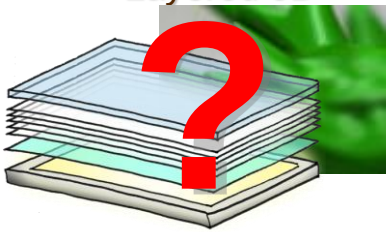
Integral Imaging

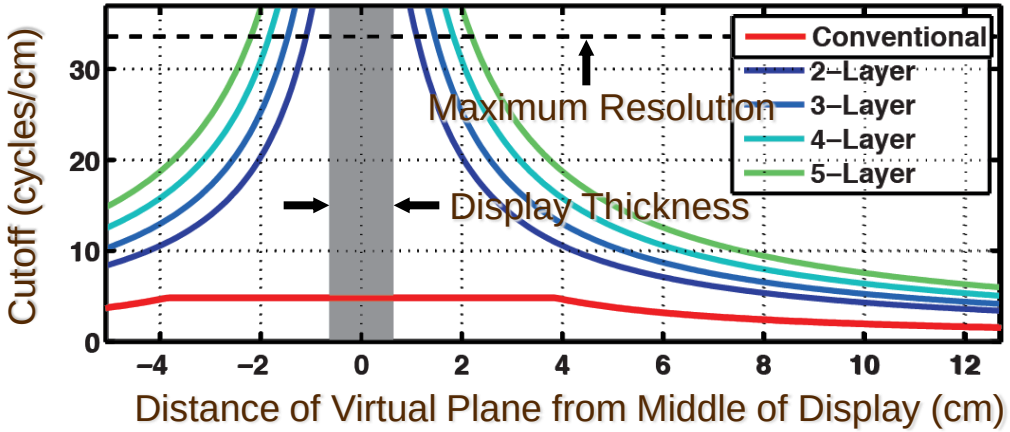


Parallax Barriers

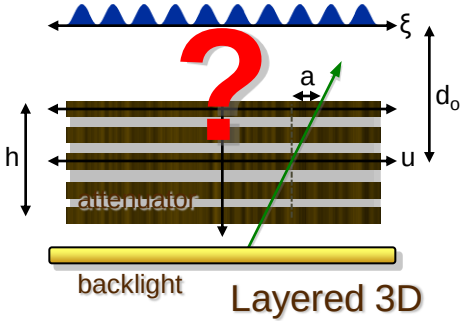


Layered 3D





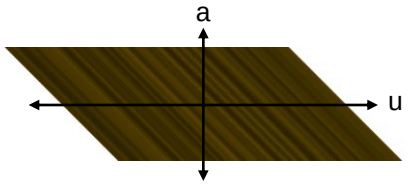
Review of Frequency-Domain Light Field Analysis



Layered 3D

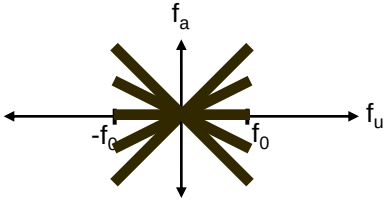
Chai et al. 2000; Durand et al. 2005;
Veeraraghavan et al. 2007;
Lanman et al. 2008; Ihrke et al. 2010

Light Field

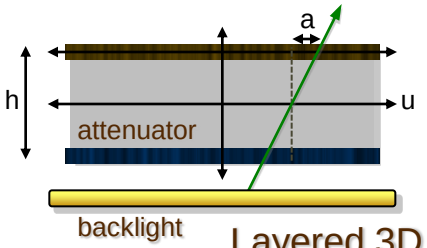


Fourier Transform

Light Field Spectral Support

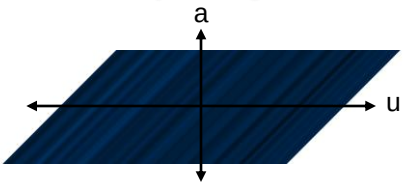


Multi-Layer Frequency-Domain Analysis

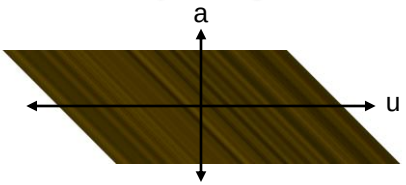


Layered 3D

Rear Layer Light Field

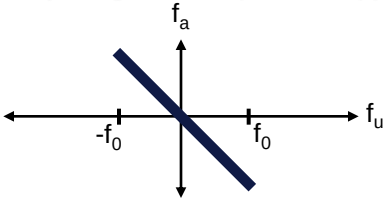


Front Layer Light Field

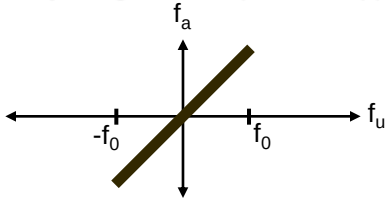


Fourier Transform

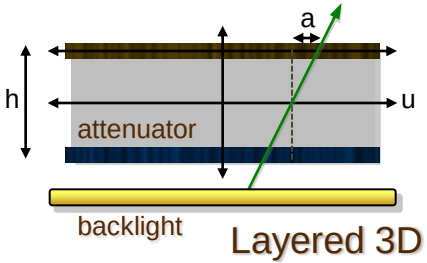
Rear Layer Light Field Spectral Support



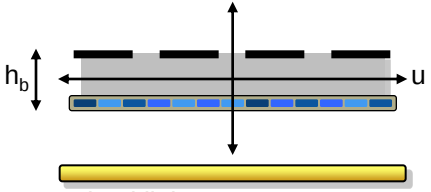
Front Layer Light Field Spectral Support



Multi-Layer Frequency-Domain Analysis

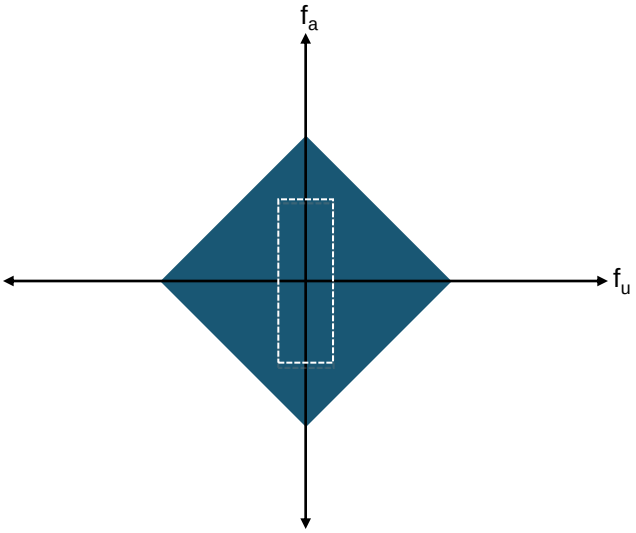


Layered 3D

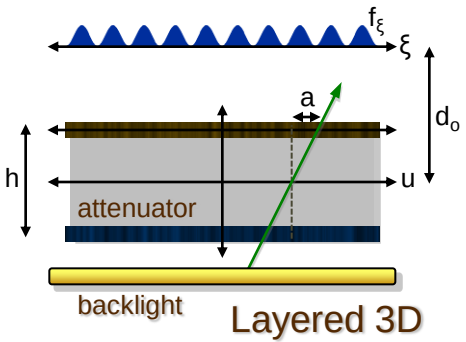


Parallax Barrier

Emitted Light Field Spectral Support

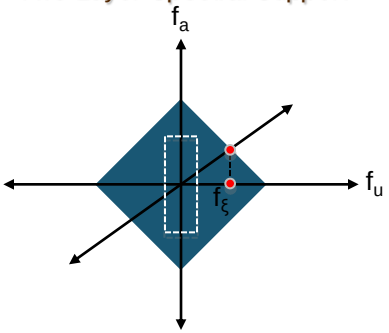


Multi-Layer Frequency-Domain Analysis



Layered 3D

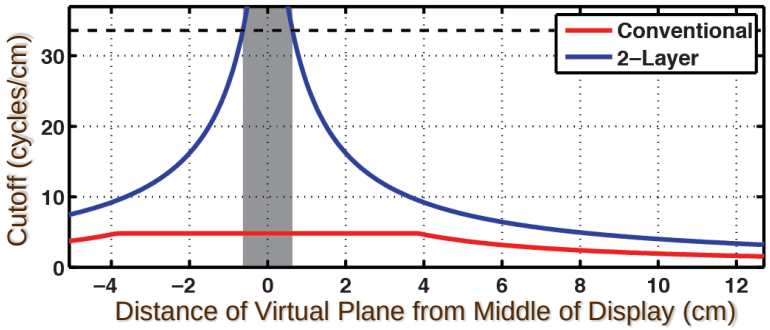
Two-Layer Spectral Support



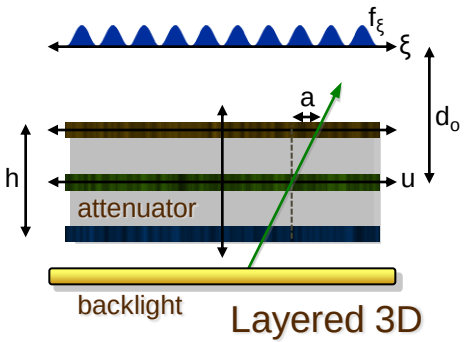
Two-Layer Depth of Field

$$|f_\xi| \leq \left(\frac{h}{(h/2) + |d_o|} \right) f_0$$

Depth of Field

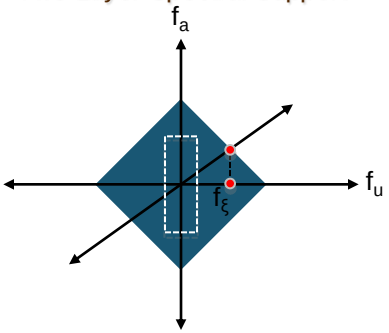


Multi-Layer Frequency-Domain Analysis

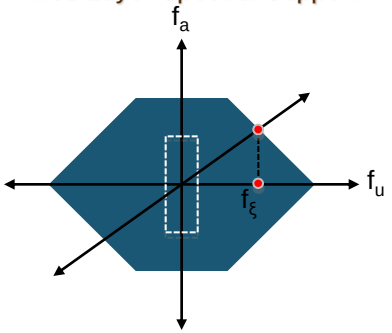


Layered 3D

Two-Layer Spectral Support



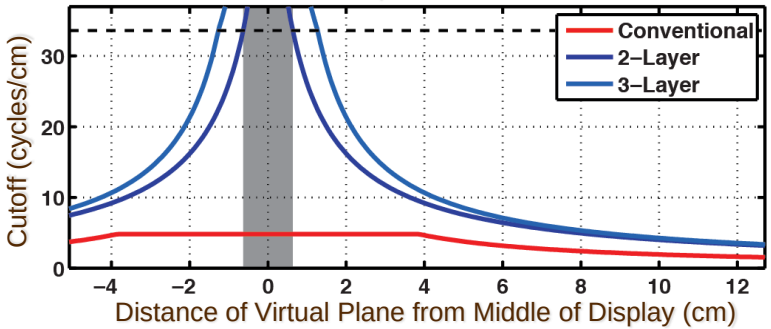
Three-Layer Spectral Support



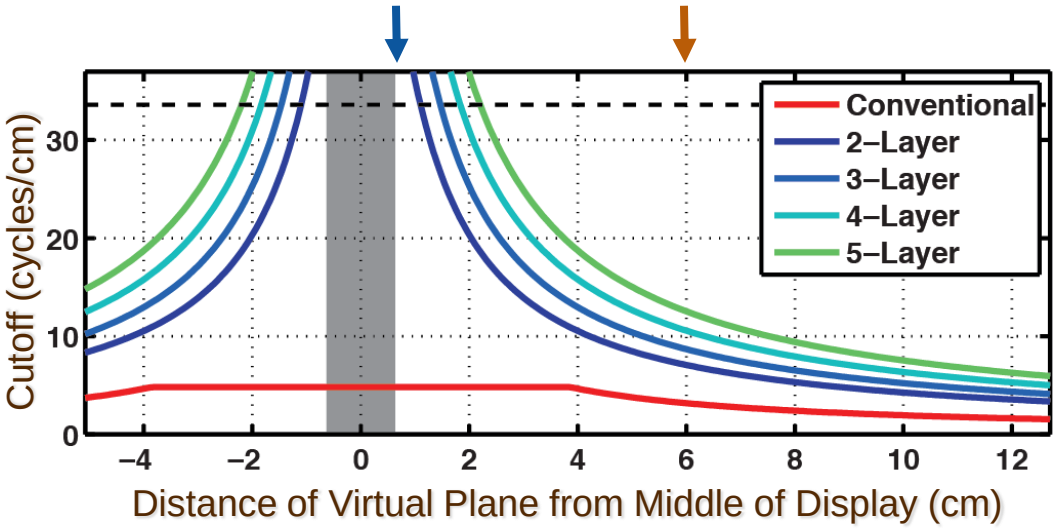
Three-Layer Depth of Field

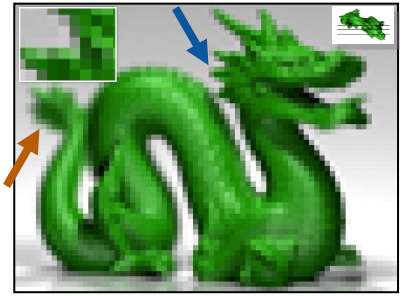
$$|f_\xi| \leq \begin{cases} \left(\frac{3h/2}{(h/2)+|d_o|}\right) f_0, & \text{for } |d_o| \leq h \\ \left(\frac{h}{|d_o|}\right) f_0, & \text{otherwise} \end{cases}$$

Depth of Field

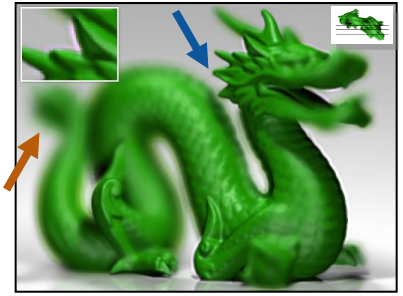


Multi-Layer Depth of Field





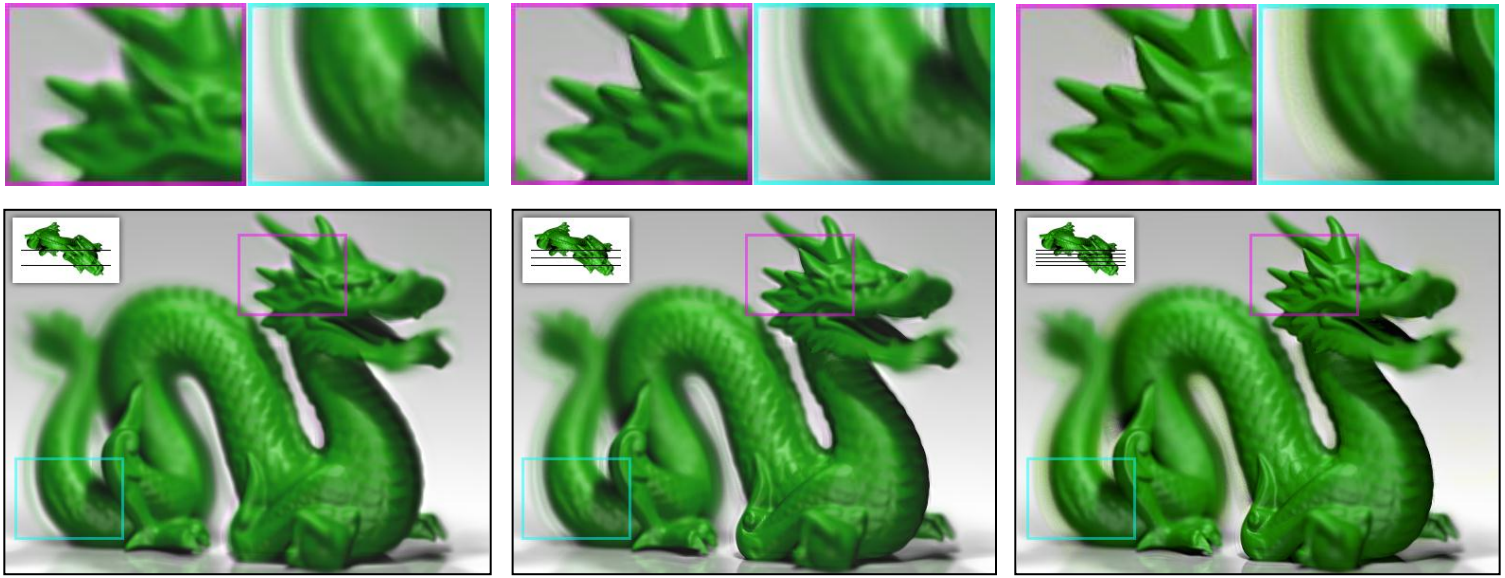
Conventional*



Layered 3D

*Includes integral imaging and parallax barriers

Optimization: Number of Layers

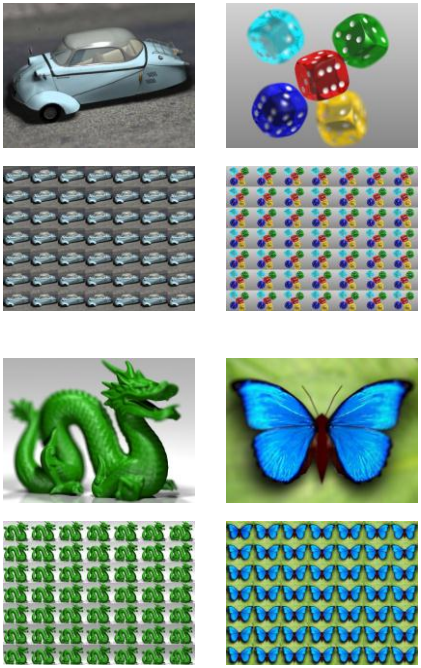


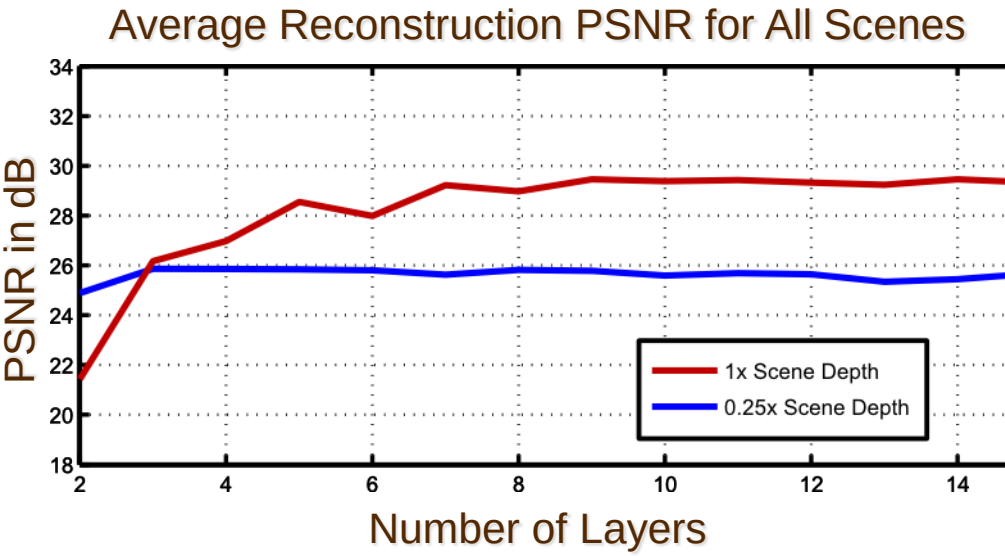
Two Layers

Three Layers

Five Layers

Optimization: Display Thickness





Application to HDR Display

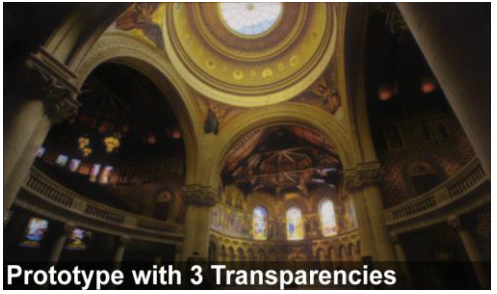
“Square Root” Layers

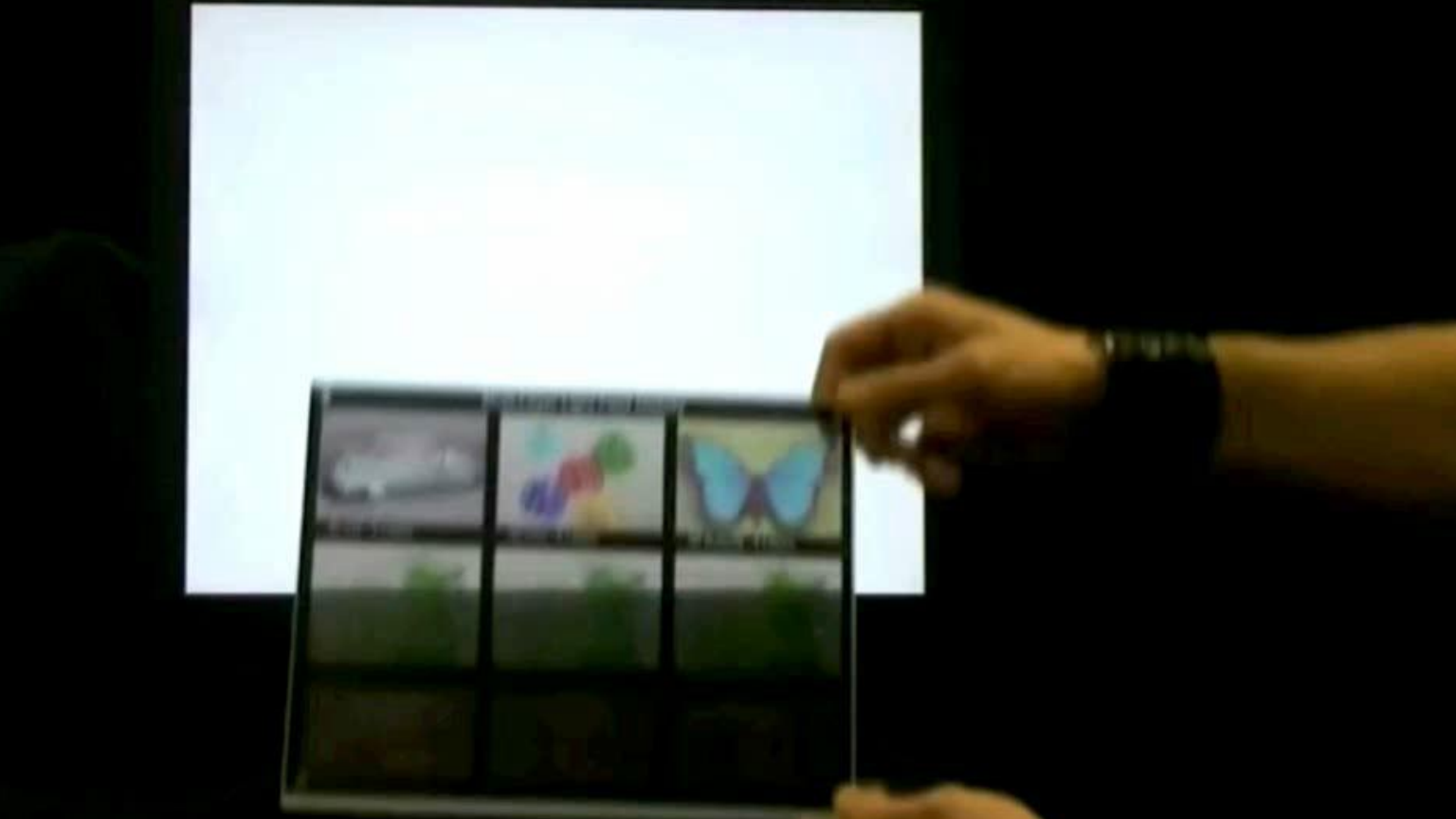
Application to HDR Display

"Square Root" Layers

Application to HDR Display

Optimized Layers





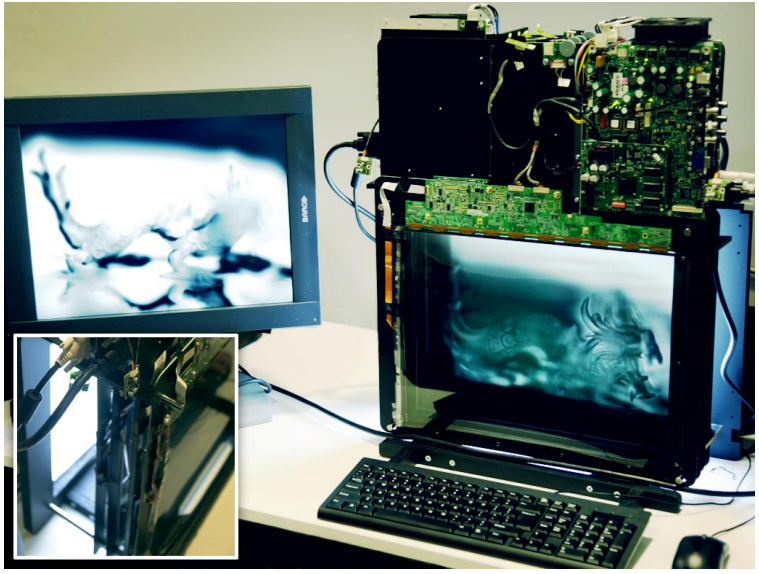
Limitations: Field of View

Personal Glasses-Free 3D Display

Challenges for dynamic display:

- Real-time computation
- Engineering issues, moiré

Dynamic Multi-Layer LCDs

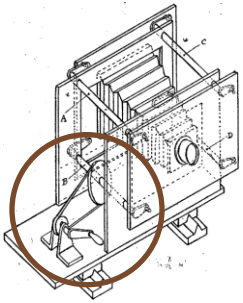


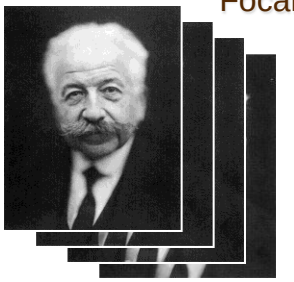
Dynamic Light Field Display using Multi-Layered LCDs, to appear in Siggraph Asia 2011

Douglas Lanman, Gordon Wetzstein, Matthew Hirsch, Wolfgang Heidrich, Ramesh Raskar

Louis Lumière 1920

Photo-stéréo-synthesis

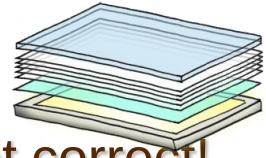




Focal Stack

Computational Photography

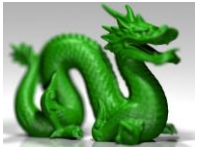
Computational Displays



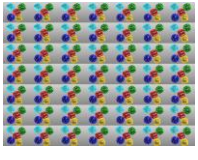
Layered
Transparencies

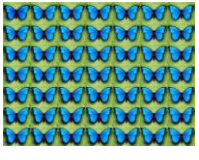
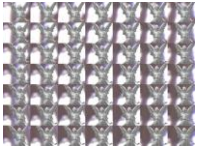
- 3D effect, but not correct!







Datasets, code & videos on the website!

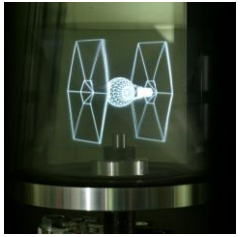
www.layered3d.com

SIGGRAPH 2011

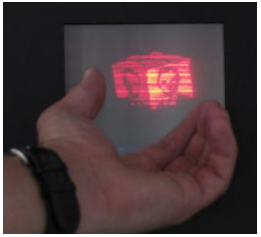
Glasses-Free 3D Display


LightSpace

Sony


Jones et al. 2007


Zebra Imaging


MIT Holovideo

Volumetric Displays

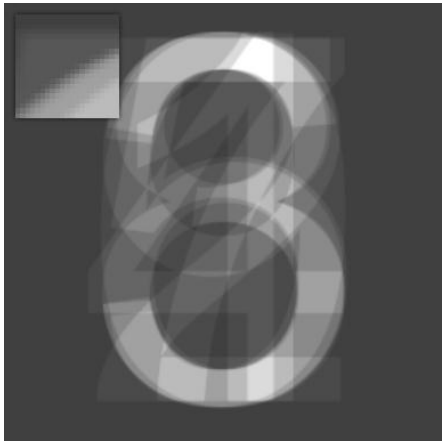
- all depicts freely inside enclosure
- computationally expensive
- moving parts

Layered 3D

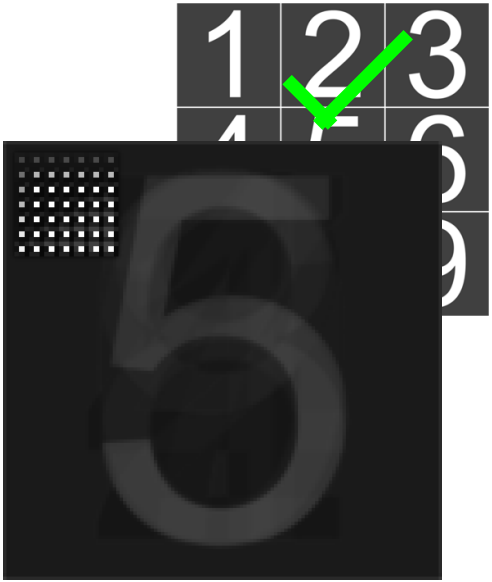
- 3D objects outside enclosure
- no moving parts
- computationally efficient

Limitations: “Flip Animations”

Parallax Barriers

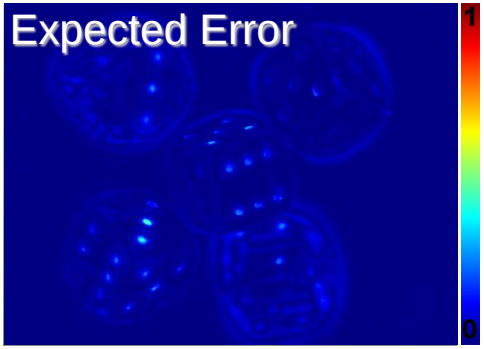


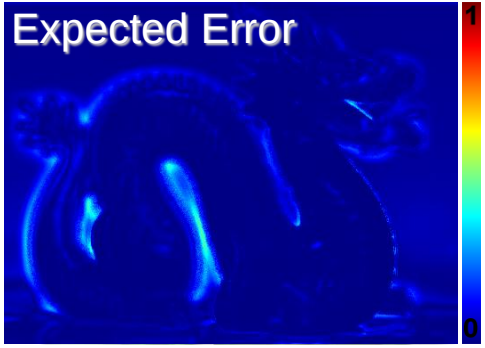
Multi-Layer
Full Resolution

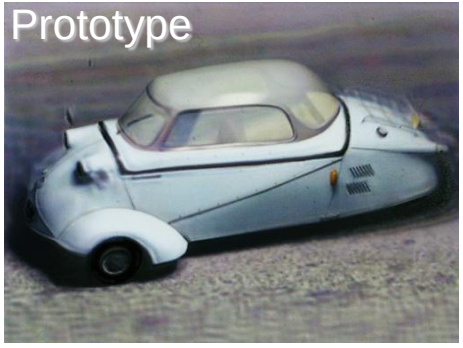


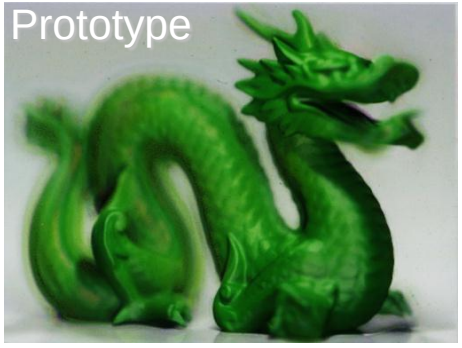
Multi-Layer
Reduced Resolution

Performance Assessment

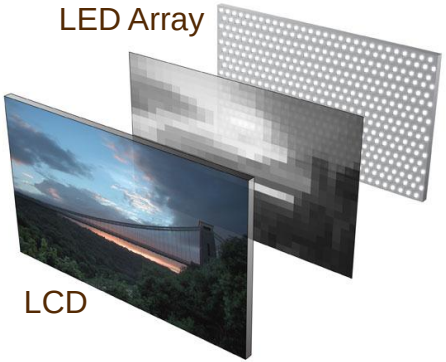




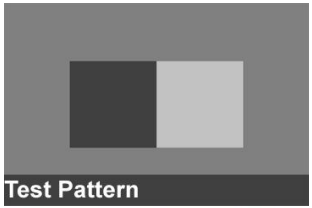


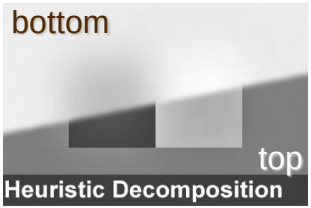


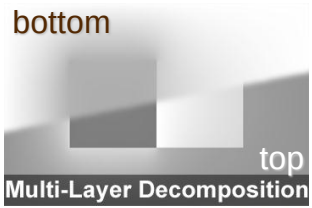
Application to HDR Display

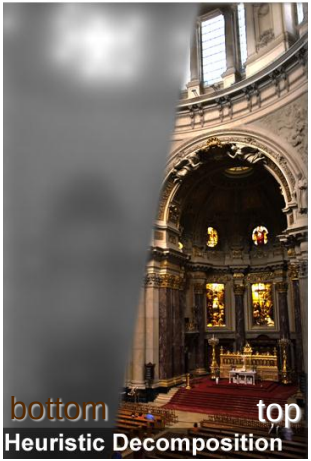


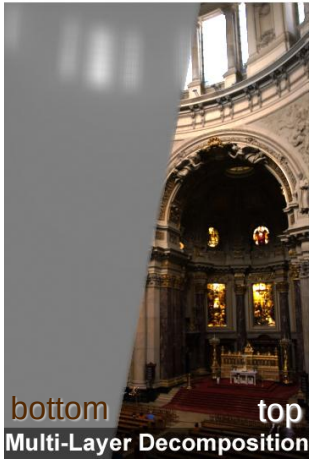
Seetzen 2004, Dolby Canada





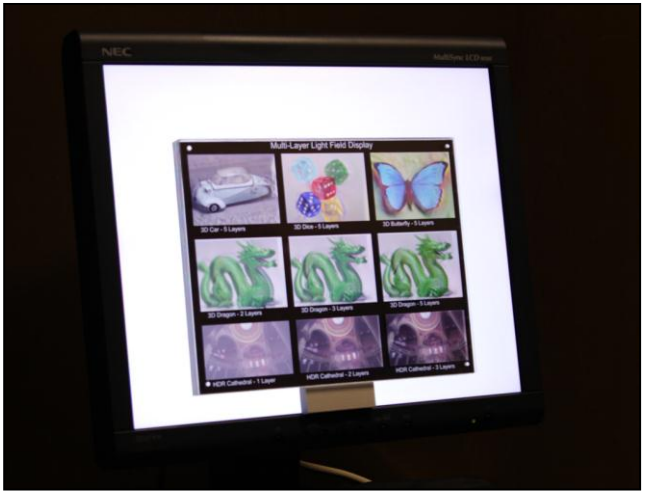






Implementation

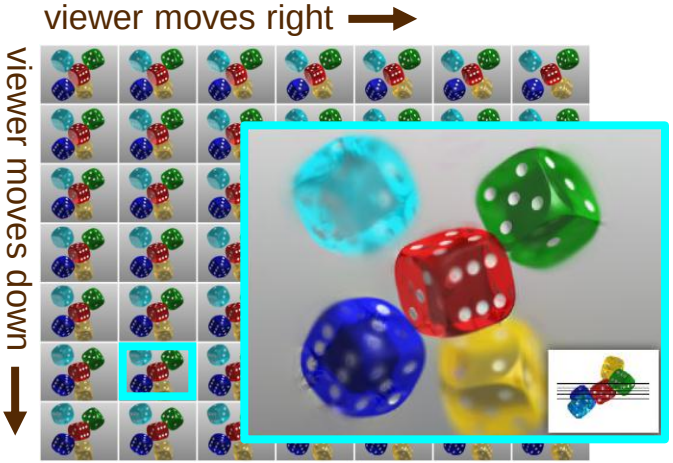
Transparencies and Acrylic Spacers

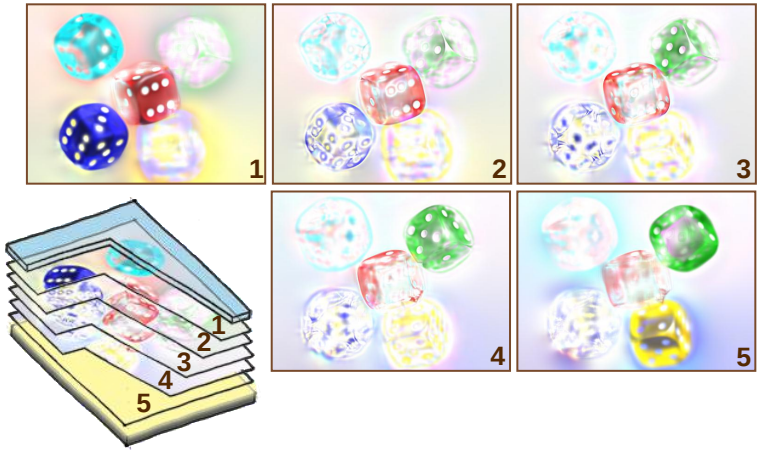


Prototype in Front of LCD (Backlight)

- Epson Stylus 2200 inkjet (300 dpi, six color primaries)
- 5 layers (5.7 × 7.6 cm),1.27 cm thickness, 10° field of view

Implementation: Software





- POV-Ray: 7 × 7 views (512 × 384 pixels), 10° field of view
  - Depth of field tuned for combined antialiasing and display prefilter
- MATLAB: LSQLIN (independently for each color channel)
- 12 minutes on 2.4 GHz Intel Core 2 with 8 GB RAM