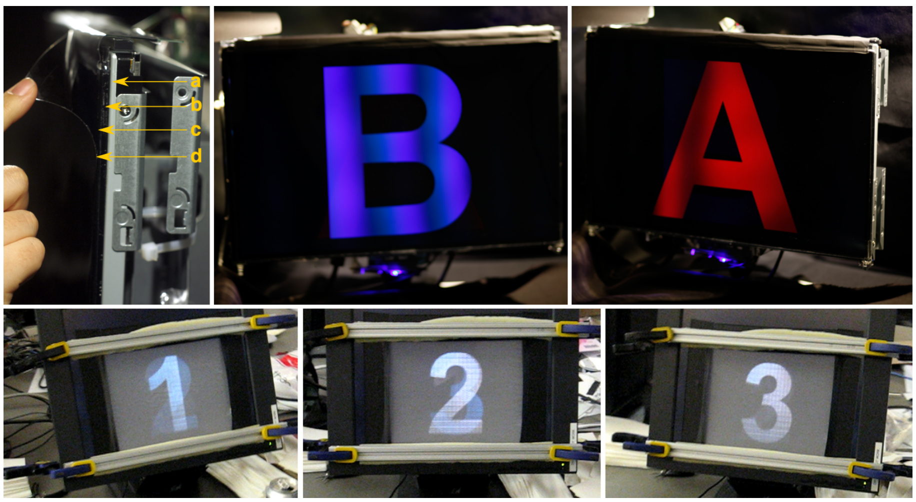
Build Your Own 3D Display



SIGGRAPH Asia 2010 Course Notes

Friday, December 17, 2010

Matthew Hirsch
MIT Media Lab
mhirsch@media.mit.edu

Douglas Lanman
MIT Media Lab
dlanman@media.mit.edu

SIGGRAPHASIA2010

Abstract

Commercial stereoscopic displays have reemerged in the consumer market within the last few years. Today, film studios routinely produce live-action and animated 3D content for theatrical release. While primarily enabled by the widespread adoption of digital projection, allowing accurate view synchronization, the underlying 3D display technologies have changed little in the last few decades. Theatrical systems rely on *stereoscopic display*: projecting a unique left/right image pair that is separated by various filters placed within a pair of glasses worn by each viewer. In contrast, several LCD manufactures are introducing *automultiscopic displays*: allowing view-dependent imagery to be perceived without the aide of special glasses. Given these developments, 3D display is poised for another resurgence.

This course is a hands-on introduction to 3D display and provides attendees with the mathematics, software, and practical details necessary to build their own low-cost stereoscopic displays. An example-driven approach is used throughout, with each new concept illustrated using a practical 3D display implemented with off-the-shelf parts. First, glasses-bound stereoscopic displays are explained. Detailed plans are provided for attendees to construct their own LCD shutter glasses. Next, unencumbered automultiscopic displays are explained, including step-by-step directions to construct lenticular and parallax barrier designs using modified LCDs. All the necessary software, including algorithms for rendering and calibration, is provided for each example, allowing attendees to quickly construct 3D displays for their own educational, amusement, and research purposes.

The course concludes by describing various methods for capturing, rendering, and viewing various multi-view imagery sources. Stereoscopic OpenGL support is reviewed, as well as methods for ray-tracing multi-view imagery with POV-Ray. Techniques for capturing "live-action" light fields are also outlined. Finally, recent developments are summarized, inspiring attendees to evolve the capabilities of their self-built 3D displays.

Prerequisites

Attendees should have hobbyist-level experience with do-it-yourself electronic projects. While executables are provided for beginners, attendees with prior knowledge of Matlab, C/C++, and OpenGL will be able to directly examine and modify the provided source code.

Speaker Biographies

Matthew Hirsch
MIT Media Lab
mhirsch@media.mit.edu
http://web.media.mit.edu/~mhirsch

Matthew Hirsch is a Ph.D. student at the MIT Media Lab. His research focuses on imaging devices that enable new understanding and interaction scenarios. He works with Henry Holtzman and Ramesh Raskar in the Information Ecology and Camera Culture groups, respectively. Matthew graduated from Tufts University in 2004 with a B.S. in Computer Engineering. He worked as an Imaging Engineer at Analogic Corp. from 2004 to 2007, where he designed threat detection algorithms for computed tomography security scanners. He presented the "Build Your Own 3D Display" course at SIGGRAPH 2010.

Douglas Lanman
MIT Media Lab
dlanman@media.mit.edu
http://web.media.mit.edu/~dlanman

Douglas Lanman is a Postdoctoral Associate at the MIT Media Lab. His research is focused on computational photography, particularly in the use of active illumination for 3D reconstruction and light field capture and display. 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 3D Scanner" course at SIGGRAPH 2009 and SIGGRAPH Asia 2009 and the "Build Your Own 3D Display" course at SIGGRAPH 2010.

Course Outline

10 minutes: Introduction: History and Physiology

Matthew Hirsch

This part will overview the course, review historical developments, and describe the physiology of depth perception. Random dot stereograms will be introduced to illustrate binocular disparity cues. Perceptual concerns, such as the hyperfocal distance and accommodation, will be described before the comprehensive review of display technologies in the following part.

15 minutes: Representation and Display

Douglas Lanman

This part will first describe how light fields model the set of rays emitted by 3D displays. Afterward, a 3D display taxonomy will be presented, emphasizing the division between glasses-bound stereoscopic displays and unencumbered automultiscopic displays.

20 minutes: Glasses-bound Stereoscopic Displays

Matthew Hirsch

This part will describe stereoscopic display methods that require the use of special eyewear, including:

- color filters (anaglyph images)
- linear/circular polarizers (including dual-projectors)
- LCD shutter glasses (temporal multiplexing)
- head-mounted displays

Detailed plans, including a parts list and circuit schematics, will be provided so attendees can build their own LCD shutter glasses.

20 minutes: Unencumbered Automultiscopic Displays

Douglas Lanman

This part will describe automultiscopic display methods that do not require special eyewear, including:

- integral imaging with lenticular and fly's eye arrays
- static and dynamic parallax barriers

The projects in this part involve modifying off-the-shelf LCDs to implement various 3D displays. Practical construction details and calibration and rendering software will be provided for each device. The procedure to construct a static parallax barrier, using a single LCD and a printed mask, will be described first. Next, an improved dynamic parallax barrier will be described. This project will require disassembling an LCD so that the spatial light modulator can be used separately from the backlight. Attendees will learn how to construct a dual-stacked LCD, capable of producing left/right image pairs for viewing with linearly-polarized glasses. Finally, an improved dynamic parallax barrier, where the barrier is shifted over time, will be built using the dual-stacked LCD.

10 minutes: Source Material: Rendering and Capture

Matthew Hirsch

This part will describe how to generate multi-view content (i.e., light fields) for use with the displays constructed in prior parts. Topics to be covered, include:

- light field capture (e.g., translated cameras and stereo rigs)
- stereoscopic support in OpenGL
- light field rendering (e.g., modification to POV-Ray)
- commercial and open source materials (e.g., 3D Blu-ray)

Software details, such as rendering parallax barrier base images, will be covered in earlier parts; this part will emphasize general methods for acquiring multi-view imagery.

10 minutes: Emerging Technology

Douglas Lanman

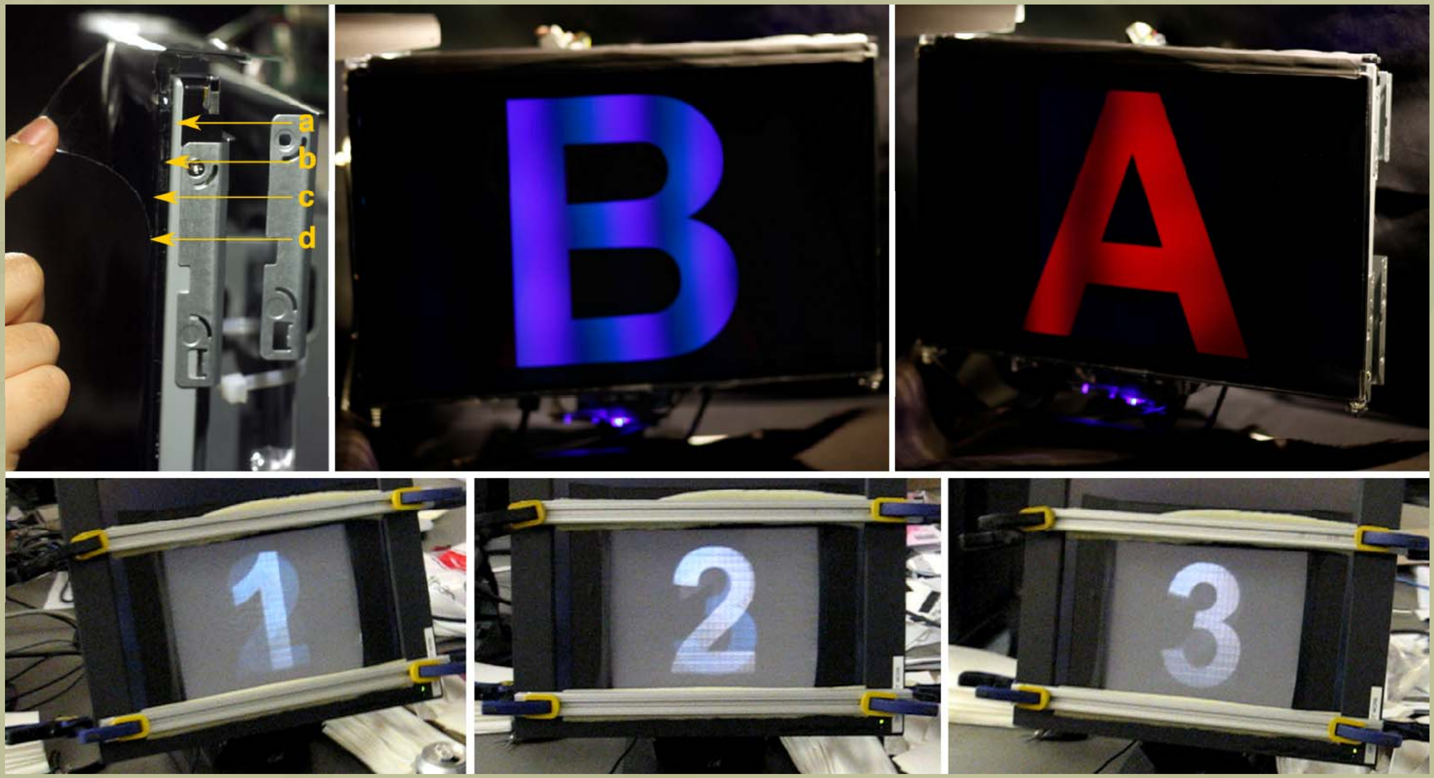
This part will review recent commercial and academic methods, including those from prior SIGGRAPH and SIGGRAPH Asia proceedings.

5 minutes: Q & A

Matthew Hirsch and Douglas Lanman

Attendees will be invited to view the prototype hardware.

Build Your Own 3D Display



Matthew Hirsch **Douglas Lanman**

MIT Media Lab

SIGGRAPH Asia 2010

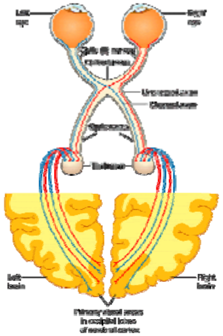
Friday, 17 December, 4:15 PM – 6:00 PM

Course Outline

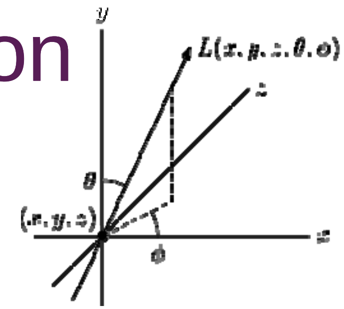
- ***Introduction: History and Physiology***
- Representation and Display
- Glasses-bound Stereoscopic Displays
- Unencumbered Automultiscopic Displays
- Source Material: Rendering and Capture
- Emerging Technology
- Conclusion and Q & A

Goals of the Course

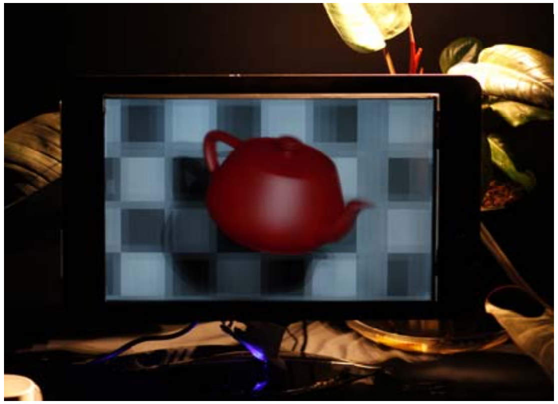
- Understand how the human visual system (HVS) perceives depth (and how to trick it)



- Understand light field representation and application to 3D display



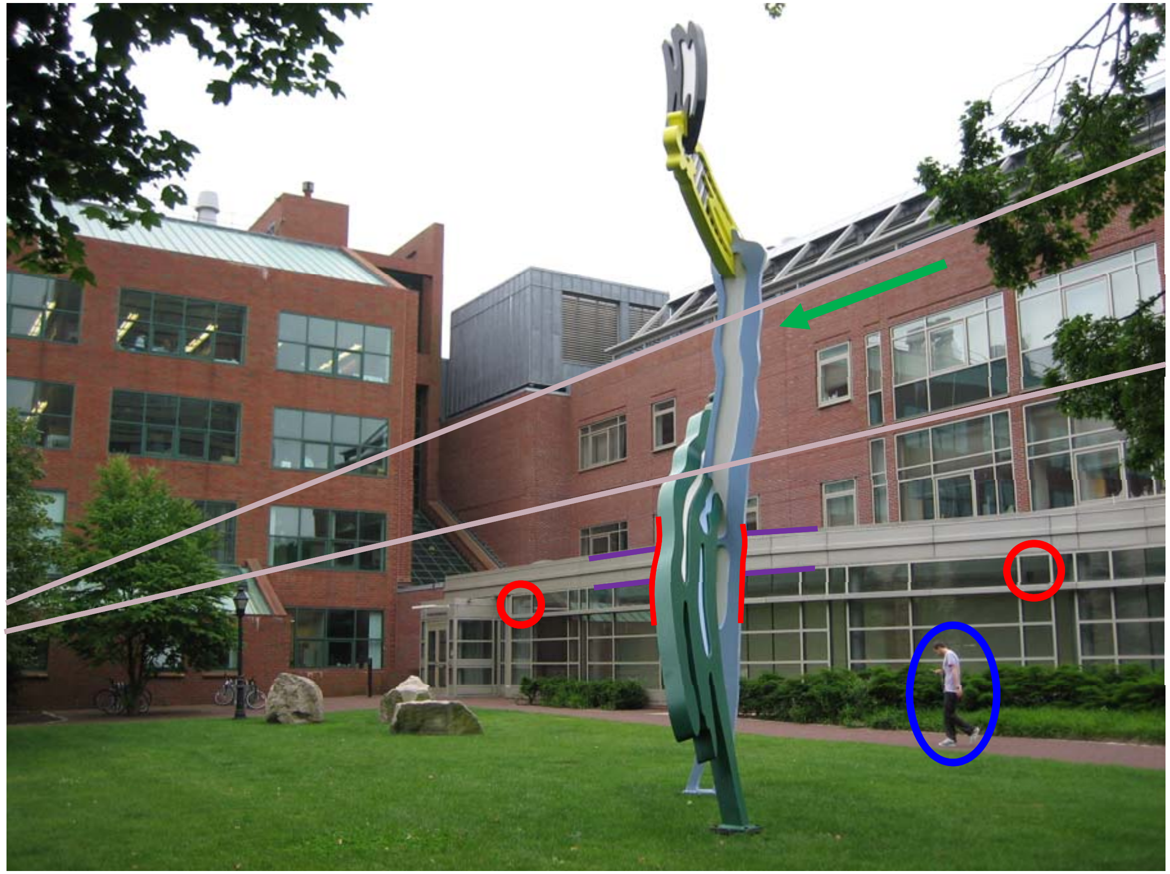
- Be able to use and modify off-the-shelf hardware to perform optics experiments and to create 3D display devices



Course Outline

- ***Introduction: History and Physiology***
  - ***Physiology***
  - History
- Representation and Display
- Glasses-bound Stereoscopic Displays
- Unencumbered Automultiscopic Displays
- Source Material: Rendering and Capture
- Emerging Technology
- Conclusion and Q & A

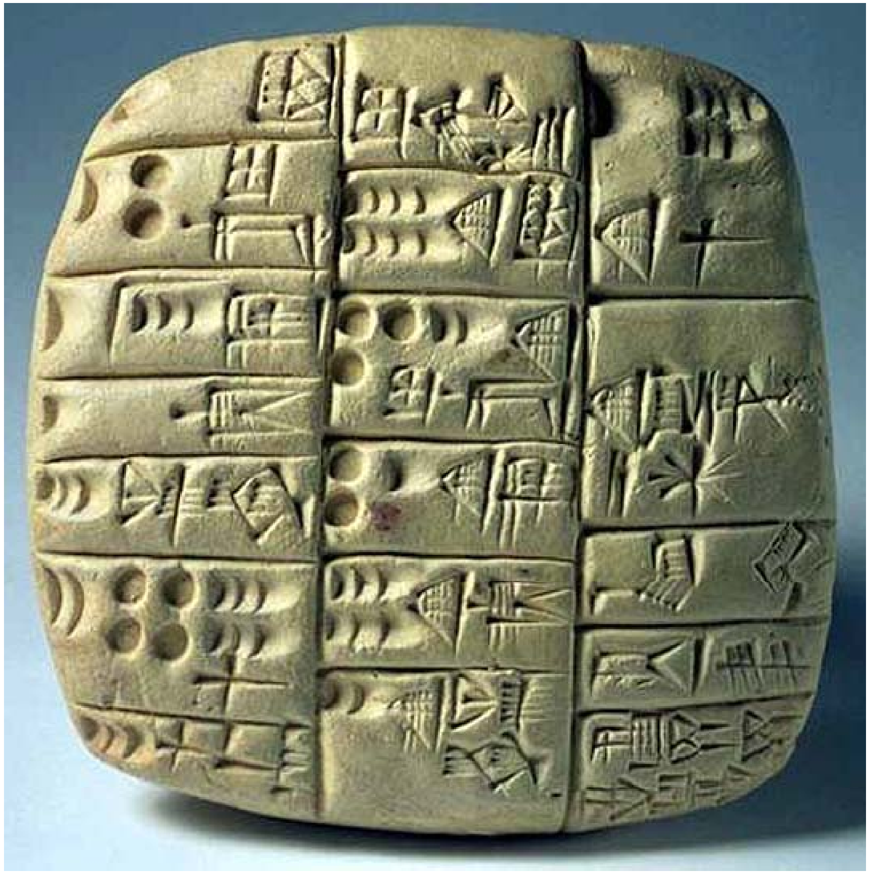
Limitations of Conventional Displays



Monocular Depth Cues Supported by Conventional Displays

- relative and familiar size
- perspective and occlusion
- texture gradient, shading and lighting, atmospheric effects

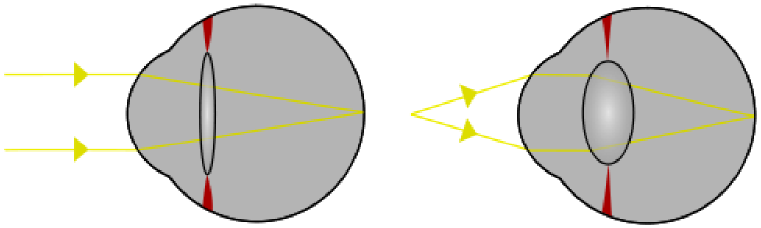
Limitations of Conventional Displays



Monocular Depth Cues with Conventional Displays

- relative and familiar size
- perspective and occlusion
- texture gradient, shading and lighting, atmospheric effects

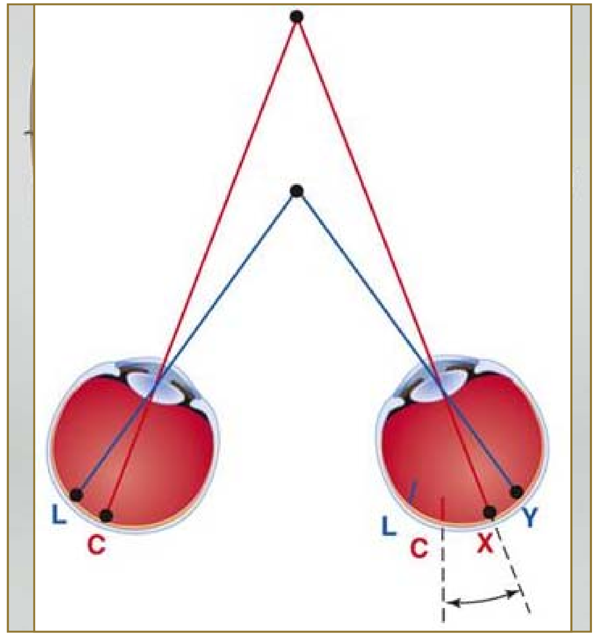
What is missing?



Additional Monocular Depth Cues

- motion parallax [Hermann von Helmholtz, 1866]
- accommodation

Binocular Depth Cues



THE HOLMES STEREOSCOPE,
With the Inventions and Improvements added by
JOSEPH L. BATES,
129 Washington Street, Boston.

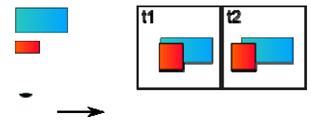
"It being thus established that the mind perceives an object of three dimensions by means of the two dissimilar pictures projected by it on the two retinae, the following question occurs: What would be the visual effect of simultaneously presenting to each eye, instead of the object itself, its projection on a plane surface as it appears to that eye?"

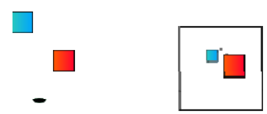
Binocular Depth Cues

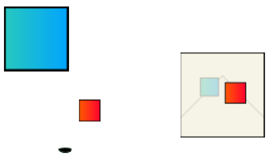
- retinal disparity [Charles Wheatstone, 1838]
- convergence

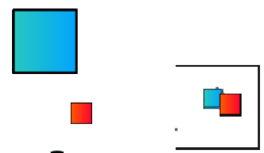
Physiology of Depth Perception

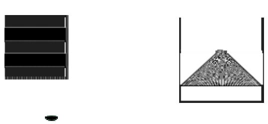
- Monocular Cues
  - Motion Parallax
  - Perspective
  - Relative Size
  - Atmospheric Effects
  - Occlusion
  - Texture
  - Shading/Lighting







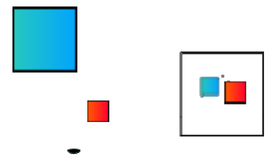




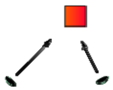
Also sometimes called psychological cues, these effects can be captured by a monocular camera and perceived by a viewer of a traditional screen.

Physiology of Depth Perception

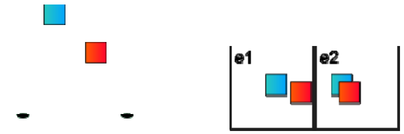
- Another Monocular Cue
  - Accommodation



- Binocular Cues
  - Convergence



  - Stereopsis



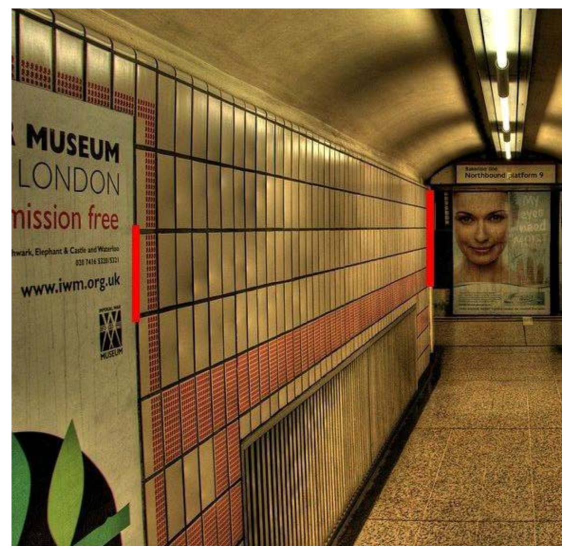
    - This is the cue added by 3D displays covered in this course
    - The brain determines depth by observing the scene disparity between two viewpoints
    - Can simulate this depth cue by multiplexing a different synthetic image to each eye

These effects are due to physical functions of the eye, and not interpretation of the scene

Conflicting Cues

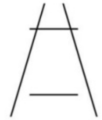
- The HVS can ignore conflicting or missing depth cues
- Understand depth in 2D (monocular) video
- Perceive shape in “noise”

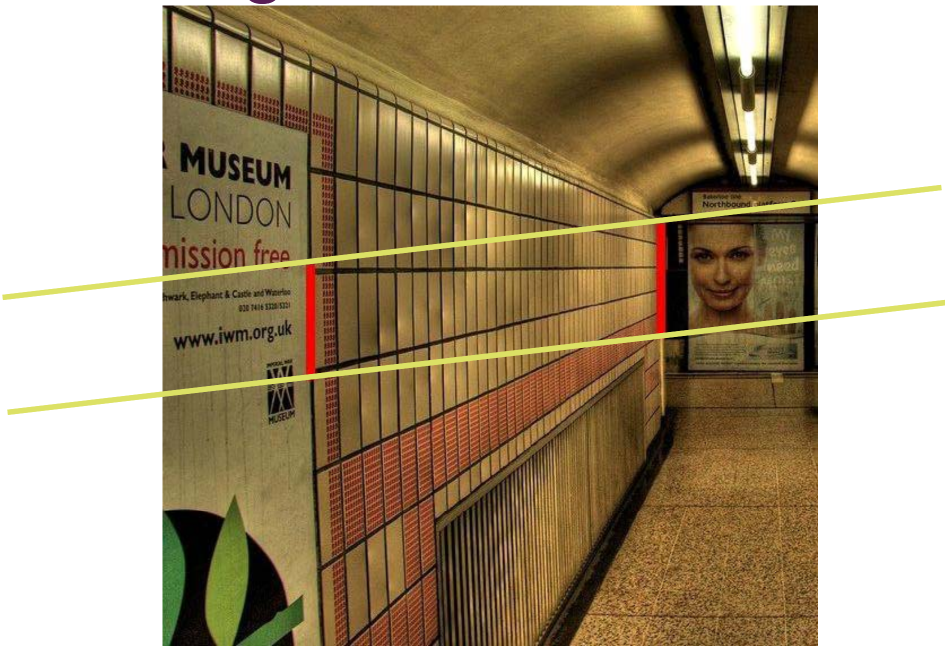
magiceye.com

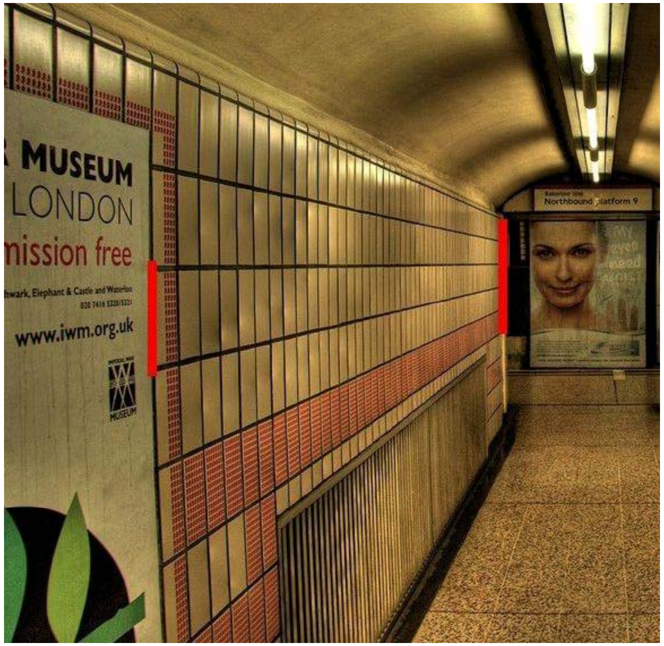


Ponzo Illusion: © Walt Anthony 2006

Conflicting Cues: Missing Binocular

- Ponzo Illusion 
- We perceive depth without binocular cues
- Depth perception changes perception of line length





Conflicting Cues: Only Binocular

- Random Dot Stereograms

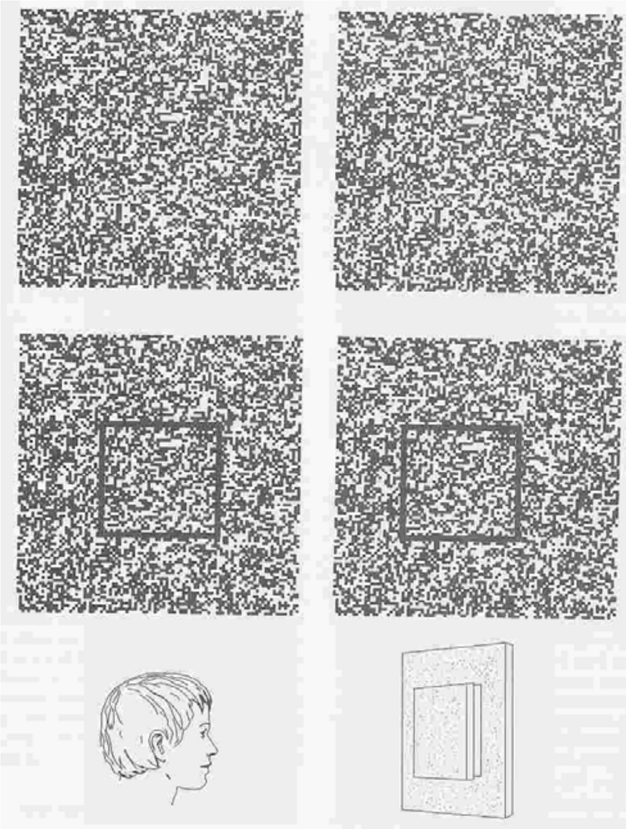
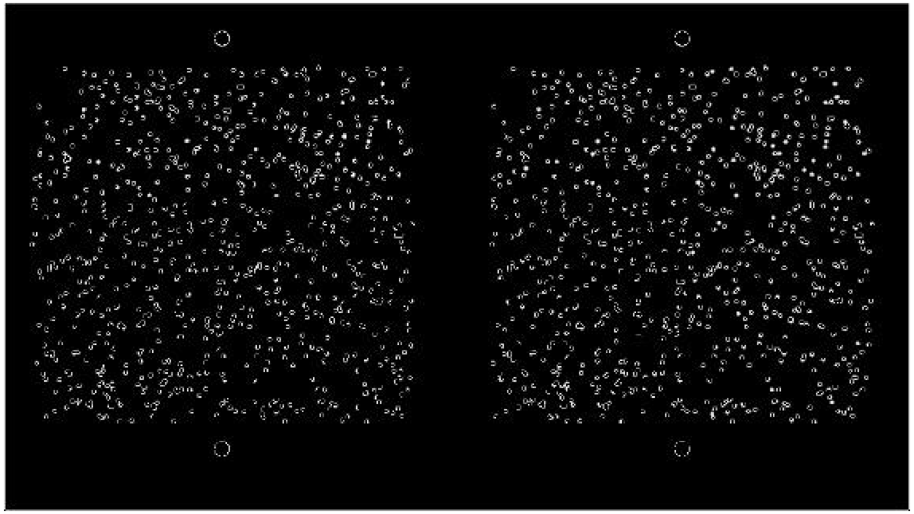


FIGURE 8.13

Bela Julesz



Violating Accommodation Cues

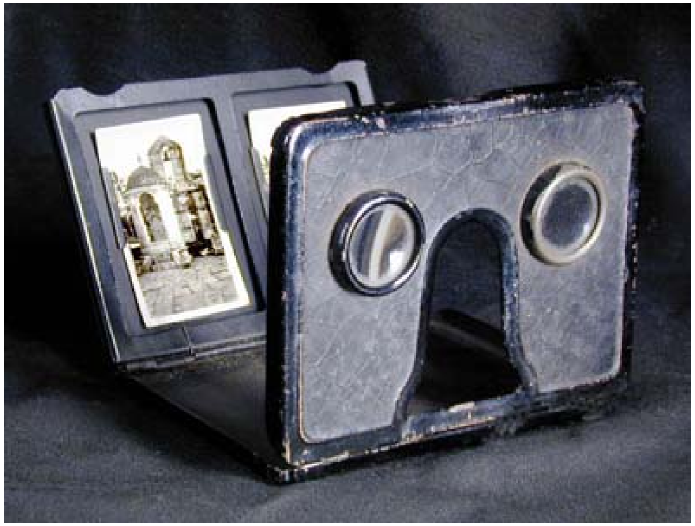
- All presented displays do this
- Possibly leads to fatigue over time

Course Outline

- ***Introduction: History and Physiology***
  - Physiology
  - ***History***
- Representation and Display
- Glasses-bound Stereoscopic Displays
- Unencumbered Automultiscopic Displays
- Source Material: Rendering and Capture
- Emerging Technology
- Conclusion and Q & A

Early History

- 1838 Wheatstone Stereoscopes
  - 1848 Brewseter
  - 1881 Popularized by Oliver Wendell Holmes
- 1853 Earliest Anaglyph photographs

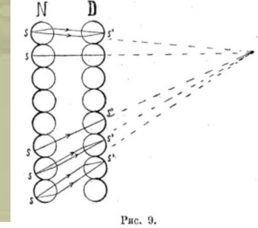


http://courses.ncssm.edu/gallery/collections/toys/html/exhibit01.htm

Viewmaster
1939-Today Equivalent

Leonardo DaVinci had realized that two images would be needed for stereo viewing, but never created a 3D painting

20th Century



- 1908 Lippmann, Integral Imaging, Lenticular Printing
- 1934 Polarizing Glasses (two synchronized projectors)
- 1950s Anaglyph and polarizing glasses popular to counter rise of television

Course Outline

- Introduction: History and Physiology
- ***Representation and Display***
- Glasses-bound Stereoscopic Displays
- Unencumbered Automultiscopic Displays
- Source Material: Rendering and Capture
- Emerging Technology
- Conclusion and Q & A

Course Outline

- Introduction: History and Physiology
- ***Representation and Display***
- Glasses-bound Stereoscopic Displays
- Unencumbered Automultiscopic Displays
- Source Material: Rendering and Capture
- Emerging Technology
- Conclusion and Q & A

Taxonomy of 3D Displays:
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 adapted from Hong Hua

Taxonomy of 3D Displays:
Immersive Head-mounted Displays (HMDs)

Glasses-bound Stereoscopic

Head-mounted
(eyepiece-objective and microdisplay)

Immersive
(blocks direct-viewing of real world)

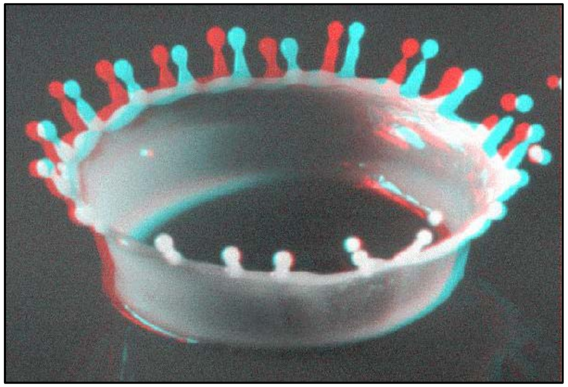
Multiplexed
(stereo pair with same display surface)

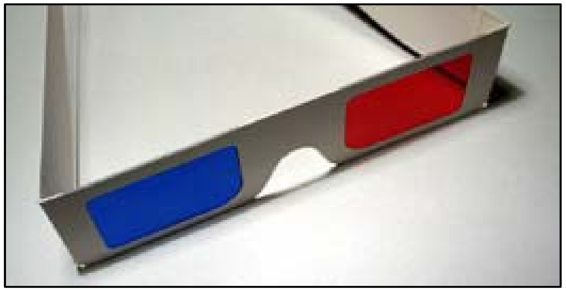
Taxonomy of 3D Displays:
See-through Head-mounted Displays (HMDs)

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)

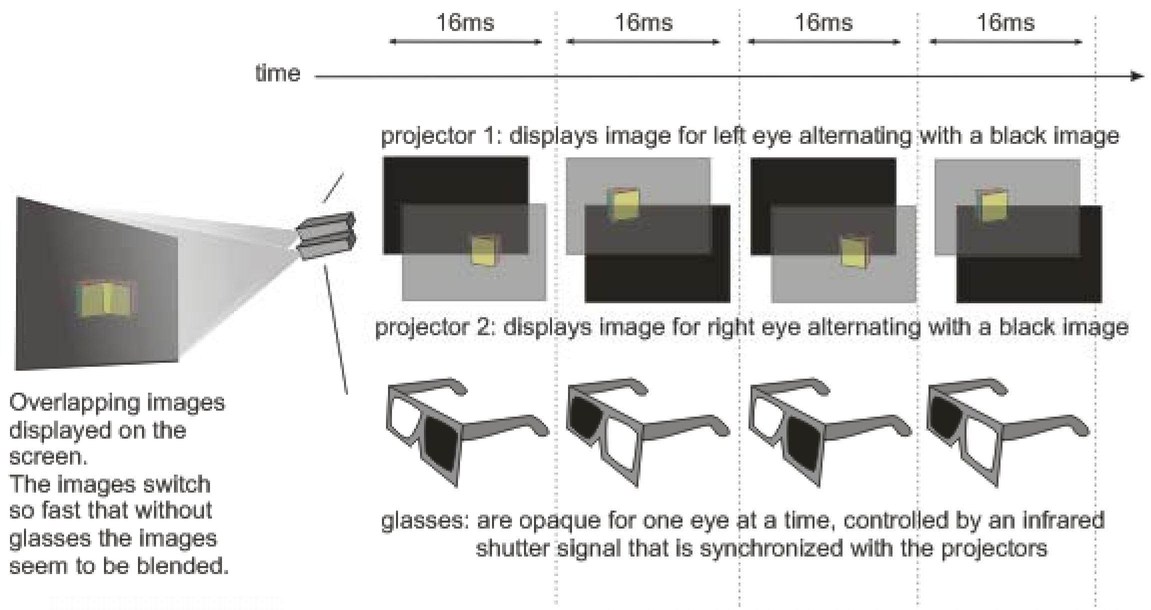
Taxonomy of 3D Displays:
Spatial Multiplexing (e.g., Anaglyphs)





- **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, etc.)

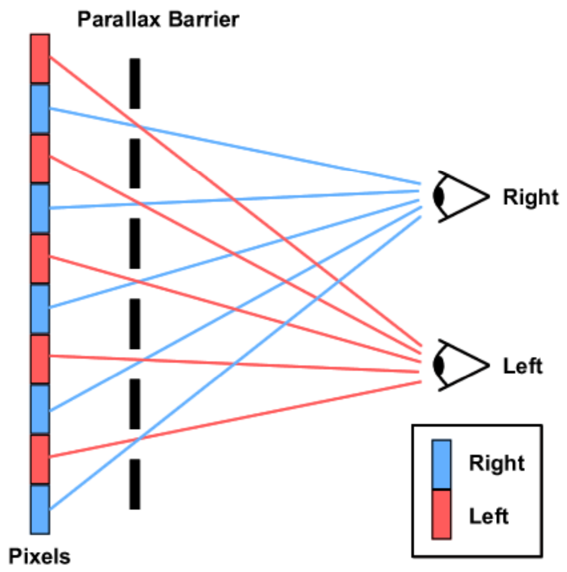
Taxonomy of 3D Displays:
Temporal Multiplexing (e.g., Shutter Glasses)



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)

Taxonomy of 3D Displays:
Parallax Barriers



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

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

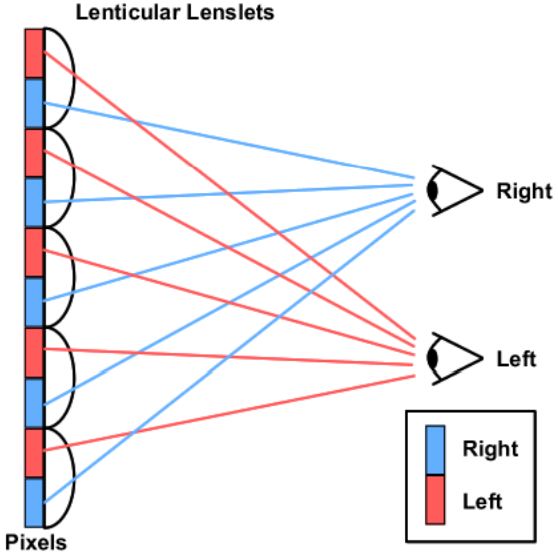
Parallax-based
(2D display with light-directing elements)

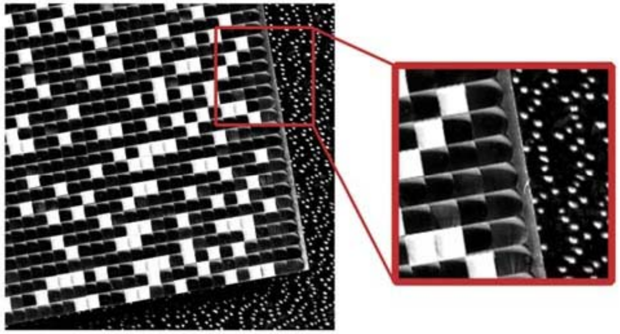
Unencumbered Automultiscopic

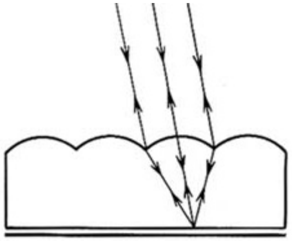
Volumetric
(directly illuminate points within a volume)

Holographic
(reconstructs wavefront using 2D element)

Taxonomy of 3D Displays:
Integral Imaging





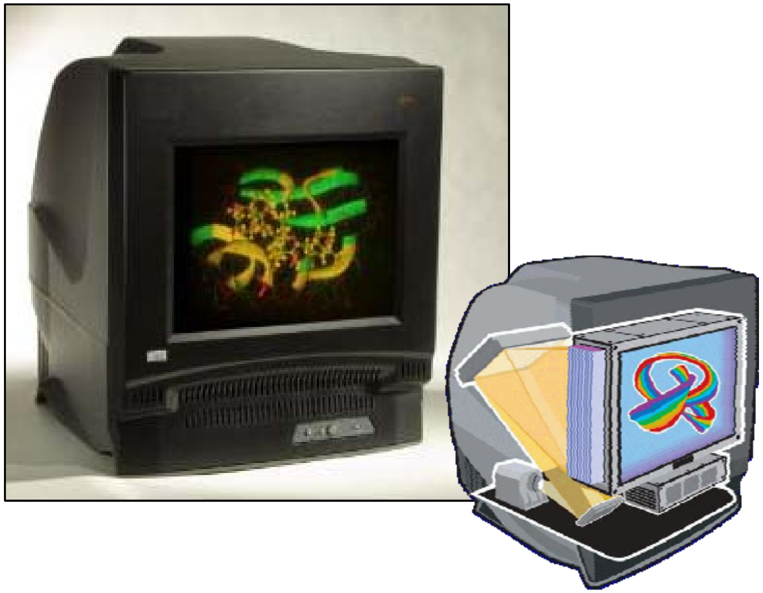


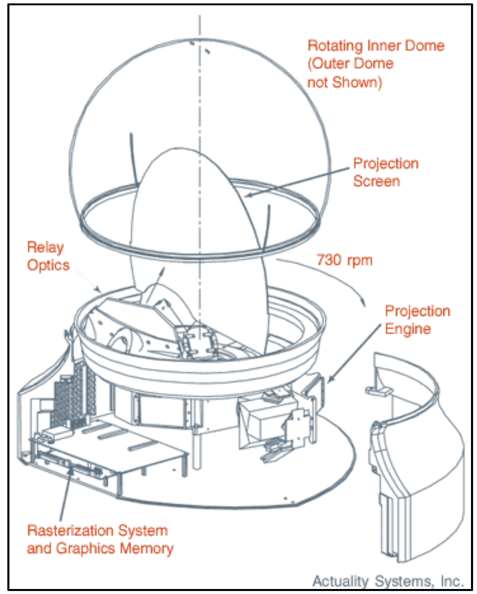
Alioscopy 3DHD 42"
(1920x1200, 1x8 views)

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

Taxonomy of 3D Displays:
Multi-planar Volumetric Displays

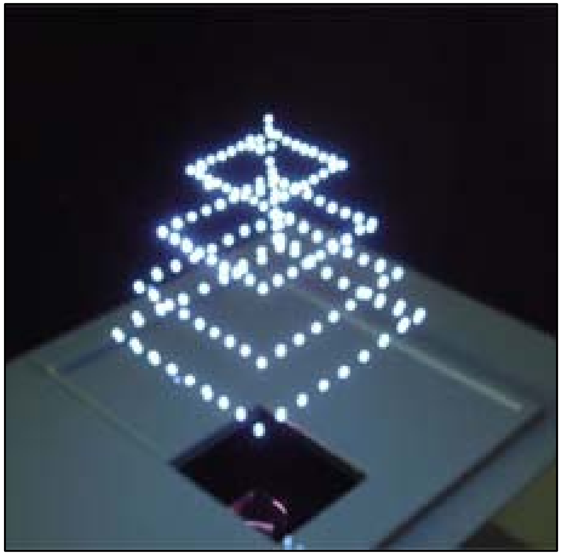


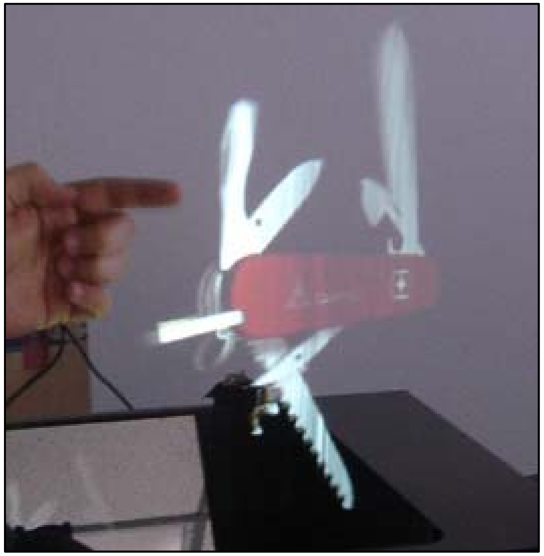


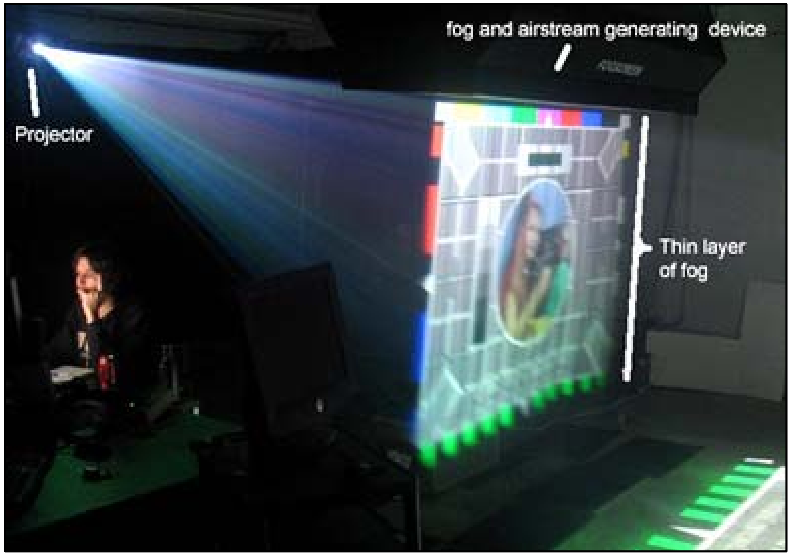
Unencumbered Automultiscopic

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

Taxonomy of 3D Displays:
Transparent-substrate Volumetric Displays



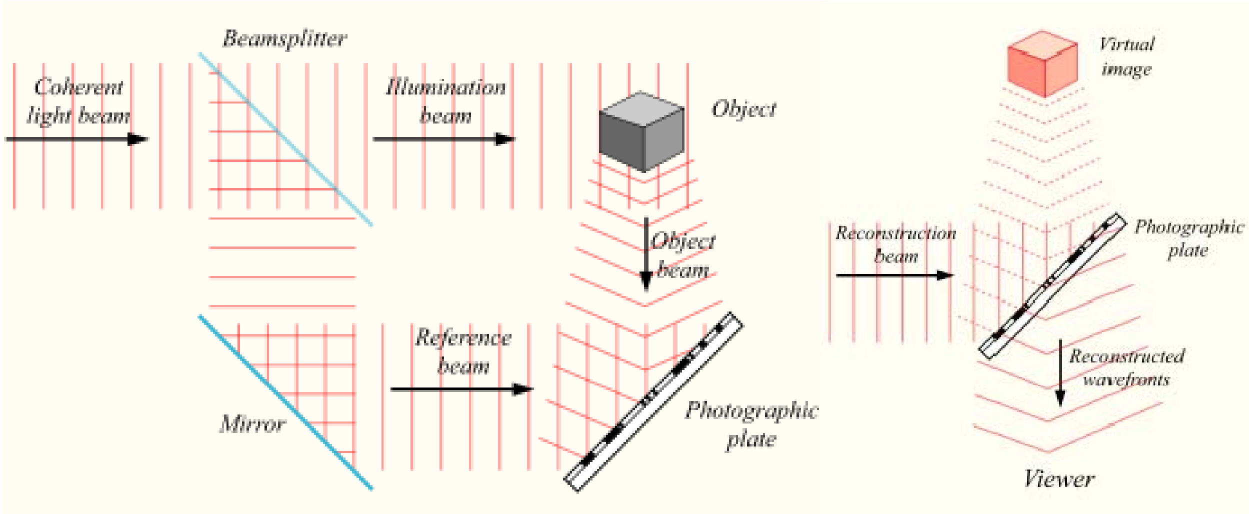




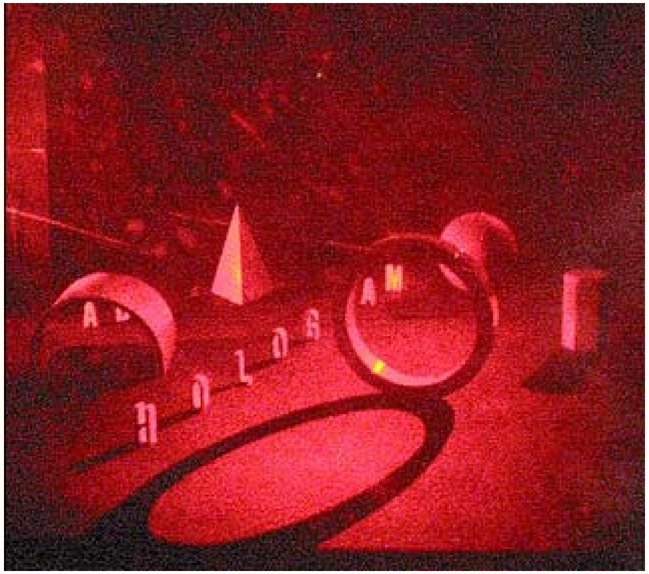
Unencumbered Automultiscopic

- **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)

Taxonomy of 3D Displays:
Static Holograms



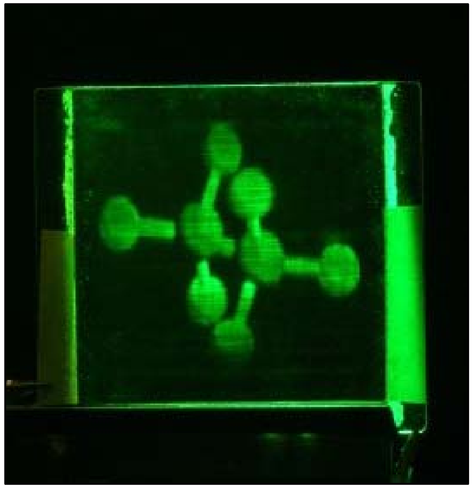
capture reconstruction



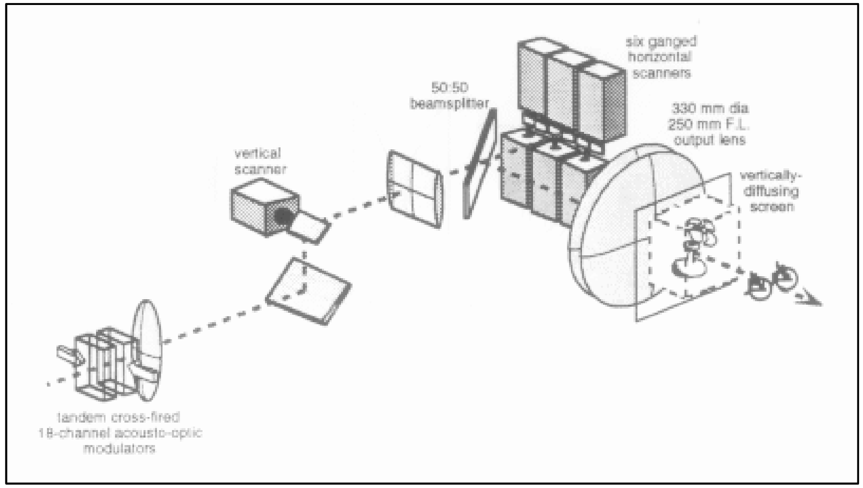
Unencumbered Automultiscopic

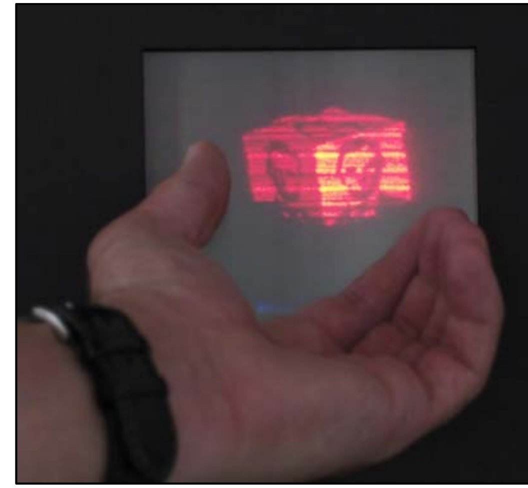
- **Parallax-based** (2D display with light-directing elements)
  - Parallax Barriers (uniform array of 1D slits or 2D pinhole arrays)
  - Integral Imaging (lenticular sheets or fly's eye lenslet arrays)
- **Volumetric** (directly illuminate points within a volume)
  - Multi-planar (time-sequential projection onto swept surfaces)
  - Transparent Substrates (intersecting laser beams, fog layers, etc.)
- **Holographic** (reconstructs wavefront using 2D element)
  - Static (holographic films)

Taxonomy of 3D Displays:
Dynamic Holograms (Holovideo)



Tay et al.
[Nature, 2008]



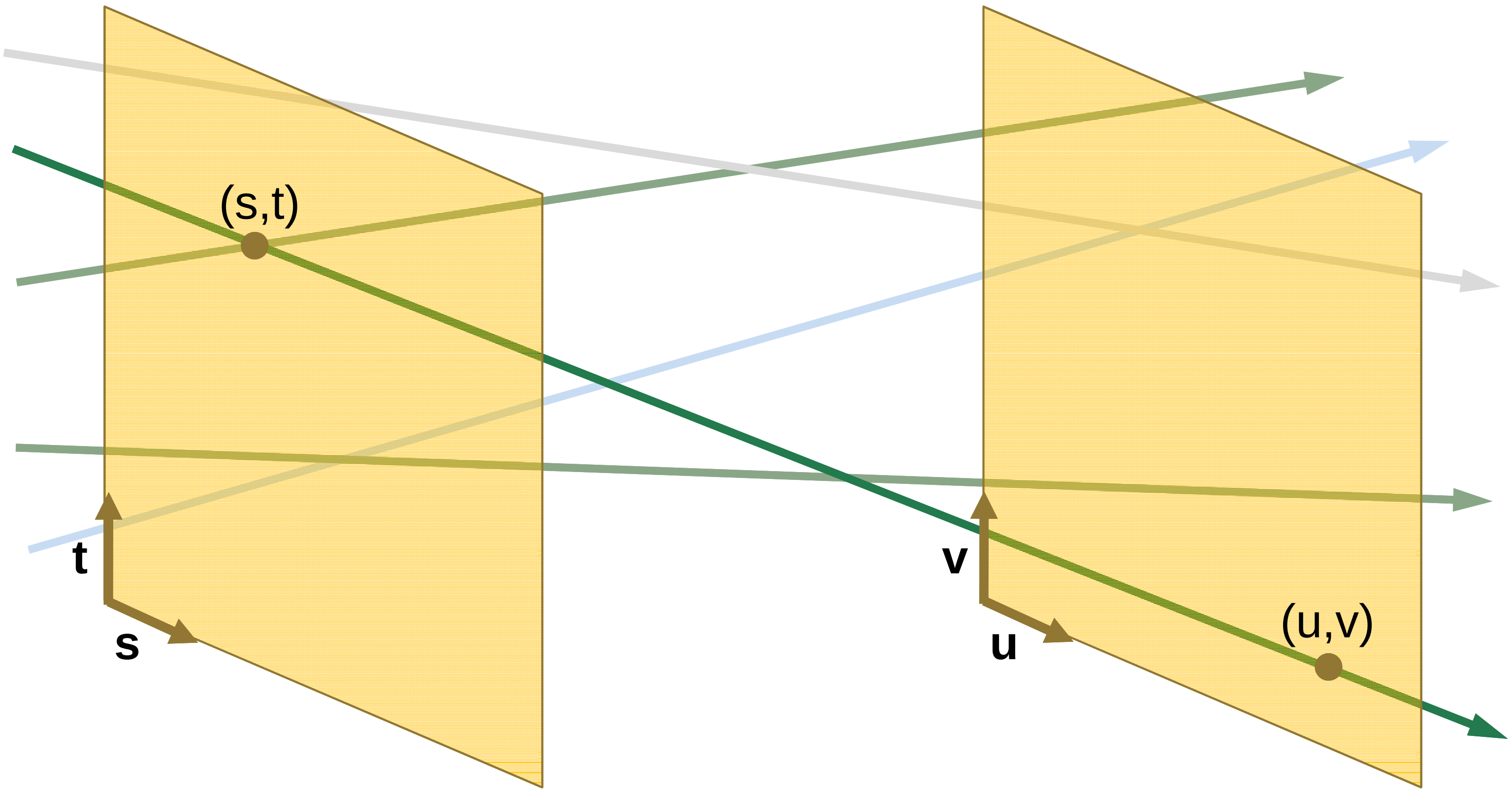


MIT Media Lab Spatial Imaging Group
[Holovideo, 1989 – present]

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)

Introduction to Light Fields

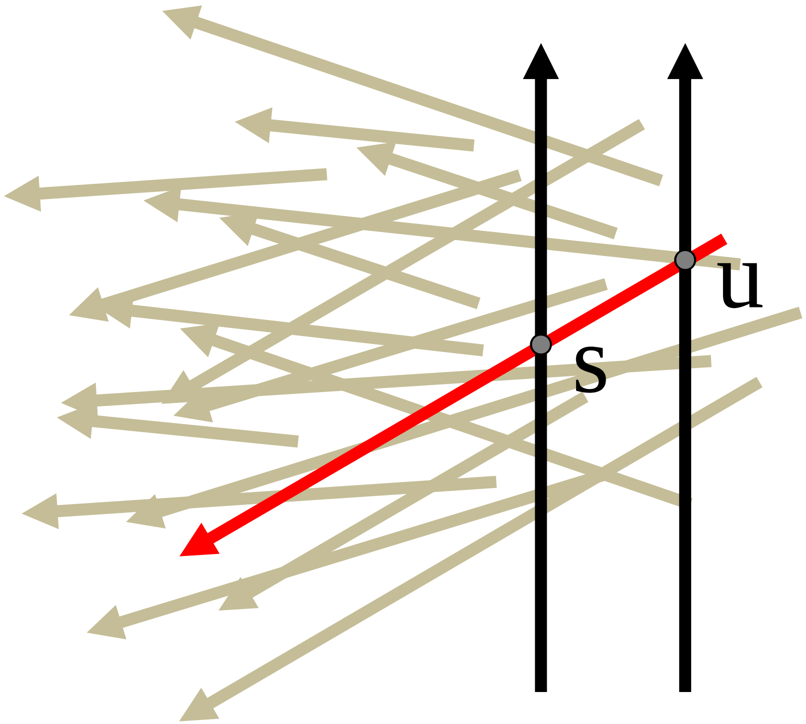


Representing Light Transport

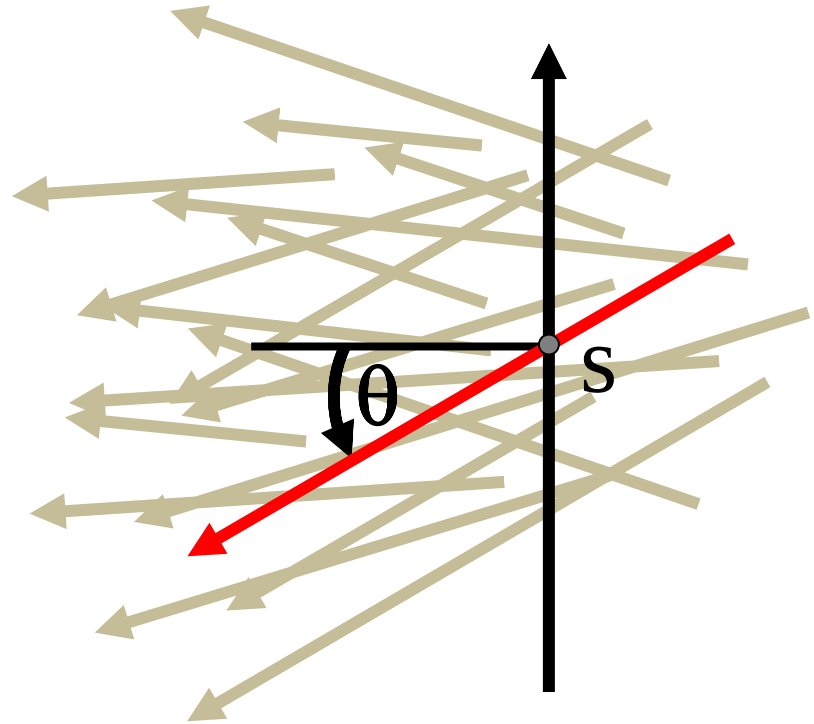
- Assume geometrical (ray) optics approximation
- Parameterize radiance of 3D rays using a *4D light field L(u,v,s,t)*

Marc Levoy and Pat Hanrahan. Light Field Rendering. 1996.
Steven Gortler *et al*. The Lumigraph. 1996.

Introduction to Light Fields



Two Plane Parameterization

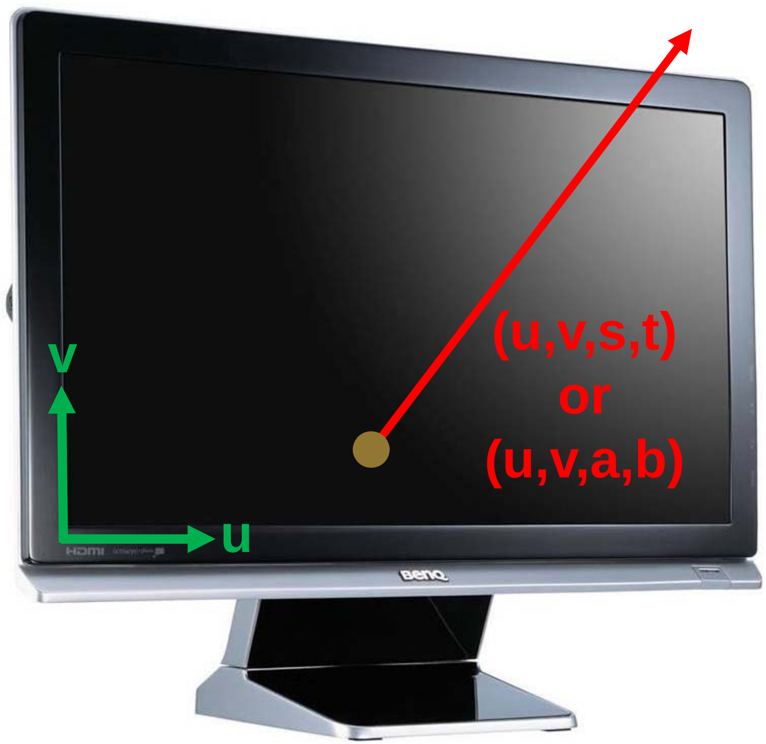


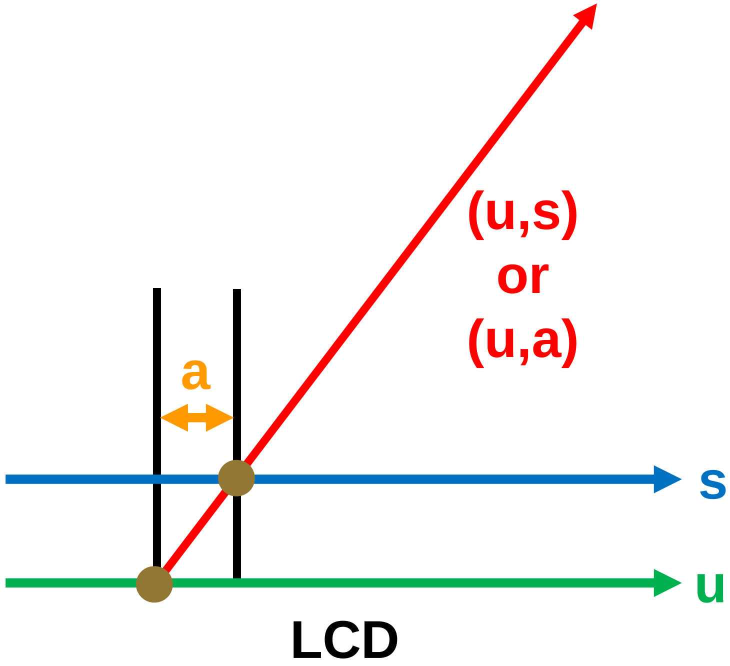
Position-Angle Parameterization

Light Fields [Levoy and Hanrahan 1996, Gortler et al. 1996]

- Radiance along any direction at every point in 3D space
- Light fields are 4D (e.g., *two plane* vs. *position-angle* parameterization)

Representing 3D Displays with Light Fields

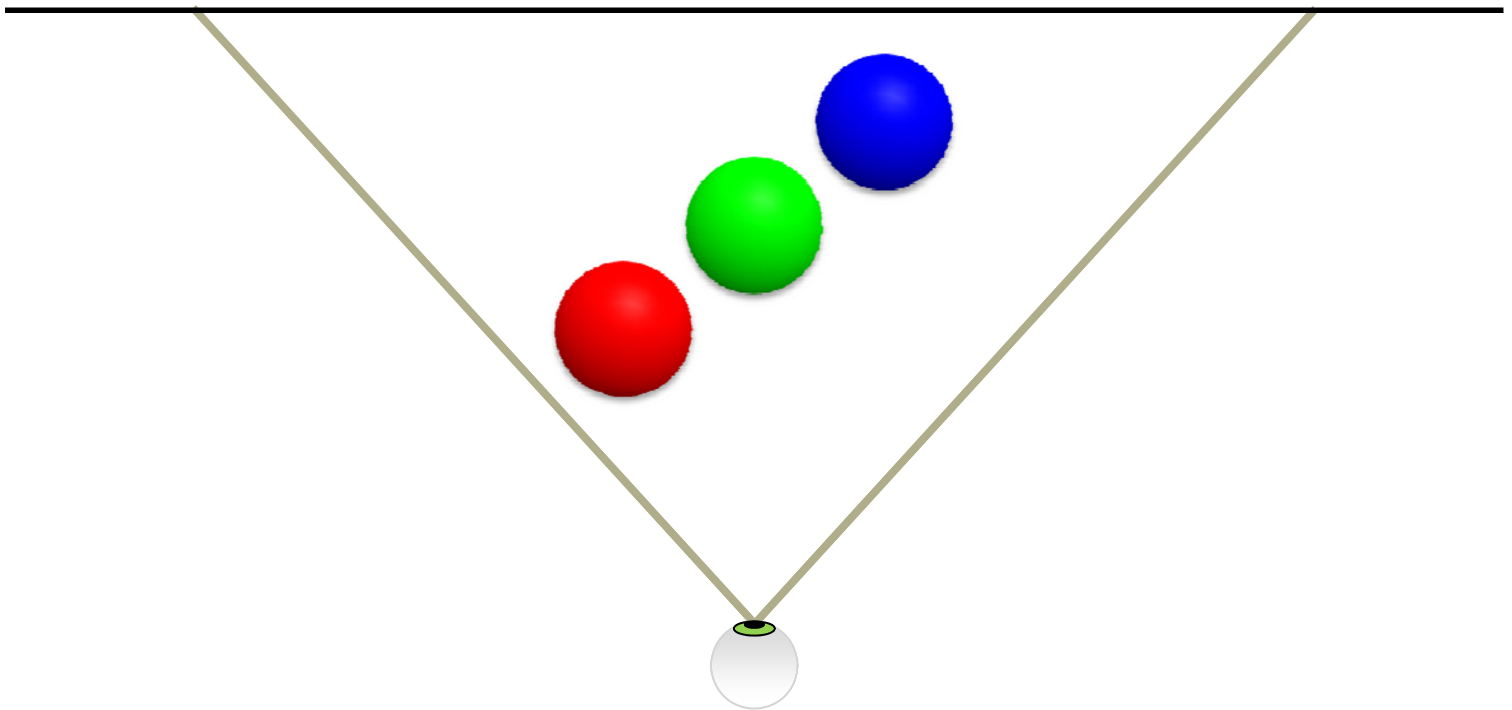




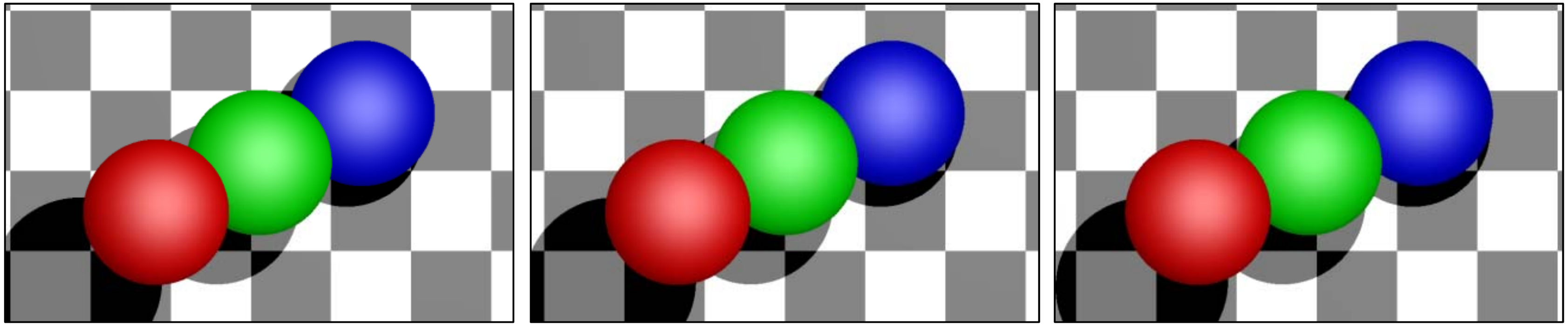
Light Fields [Levoy and Hanrahan 1996, Gortler et al. 1996]

- Radiance along any direction at every point in 3D space
- For a planar 3D display, the emitted light field is a 4D function
- Parameterized using *absolute* or *relative* two plane parameterization

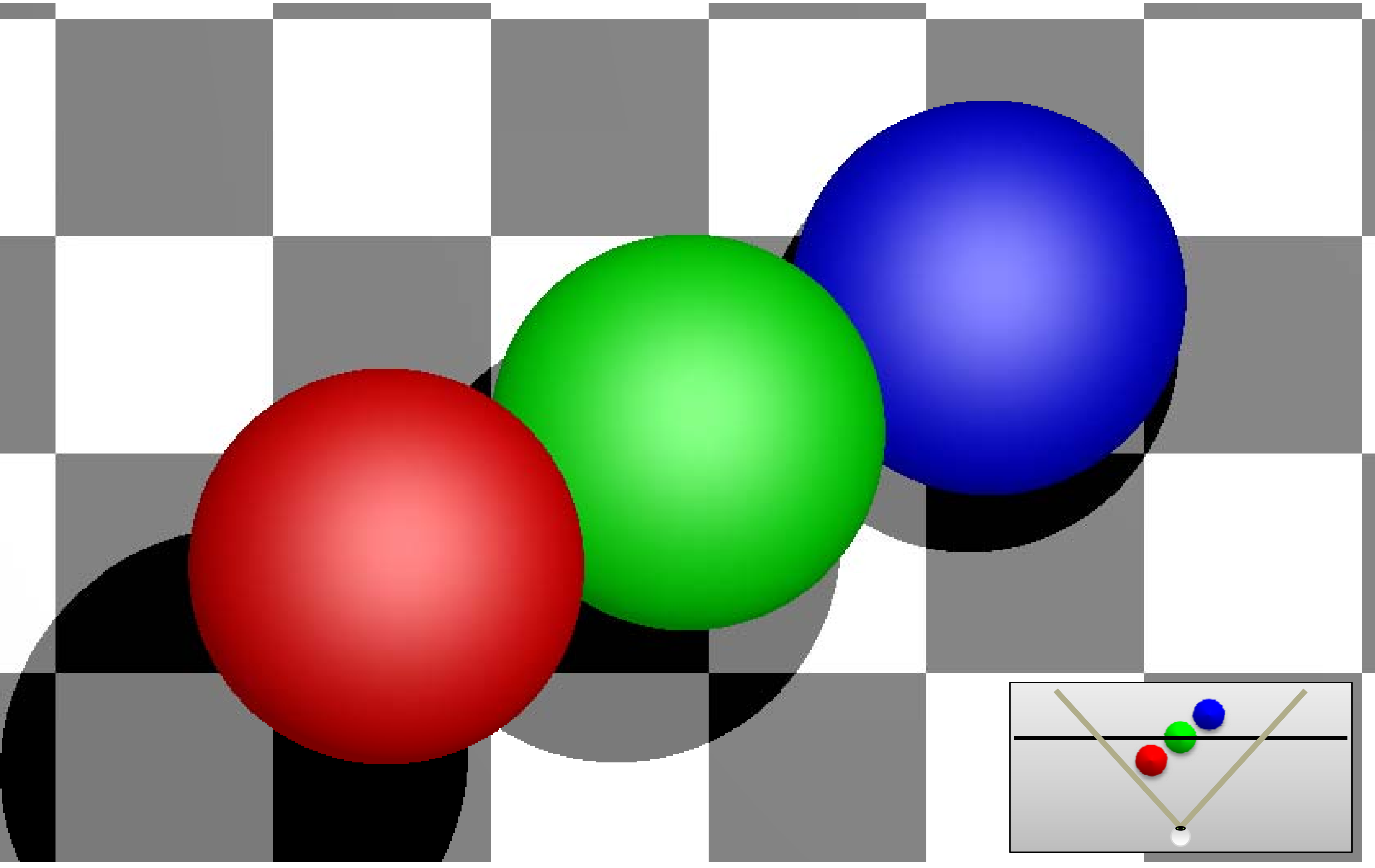
Representing Multiple Views with Light Fields



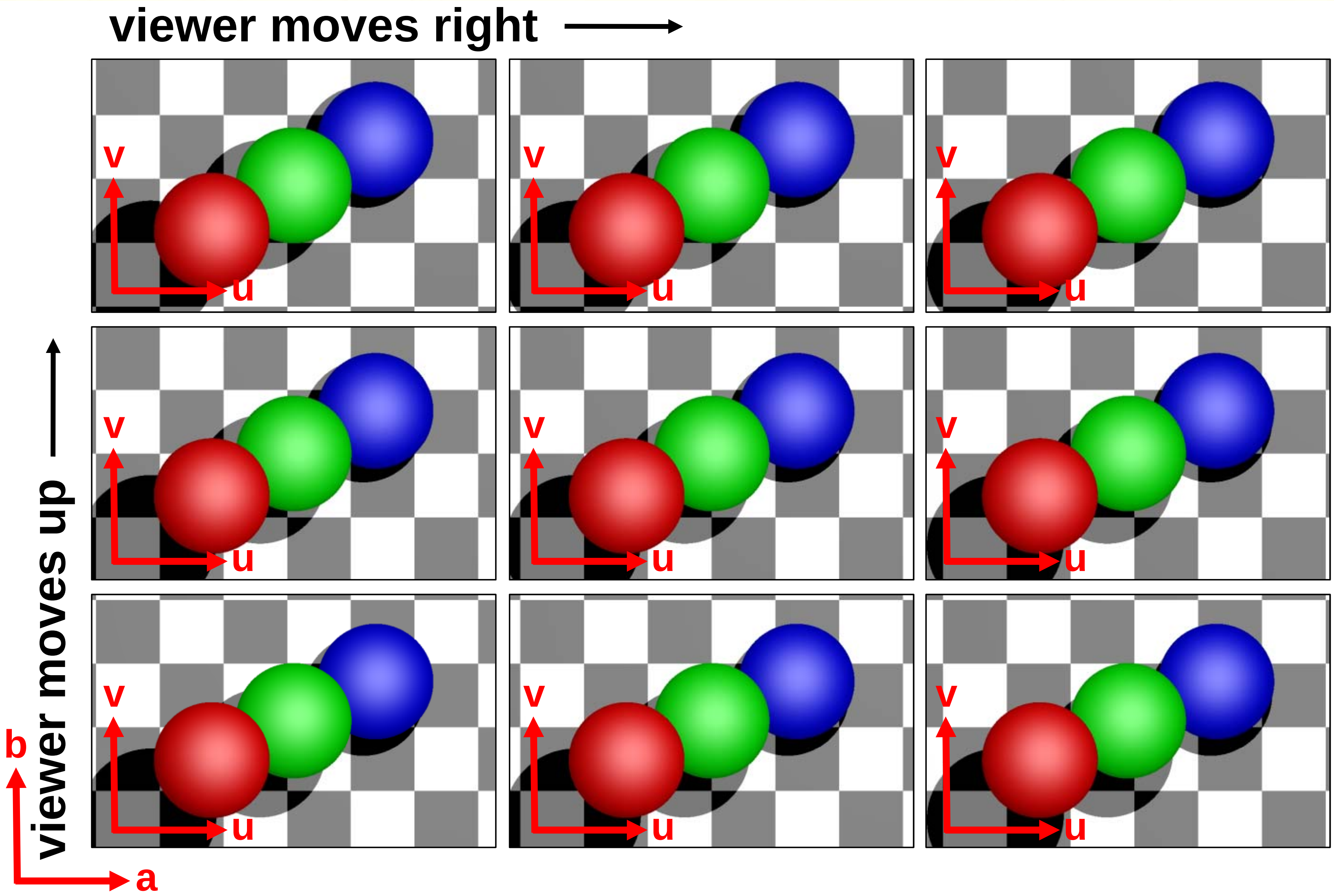
viewer moves right →



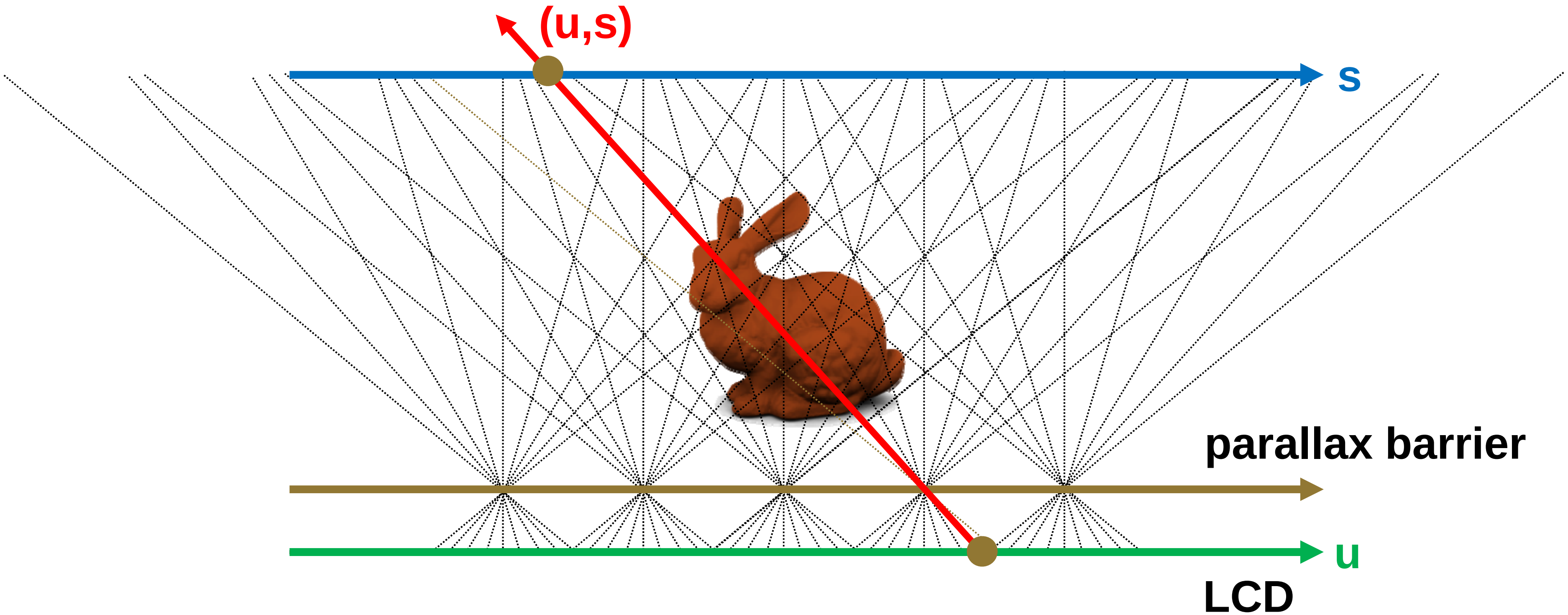
Representing Multiple Views with Light Fields



Representing Multiple Views with Light Fields



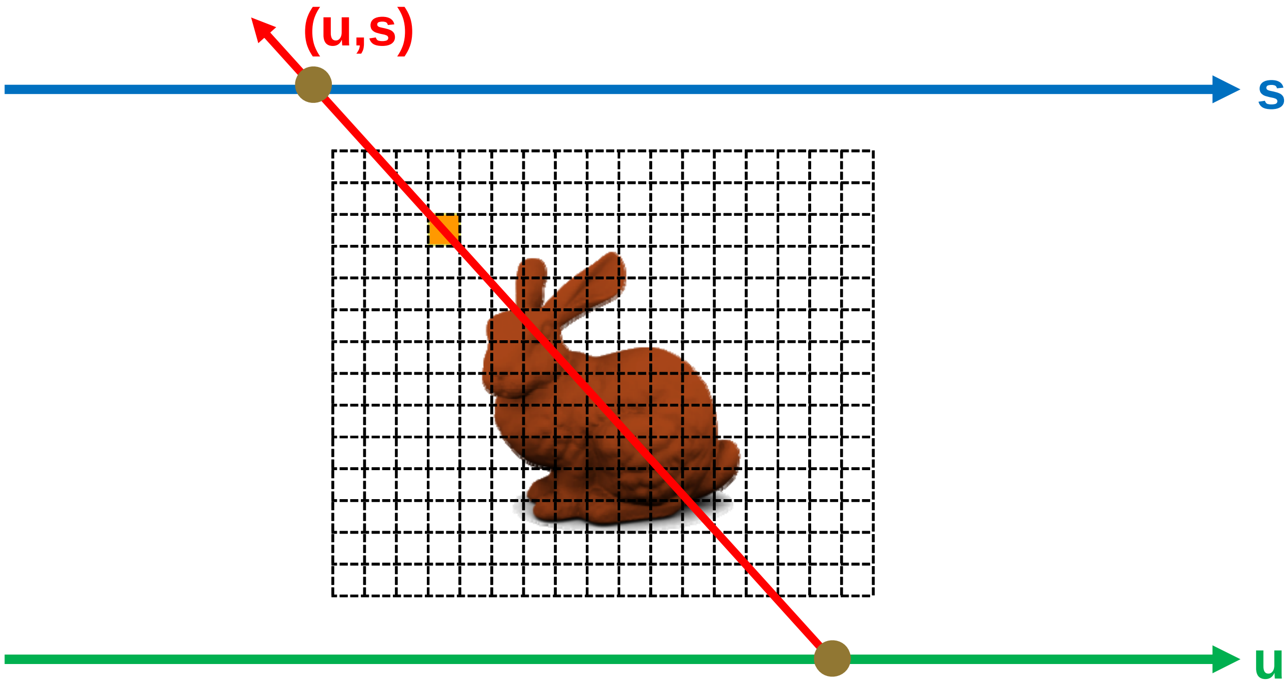
Example: Parallax Barriers



Light Fields [Levoy and Hanrahan 1996, Gortler et al. 1996]

- Radiance along any direction at every point in 3D space
- For a planar 3D display, the emitted light field is a 4D function
- Parameterized using *absolute* or *relative* two plane parameterization
- **Represents multiple views projected by parallax barrier displays**

Example: Volumetric Displays



Light Fields [Levoy and Hanrahan 1996, Gortler et al. 1996]

- Radiance along any direction at every point in 3D space
- For a general planar 3D display, the emitted light field is a 4D function
- Light field is parameterized using intersection with two planes
- **Represents multiple views projected by volumetric displays**

Course Outline

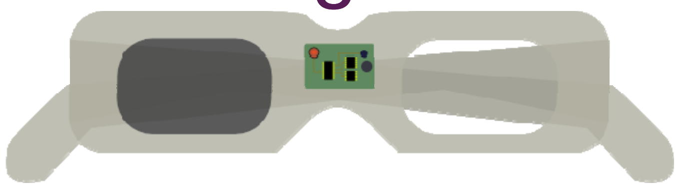
- Introduction: History and Physiology
- Representation and Display
- ***Glasses-bound Stereoscopic Displays***
- Unencumbered Automultiscopic Displays
- Source Material: Rendering and Capture
- Emerging Technology
- Conclusion and Q & A

Course Outline

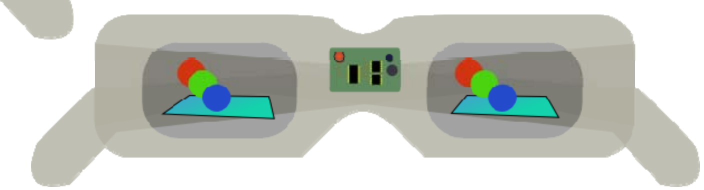
- Introduction: History and Physiology
- Representation and Display
- ***Glasses-bound Stereoscopic Displays***
- Unencumbered Automultiscopic Displays
- Source Material: Rendering and Capture
- Emerging Technology
- Conclusion and Q & A

Glasses-Bound Stereoscopic Display

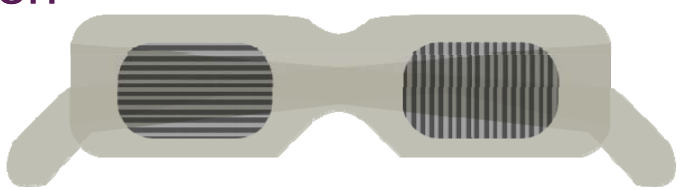
- Goal: Provide different images to each eye by modifying the scene at each eye
- Only 2 views: does not track viewer position
- Methods: Forms of glasses
  - Active
    - Shutters



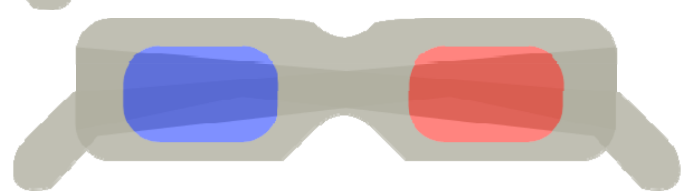
    - LCD Screen



  - Passive
    - Polarizers



    - Color Filters



Course Outline

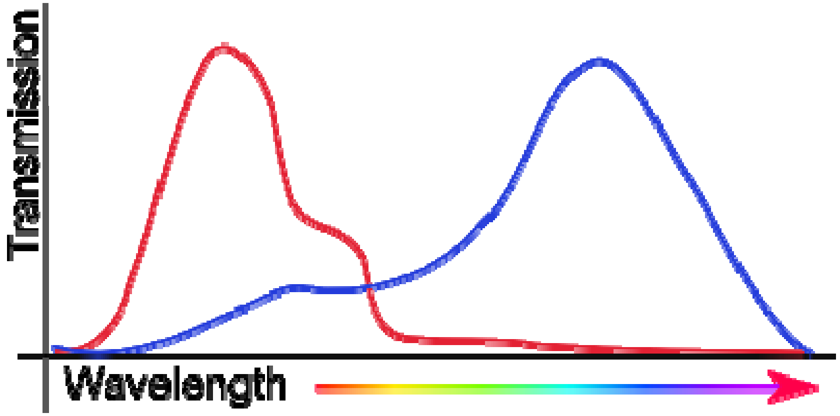
- Introduction: History and Physiology
- Representation and Display
- ***Glasses-bound Stereoscopic Displays***
  - ***Overview of Common Glasses Designs***
  - BYO Shutter Glasses
- Unencumbered Automultiscopic Displays
- Source Material: Rendering and Capture
- Emerging Technology
- Conclusion and Q & A

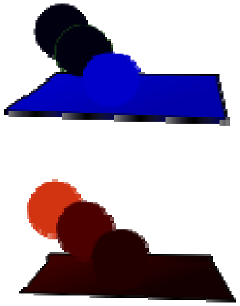
Passive Glasses

- Use passive optical filters to modify an image produced by another device
- Cheap glasses, expensive display device
- 1-to-N where N is large
  - Theaters (Movie/Omni)

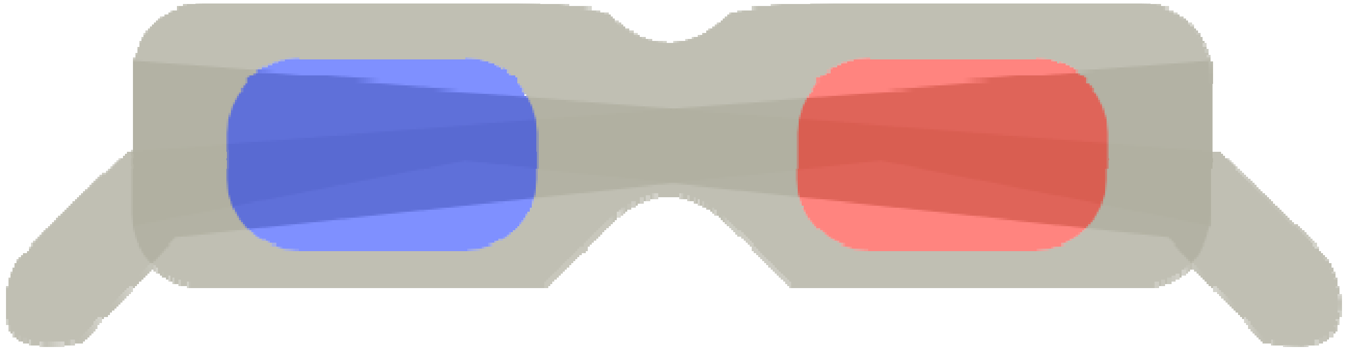
Color Filters: Anaglyph

- Anaglyph (usually red/blue) glasses an early type
- Separate images in wavelength with notch filters

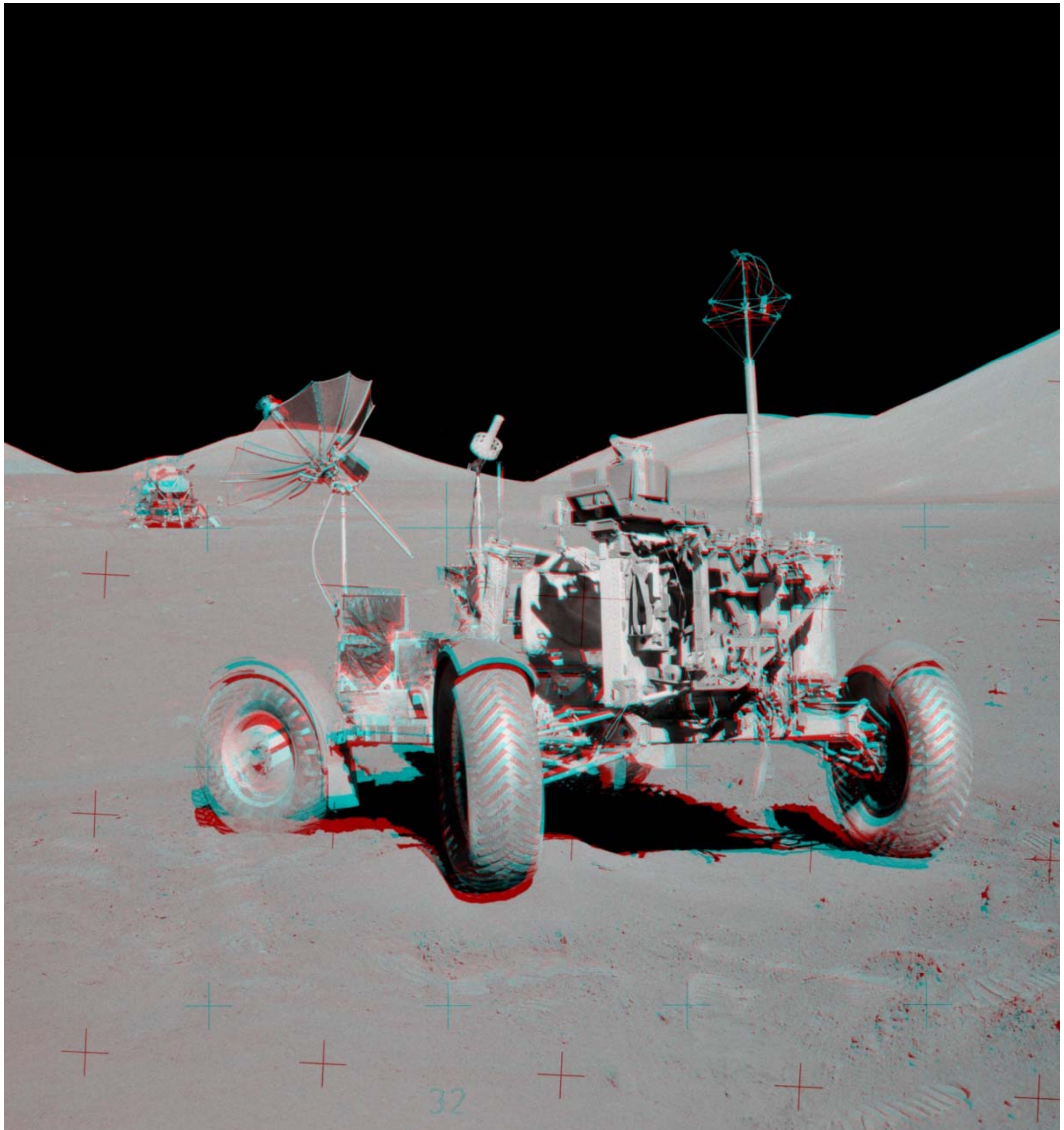




- Unpleasant color effect



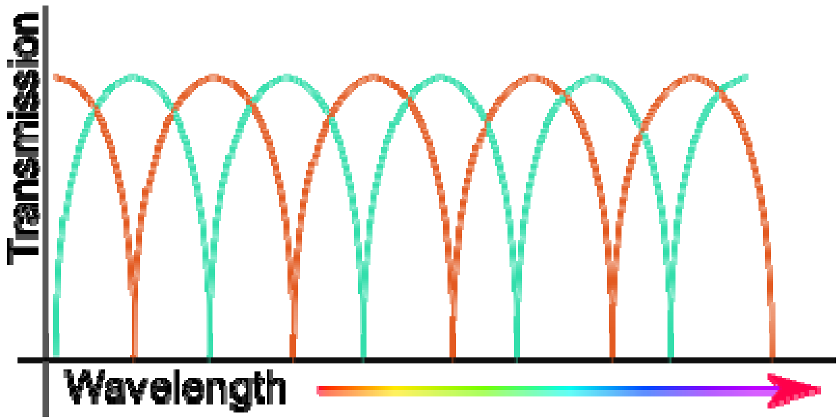
Anaglyph Image Example



Apollo17: VIP Site Anaglyph
Credit: Gene Cernan, Apollo 17, NASA
Anaglyph by Erik van Meijgaarden

Color Filters: Comb Filters

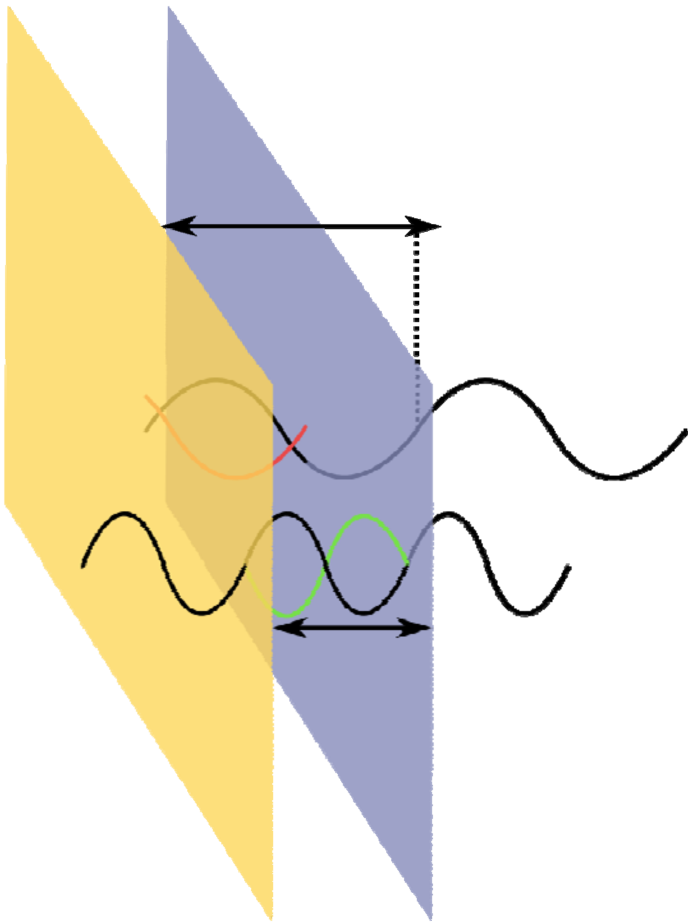
- Comb Filters: notch filters across the visible spectrum

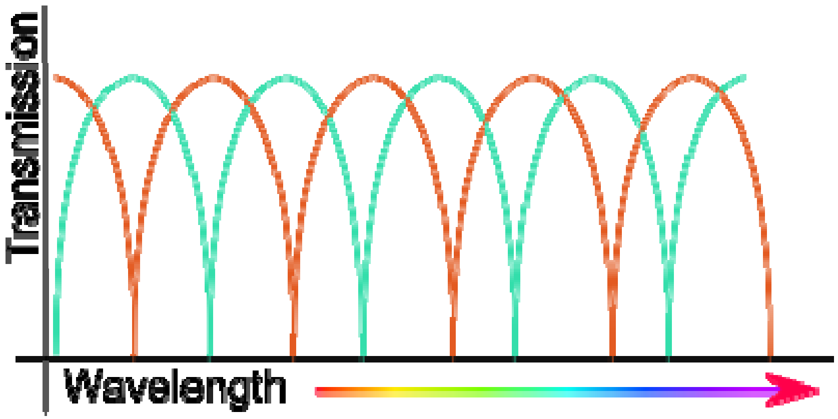


Plot not a physically accurate representation of Dolby's system

- Solve the unpleasant colored image effect
- Can be used with normal white screens (unlike polarizing glasses)

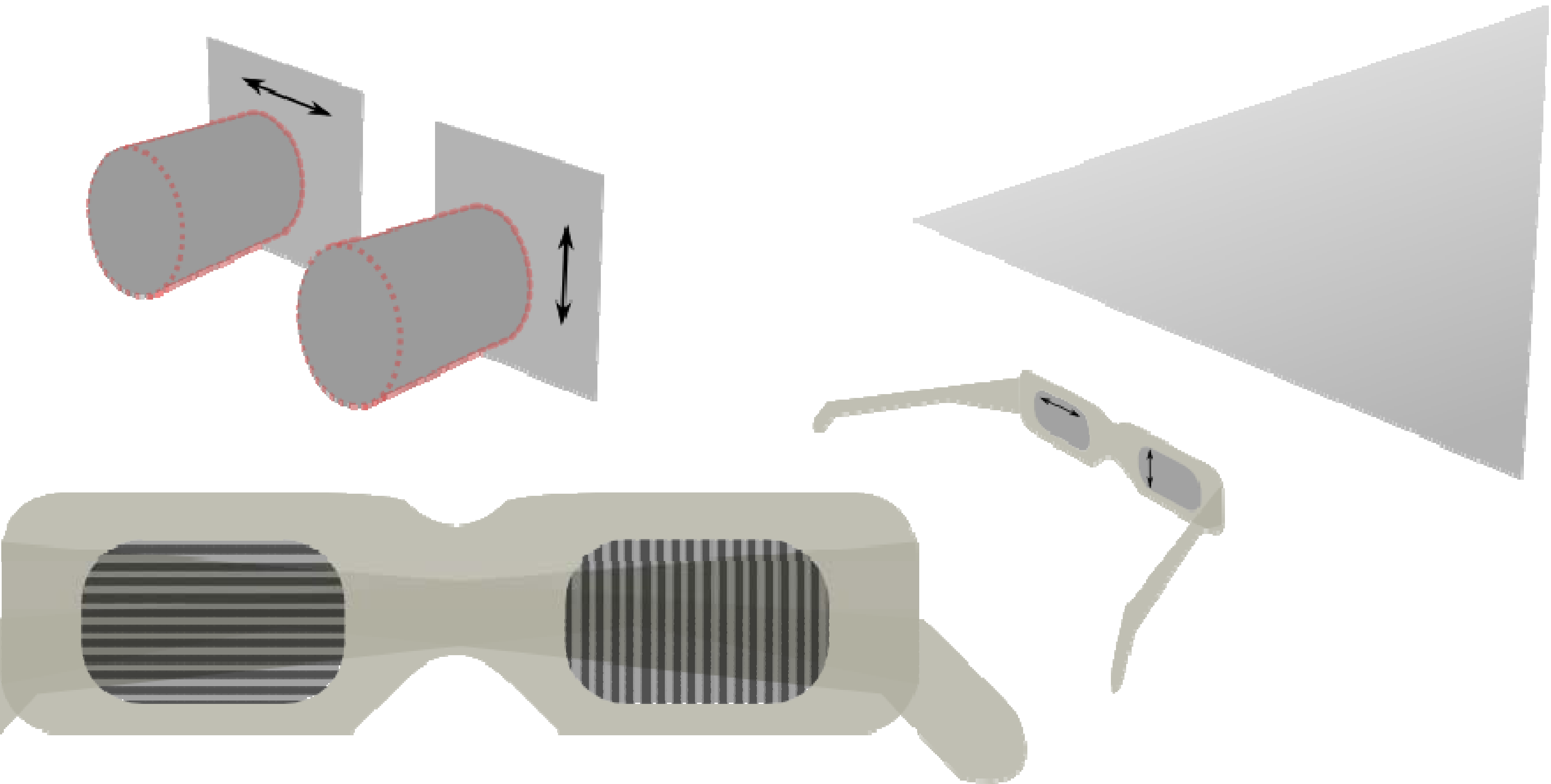
Optical comb filters





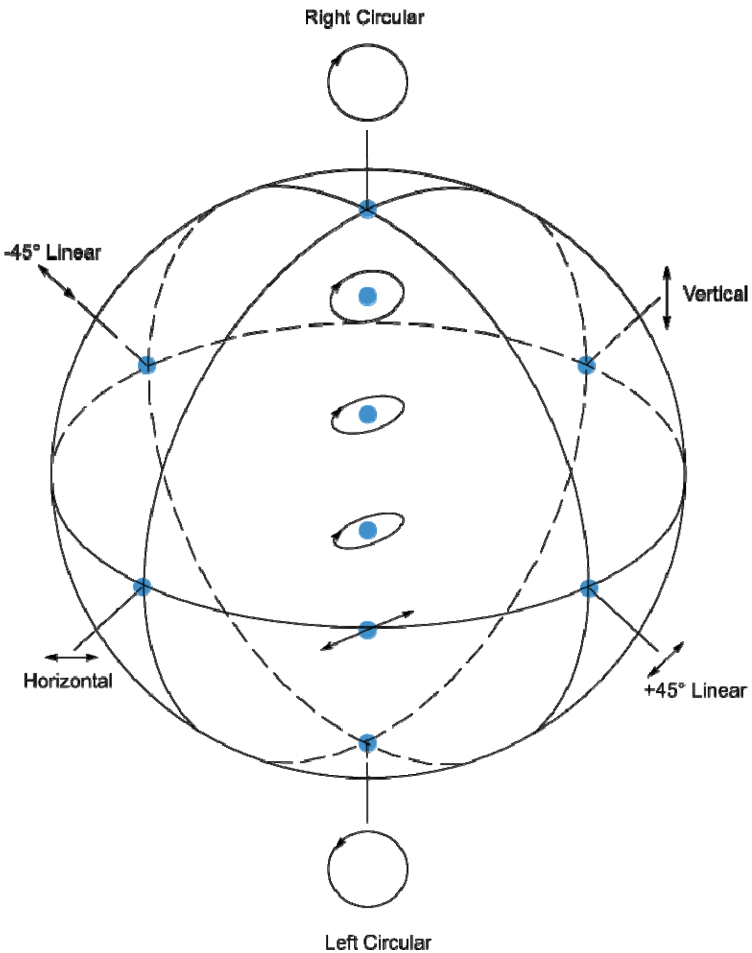
Polarizing Glasses

- Basic configuration



Circular vs. Linear Polarizers

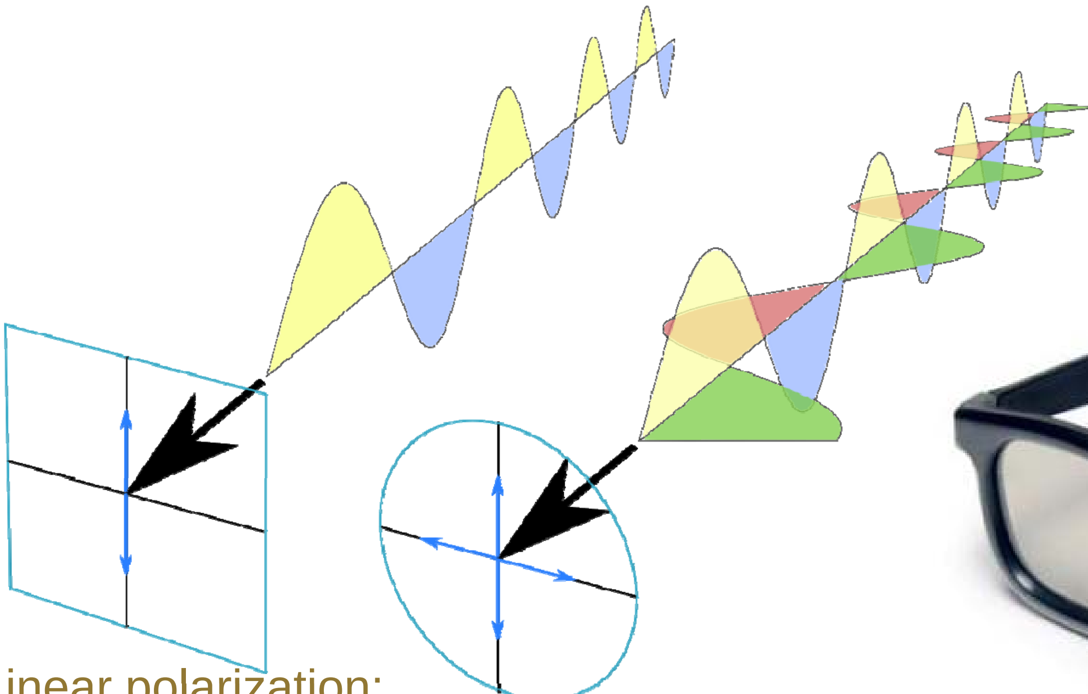
- Poincaré sphere representation
- Polarization mapped to volume of a unit sphere
- Linear states at the equator
- Circular states at the poles
- Orthogonal states diametrically opposite



http://www.hpl.hp.com/hpjournal/95feb/feb95a4b.pdf

Circular vs. Linear Polarizers

- Circular allows viewer to rotate head
- Real-D currently use circular polarizers



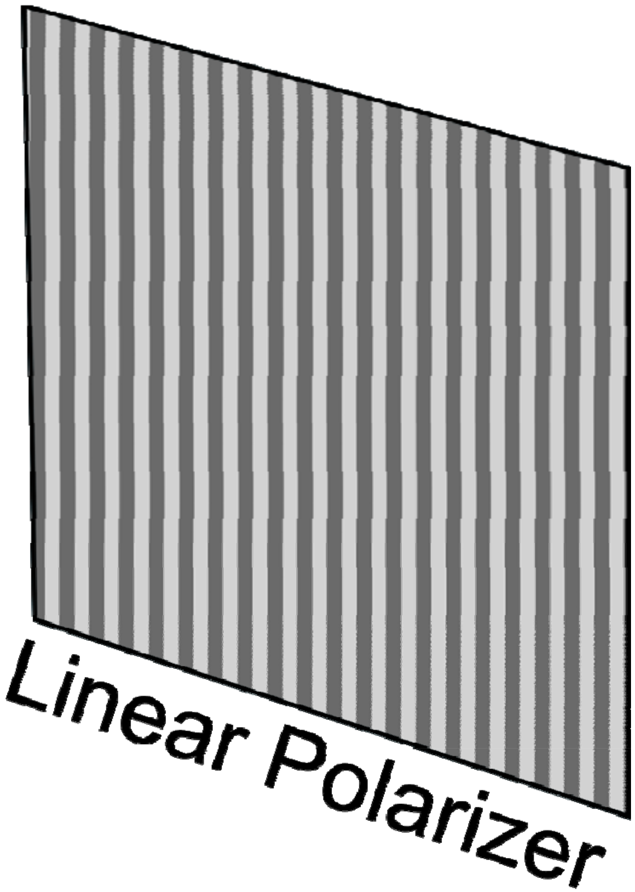
Linear polarization: Orientation dependant

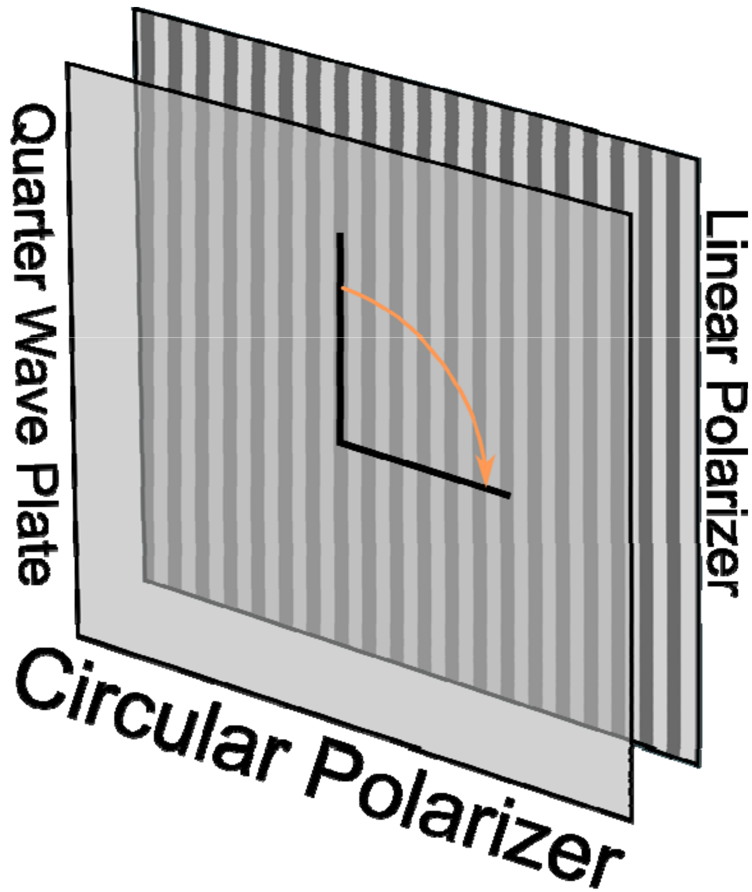
Circular polarization: Independent of orientation

Making a Polarizer

A linear polarizer is a set of conductors that “short out” the electric field in one direction

A circular polarizer is a linear polarizer followed by a quarter wave plate





Active Glasses

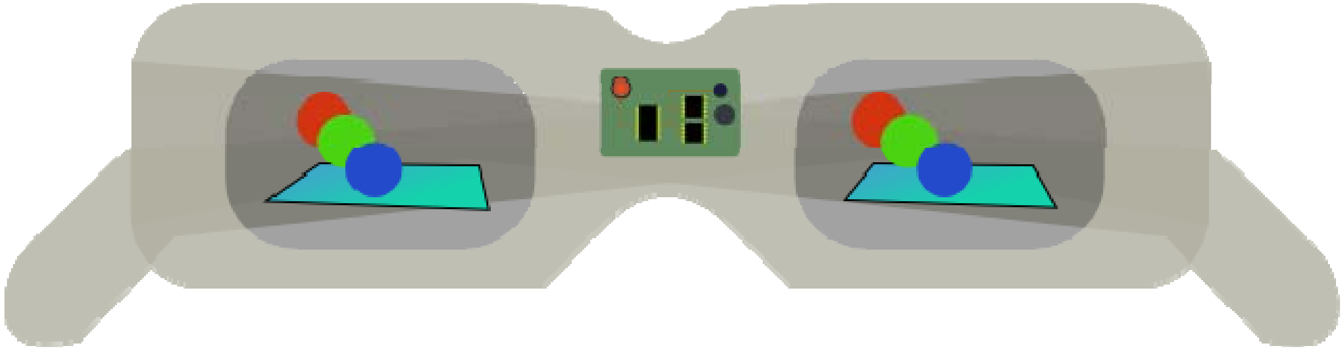
- Use electronically controlled spatial light modulators to modify or produce images of a scene
- Expensive glasses, cheap (or no) accompanying display
- Popular for personal viewing

LCD Screen Glasses

- "Simplest" idea: put screens right in front of the eye

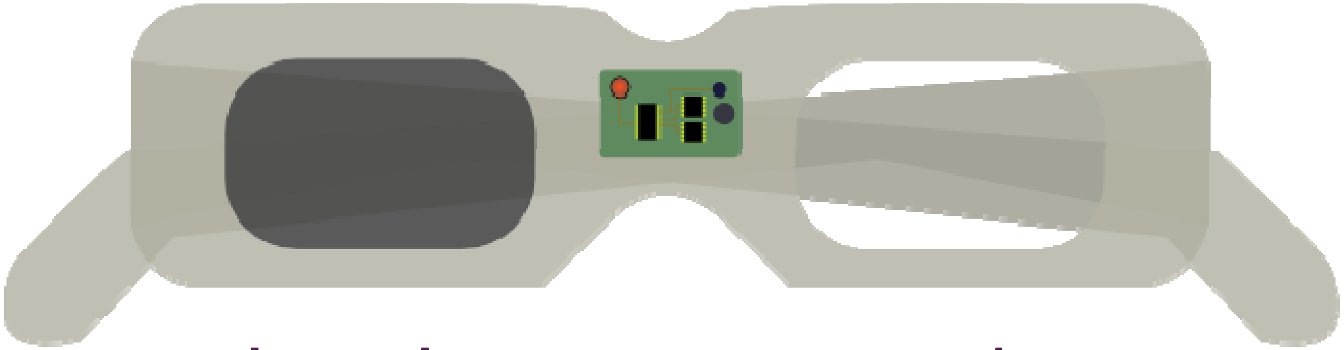
  Original immersive "VR" headgear

- Optics to make the screens visible
- Expensive and obscure other vision

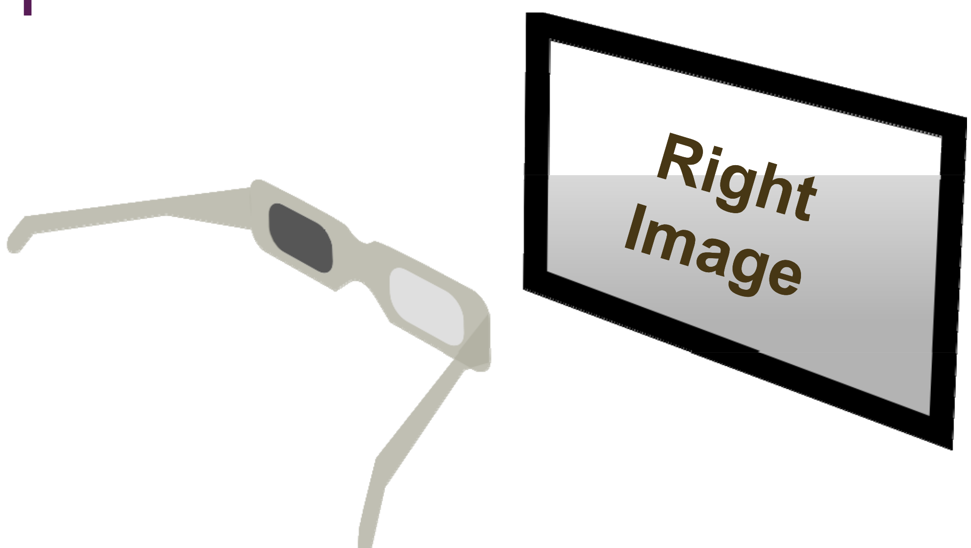


LCD Shutter Glasses

- Single LCD “pixel” in front of each eye

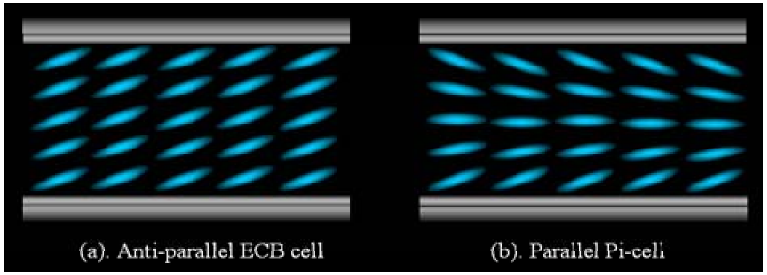


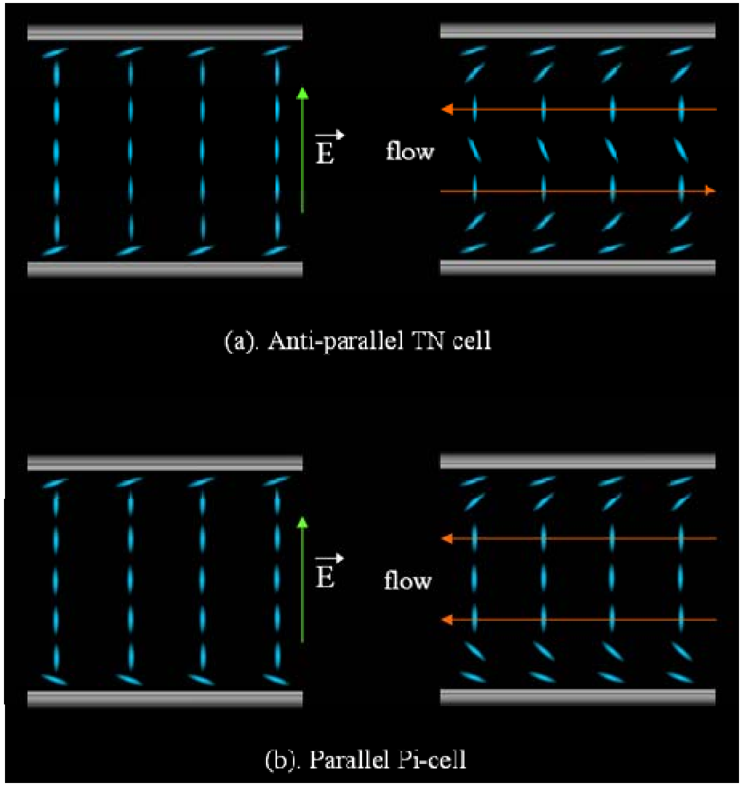
- Synchronize transparent/opaque state with screen updates to deliver correct image to eye



Types of LCD shutters

- LCD
  - “Normal” anti-parallel configuration
  - Pi Cell, parallel configuration





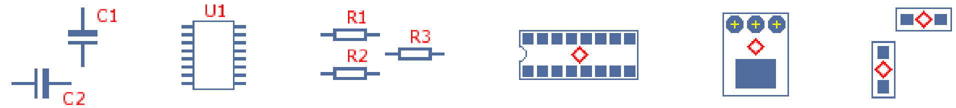
http://www.liquidcrystaltechnologies.com/tech_support/Pi_Cell.html

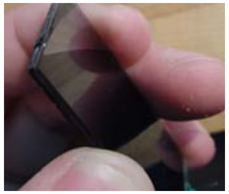
Course Outline

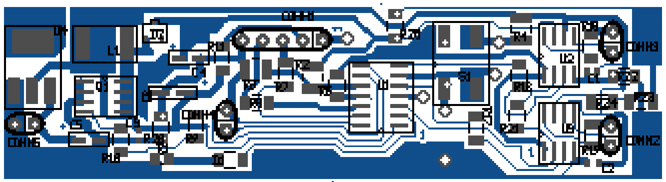
- Introduction: History and Physiology
- Representation and Display
- ***Glasses-bound Stereoscopic Displays***
  - Overview of Common Glasses Designs
  - ***BYO Shutter Glasses***
- Unencumbered Automultiscopic Displays
- Source Material: Rendering and Capture
- Emerging Technology
- Conclusion and Q & A

Build Your Own Shutter Glasses

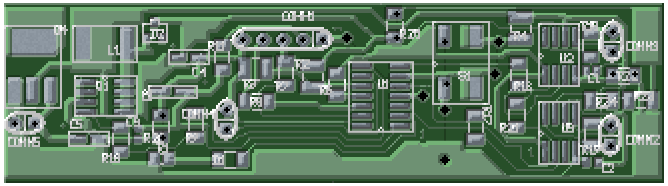
- Components Overview
  - Obtaining parts





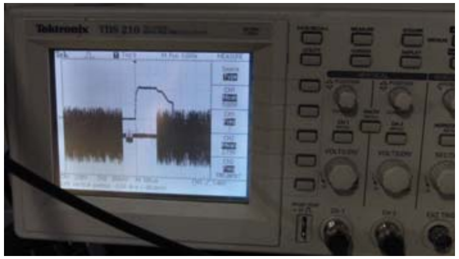


- LCD Shutters
- Controller board design



- Fabricating the board

- Making the glasses
- Syncing to a source



BYO Shutter Glasses: Components

- Electronics
  - Microcontroller, components for power supply
- LCD Shutters
  - Liquid Crystal Technologies
- Frame
  - Acrylic
  - Cardboard

Digikey Parts List

Part Description	Digikey Part Number	Qty	Cost
Microcontroller	PIC16F506-I/SL-ND	1	0.90
N-Channel MOSFET	FDS3692CT- D	1	1.17
5v Regulator	ZLDO1117G50DICT-ND	1	0.62
10uF Capacitor	338-1793-1-ND	1	0.12
100uF Capacitor	338-1820-1-ND	1	0.22
100uH Inductor	PCD2119CT-ND	1	0.86
1uF Capacitor	493-2129-1-ND	1	0.45
40V Schottky Diode	BAS40-FDICT-ND	1	0.60
10K 1210 Resistor	541-10KVCT-ND	1	0.261
100K 1210 Resistor	541-100KVCT-ND	2	0.522
Switch	SW262CT-ND	1	0.90
220 0805 Resistor	RHM220ARCT-ND	1	0.034
1K 1206 Resistor	RMCF1/81KJRCT-ND	3	0.05
.1uF 0603 Capacitor	490-3167-1-ND	3	0.032
Header (male)	A34253-40-ND	1	2.09
Jumper 1206	RMH0.0ERCT-ND	13	0.533

Parts Totals

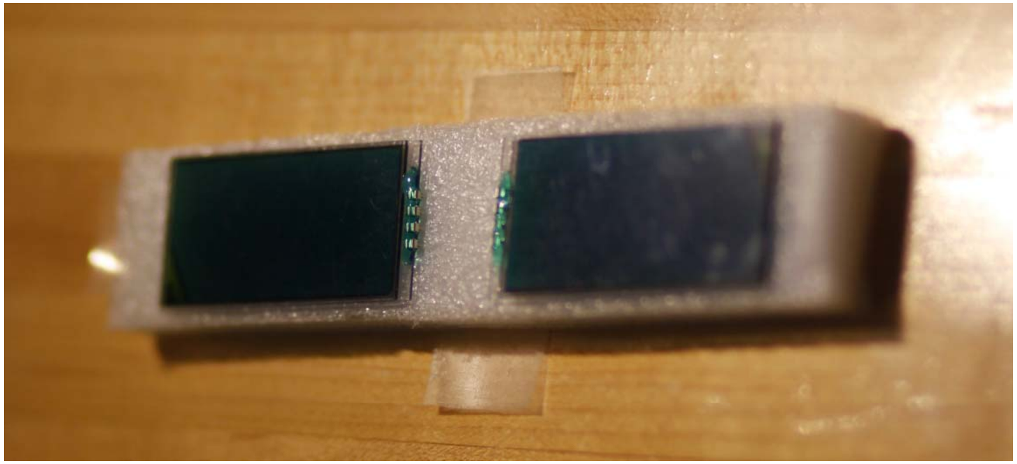
- Mouser Parts List: $4.24

Part Description	Mouser Part Number	Qty	Cost
HV508LG LCD Driver	689-HV508LG-G	1	4.24

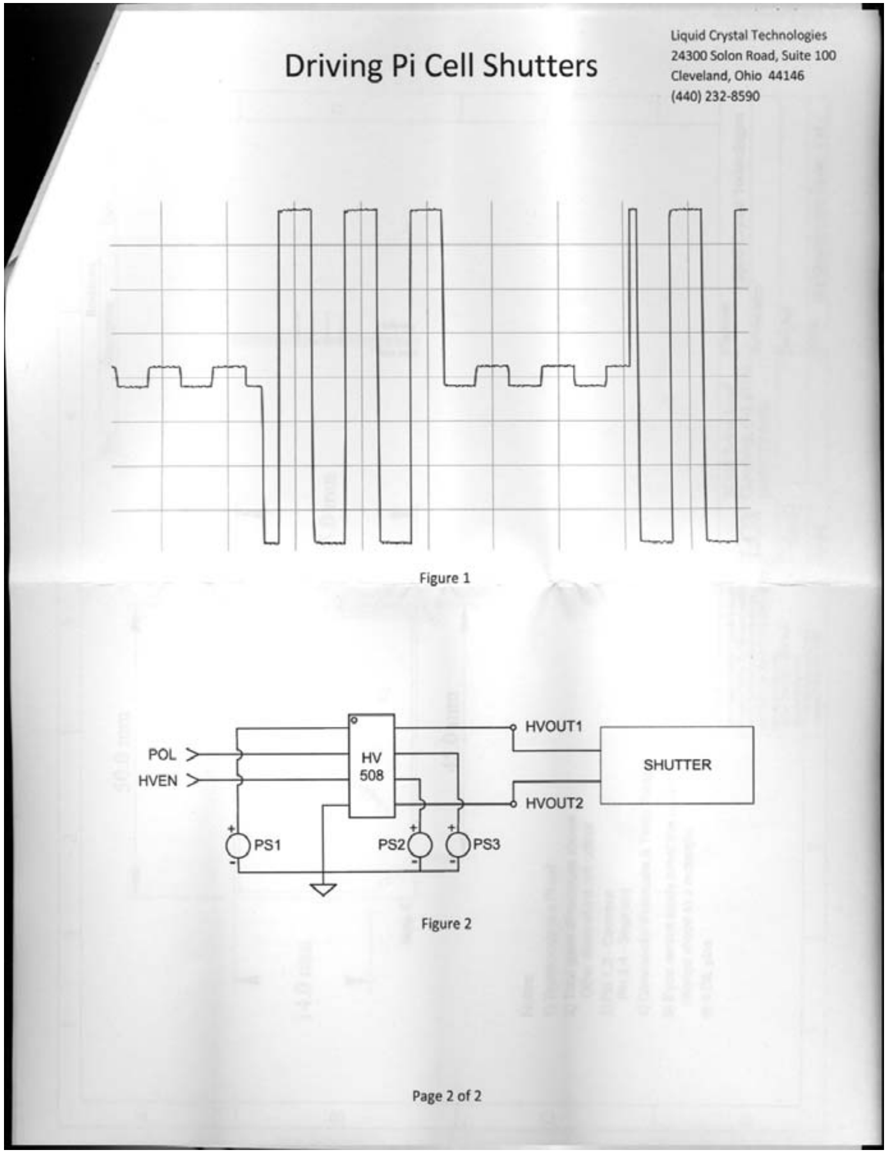
- Total Cost
  - Mouser: $4.24
  - Digikey: $9.36
  - LCT (next slide): $50
  - Total: $63.60 + shipping + time

LCD Shutters

- Liquid Crystal Technologies Pi-Cells
- sales@liquidcrystaltechnologies.com to order sample kit
- $25 per sample ($50 total)



Diving and LCD shutter


Driving Pi Cell Shutters

Liquid Crystal Technologies
24300 Solon Road, Suite 100
Cleveland, Ohio 44146
(440) 232-8590

Figure 1

Figure 2

Page 2 of 2

- LCT provides these instructions with the pi-cell kit
- High voltage (~35V) or low voltage (~3V) supply rails
- Modulated by 1kHz
- Supply rail voltage sets shutter opacity

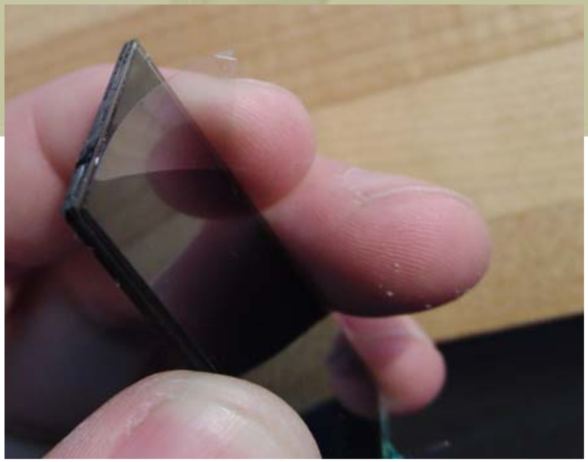
Frames

- Can be made from your favorite material
- Lasercut acrylic
- Foamcore
- I used Corrugated Cardboard
  - Hold shutter between the layers
  - Can be perforated to hinge easily
- Use lasercutter if available, or Exacto

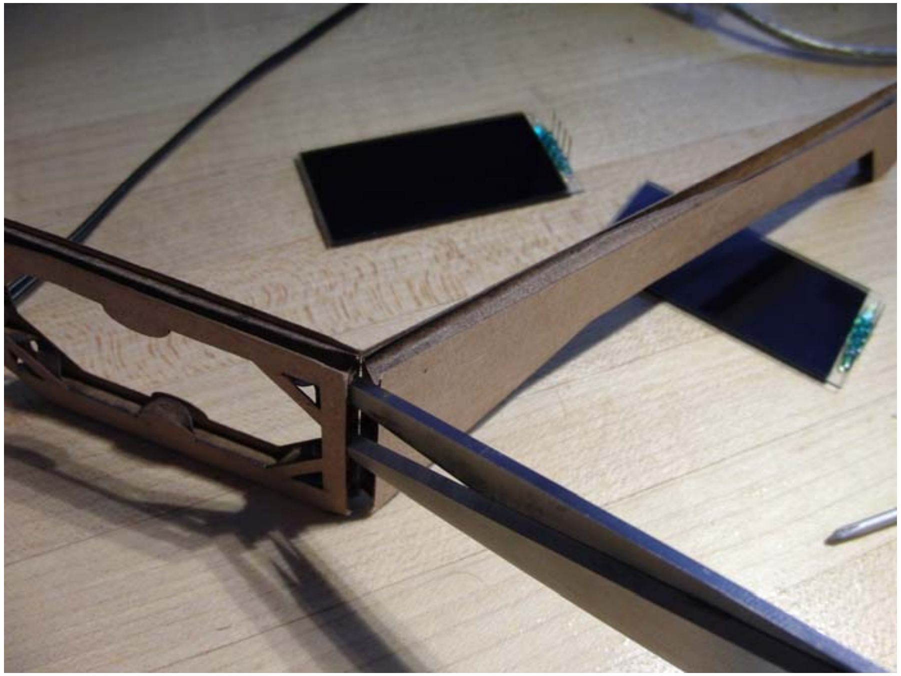
Look this cool.

Frames Template

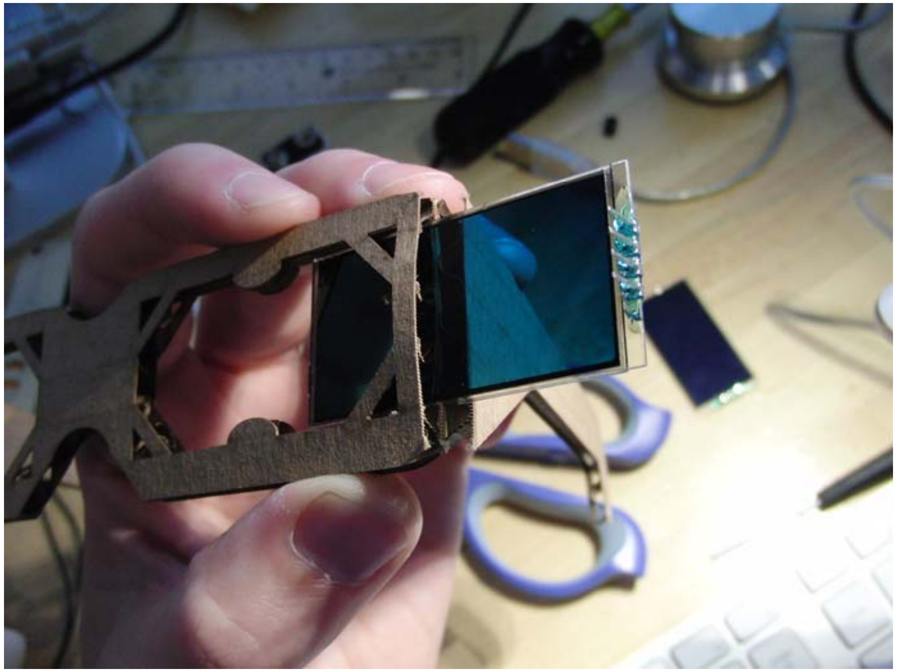
Cut out this template (found to scale on website)
Will need to print on 11x17 paper



Peel back protective coating

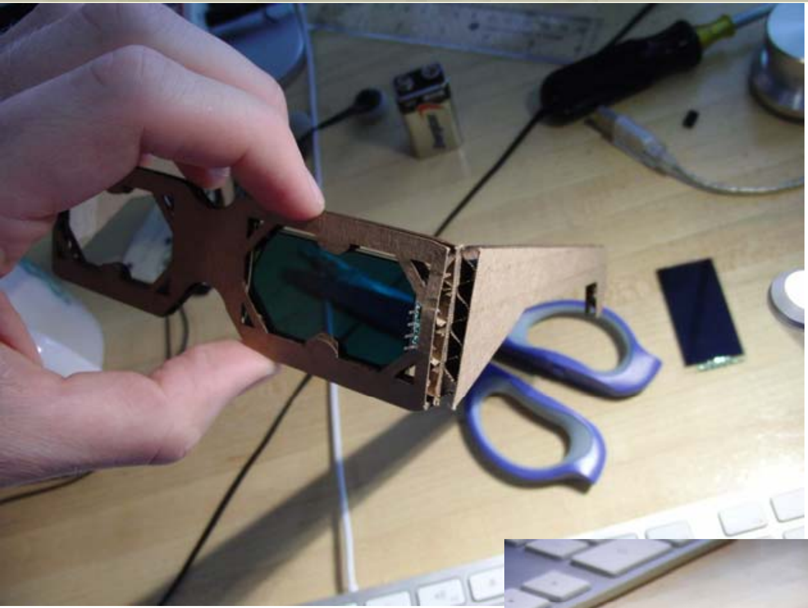


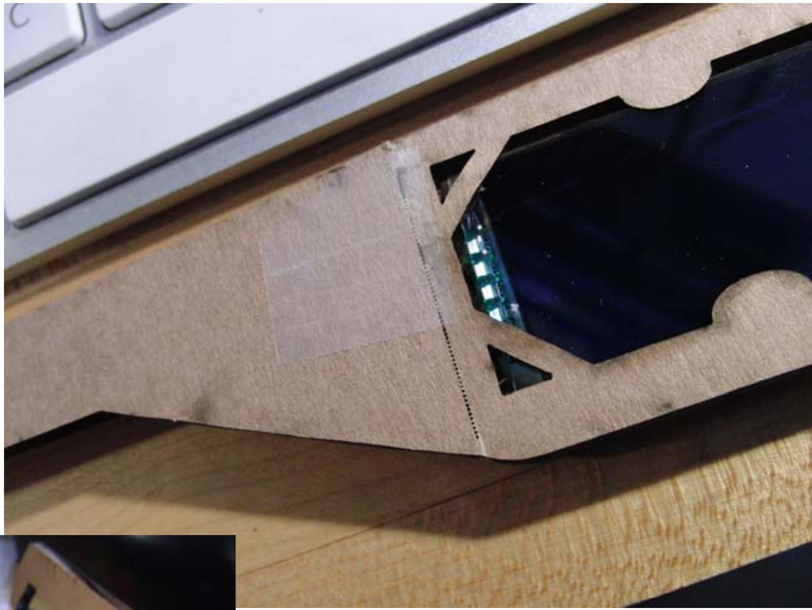
Cut corrugations out from one side



Slide in the shutter

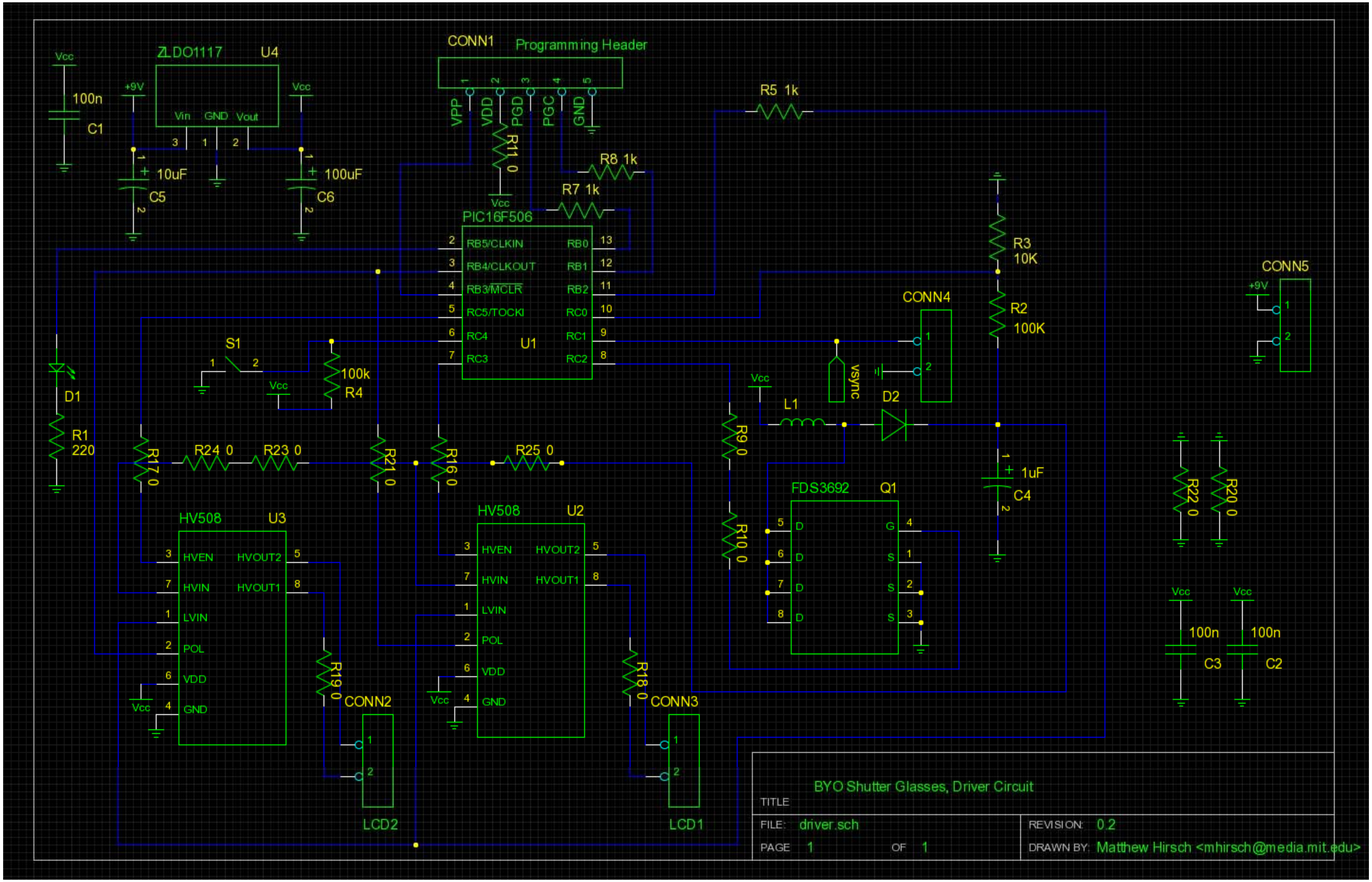
Frames Assembly





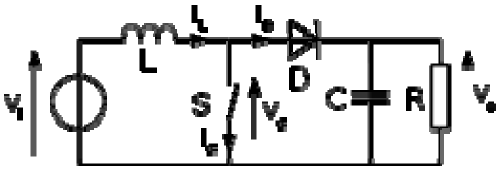
Tape will prevent
the hinge from tearing

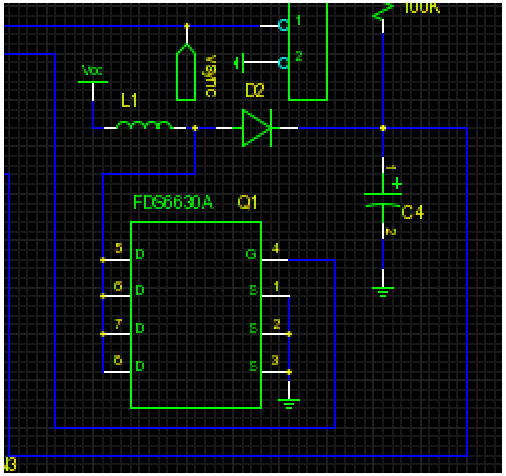
Electronics Schematic

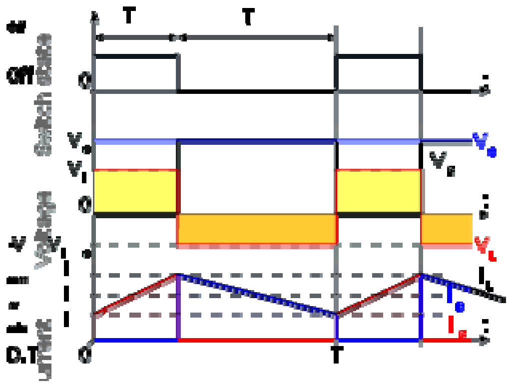


Powering the LCD: Simple boost supply

- Boost supply – generate 35v supply for LCD shutter
- Current through inductor generates high voltage when switched
- Charge stored on capacitor







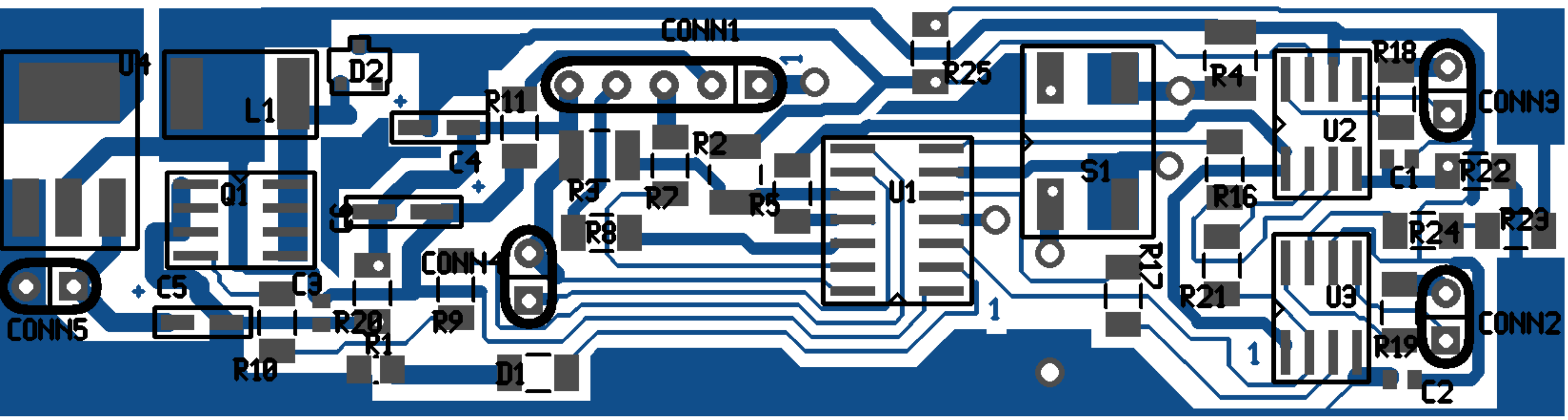
Microcontroller (PIC 16F506) code

- Code provided on our site (driver.c, GPL'd)
- Compiled with free version of HI-TECH C 9.70 (Available from Microchip website)
- Code responsible for
  - 1kHz background signal for LCD shutters
  - PWM + feedback for boost supply (35v for LCD)
  - Monitor sync pulses and flip LCD state
  - Monitor and software debounce polarity/delay button

Board layout

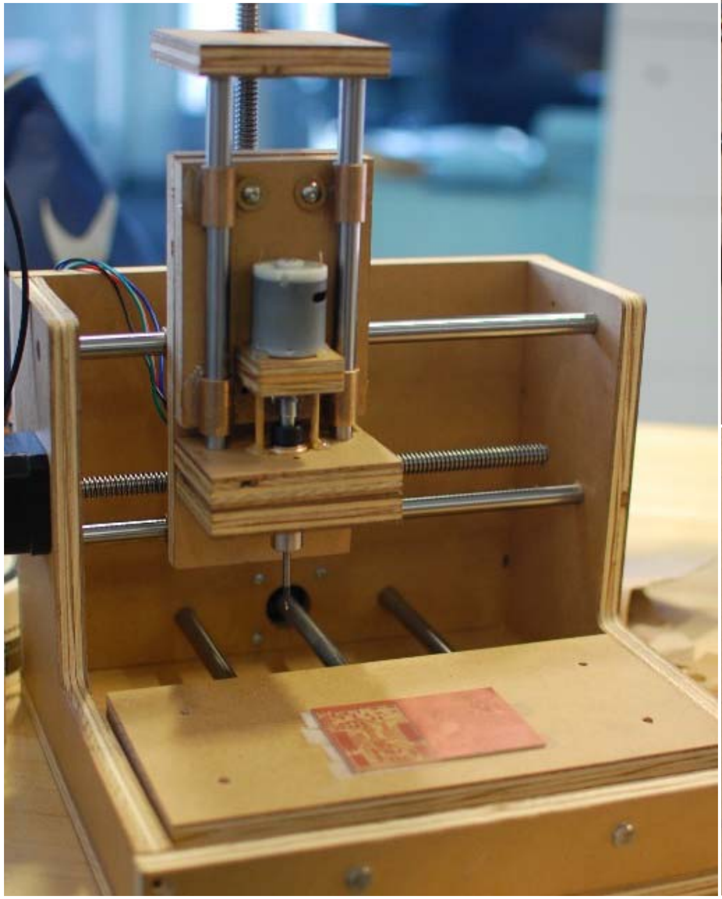
- gEDA tools:
  - gschem
  - pcb

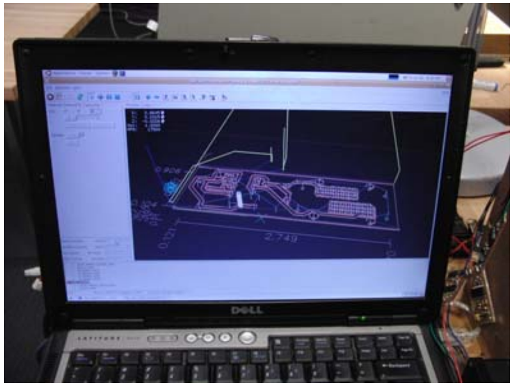
PCB Version 0.2

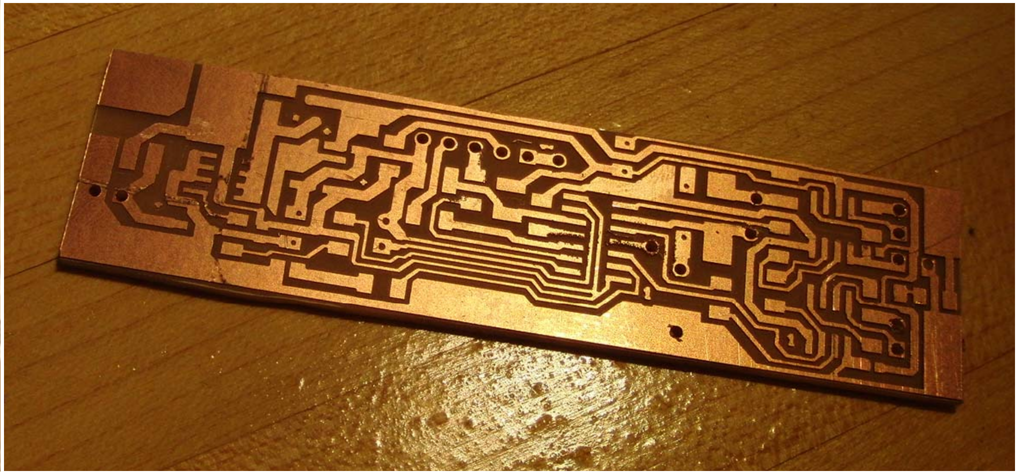


Creating the board: Milling machine

- David Carr's milling machine
- makeyourbot.org

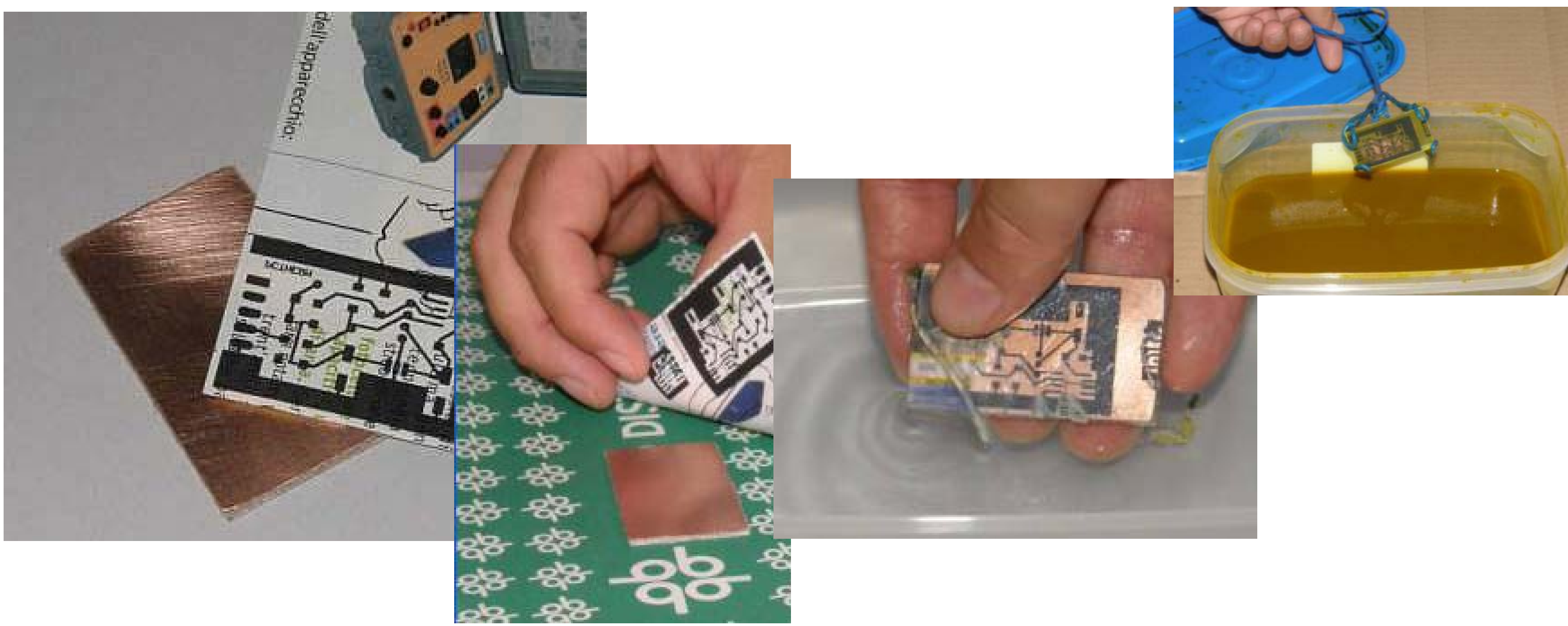




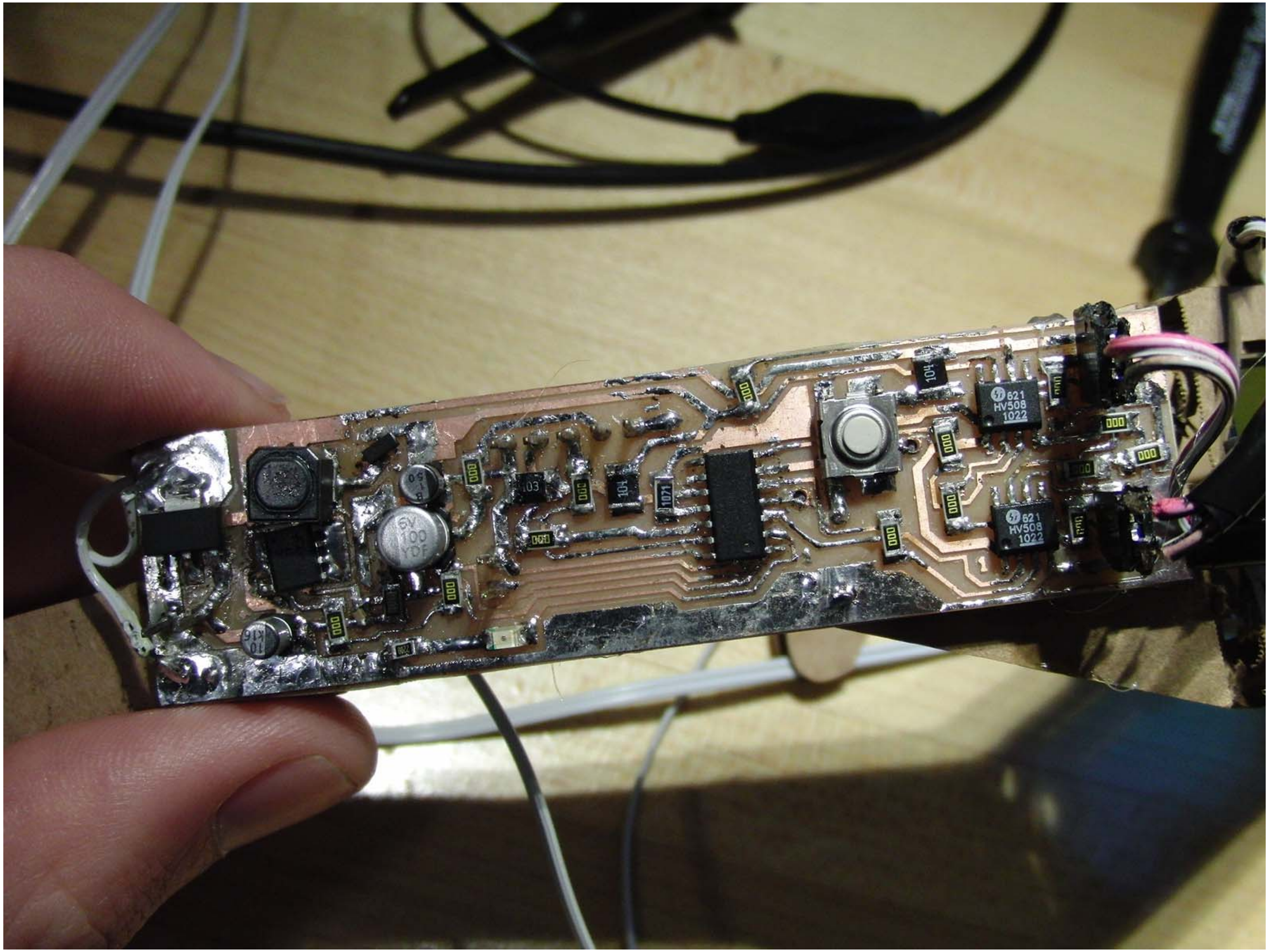


Creating the boar: Toner Transfer

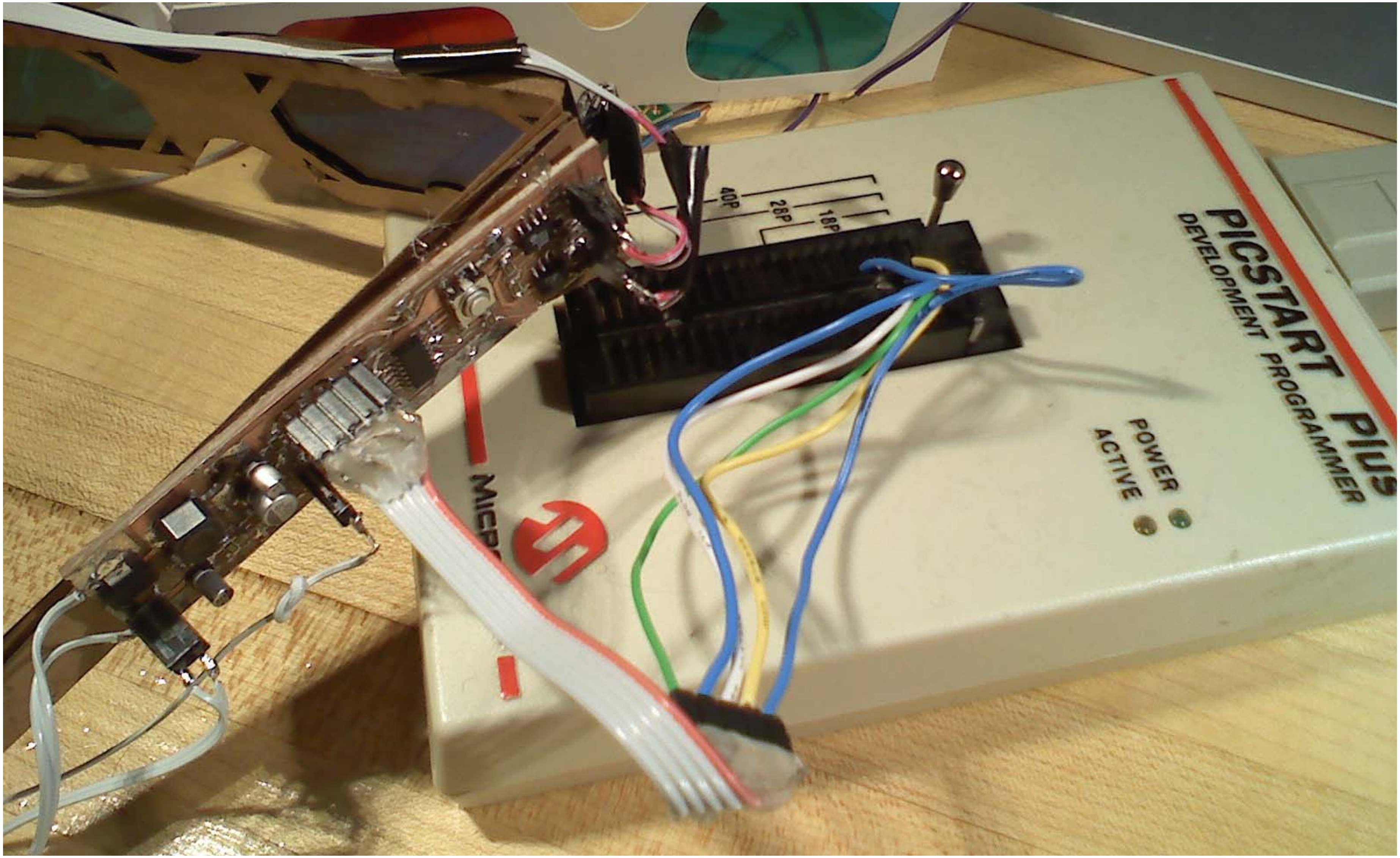
- Uses a laser printer to protect copper from acid (etching)
- http://www.riccibitti.com/pcb/pcb.htm



Solder parts

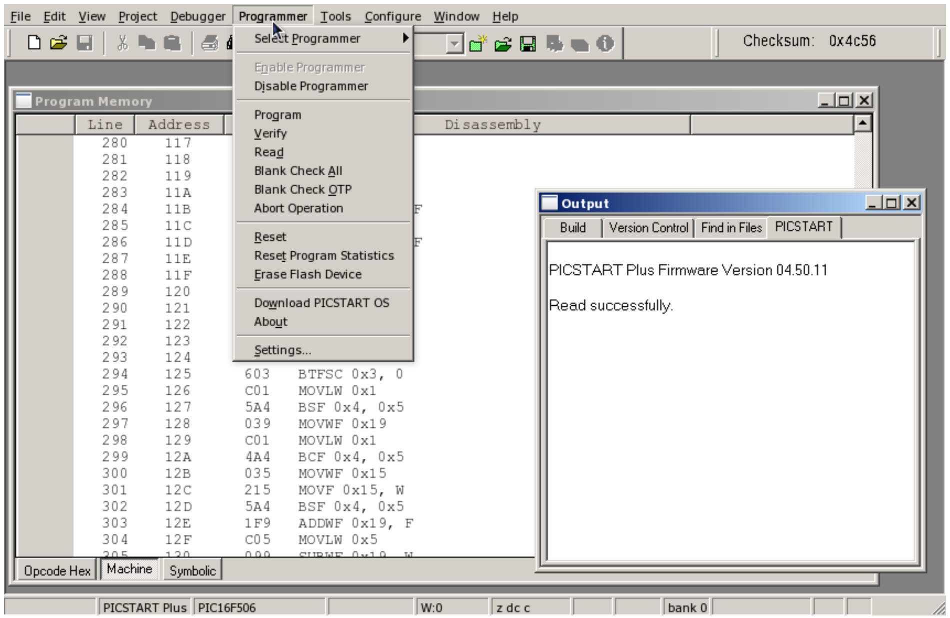


Program the microcontroller



I used an old Picstart Plus programmer wired to the ICSP header

Program the microcontroller: Software



For Picstart, MPLAB (provided by Microchip) will run in Windows or in Linux with Wine

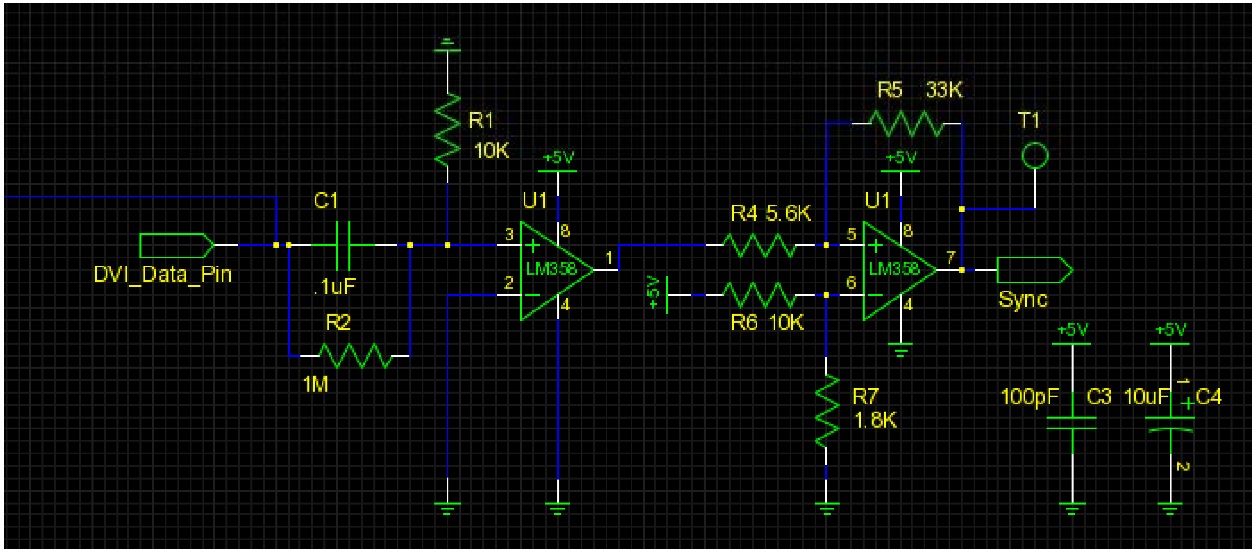
- Use any PIC programmer that supports in circuit serial programming
- MPLAB (Windows or Wine)
- Pikdev (Linux)
- Usbpicprog (when 16f506 supported) comes with its own IDE

Syncing the glasses to the screen

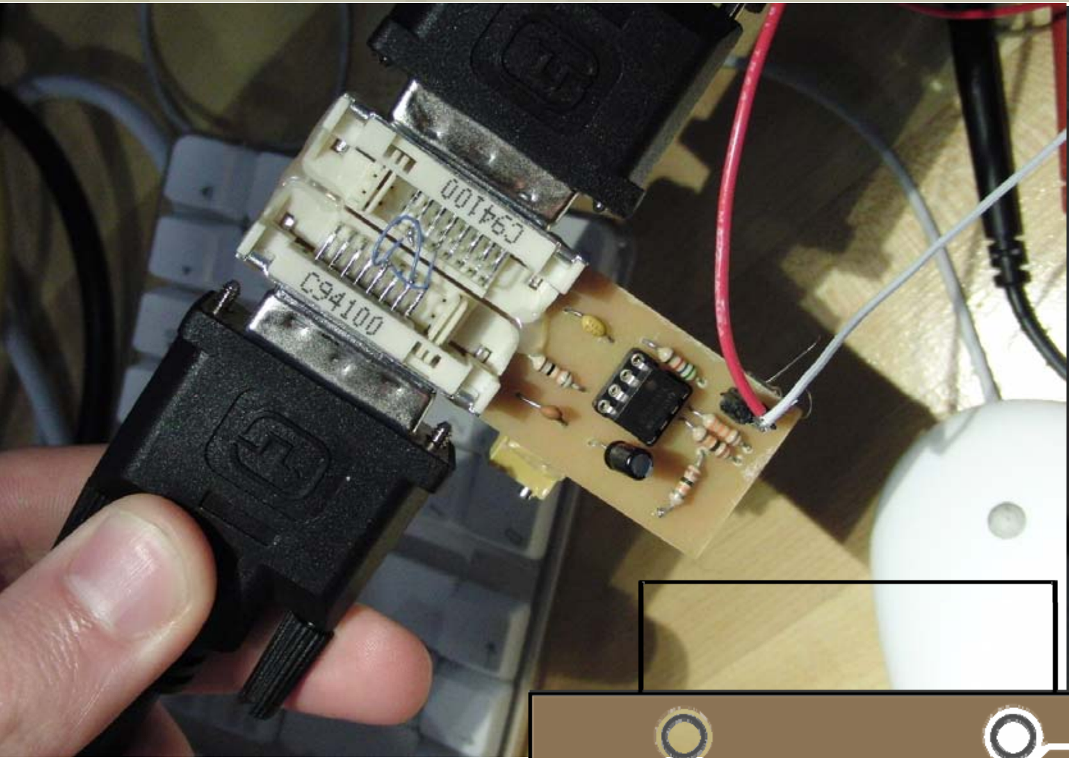
- VGA vsync pin connector
  - TTL level signal
  - Connect pin directly to onboard sync connector
- IR tower for nvidia or other glasses
  - Will require IR demodulator (design not included)
- Does not detect sense, like professional glasses – Push button to swap left and right eyes

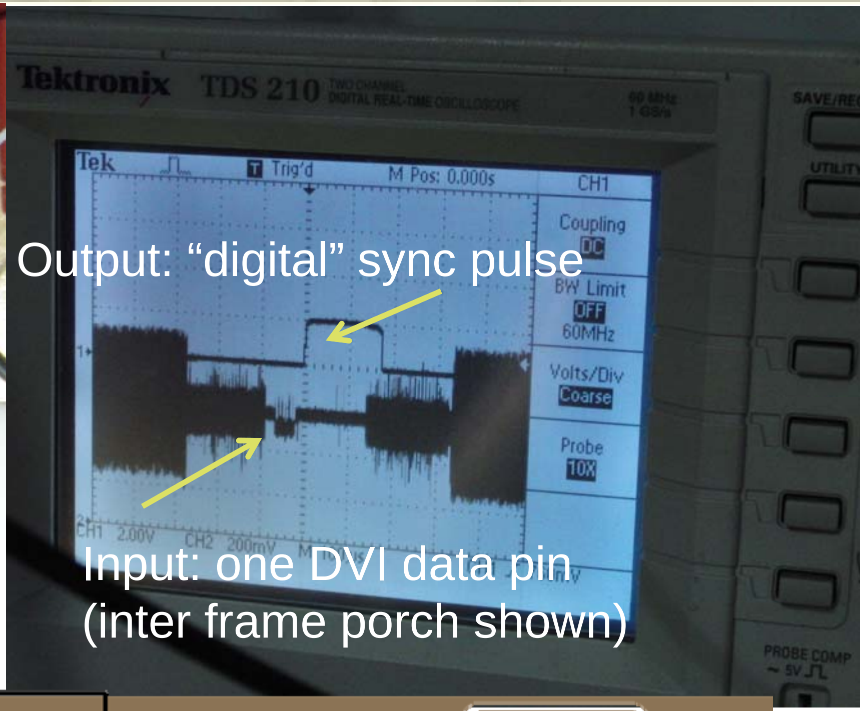
Syncing with DVI

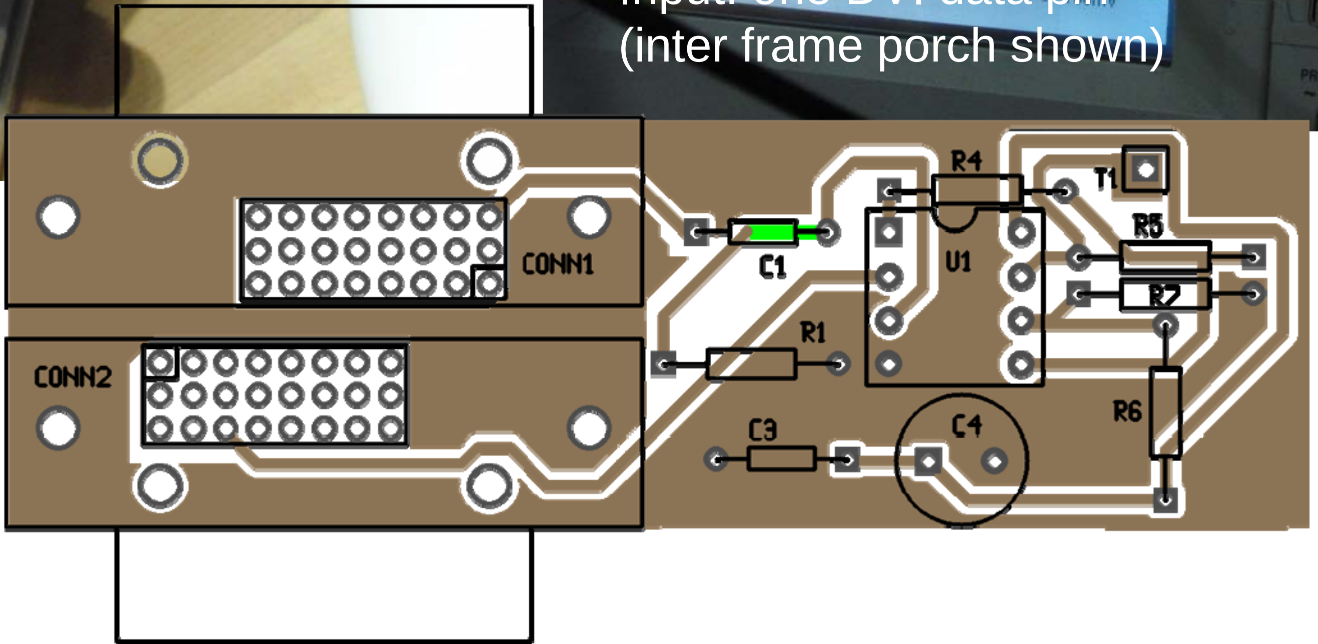
- A horrible hack!
- Most modern shutter-glasses compatible screens use DVI only at 120Hz
- Analog method to extract sync pulse from DVI (Digital Video Interface)



DVI Sync Extractor



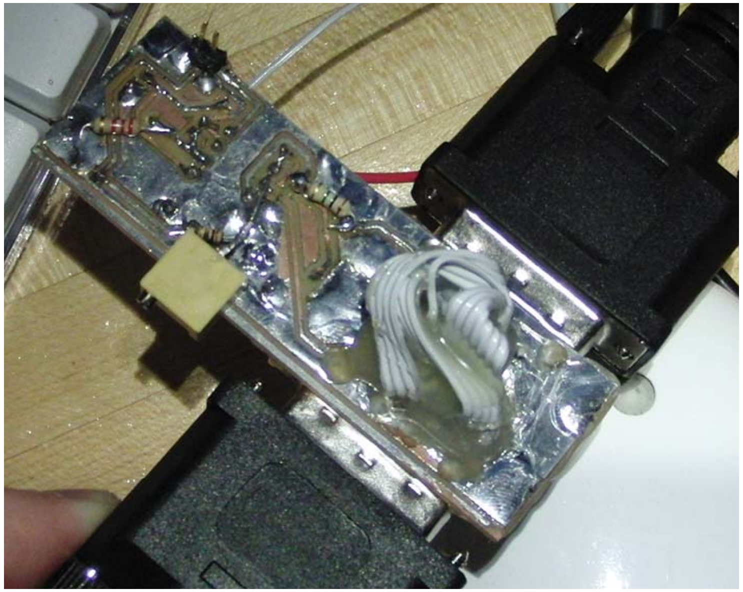




Simple op-amp comparator followed by a Schmitt Trigger. The bandwidth of the op-amp (TI TLV2462 CP) filters out the high-frequency DVI content.

Building DVI Sync Extractor

- Board fabricated using same method as for shutter glasses
- Source is provided on course website
- DVI connectors coupled with ribbon cable
  - Traces would be too small to thread through pins on single sided board
- Will probably need to tweak for your video card



DVI Sync Extractor Parts List

- DiDigikey Parts List: $13.00

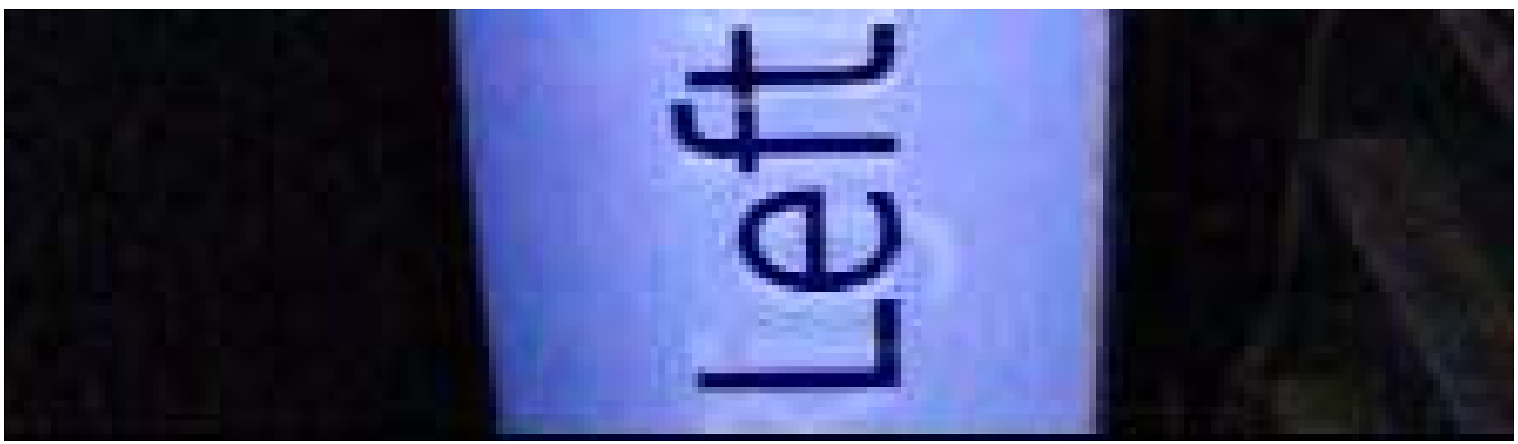
Part Description	Digikey Part Number	Qty	Cost
DVI Connector	WM5601-ND	2	9.52
Op-amp TLV2462	296-1893-5-ND	1	2.51
5v Regulator	ZLDO1117G50DICT-ND	1	0.62
10K TH Resistor	P10KBACT-ND	3	0.234
33K TH Resistor	P33KBACT-ND	1	0.078
5.6K TH Resistor	P5.6KBACT-ND	1	0.078
1M TH Resistor	P1.0MBACT-ND	1	0.078
.1uF TH Capacitor	478-3156-1-ND	1	0.16
100pF TH Capacitor	BC1042CT-ND	1	0.076
10uF TH Capacitor	P10393TB-ND	1	0.026

- May also want DVI cables

Part Description	Digikey Part Number	Qty	Cost
Male-Male DVI Cable	Q379-ND	2	29.46

Putting everything together

- Choosing the right monitor is important



- 60Hz monitors with slower crystals/drive circuitry will create too much crosstalk

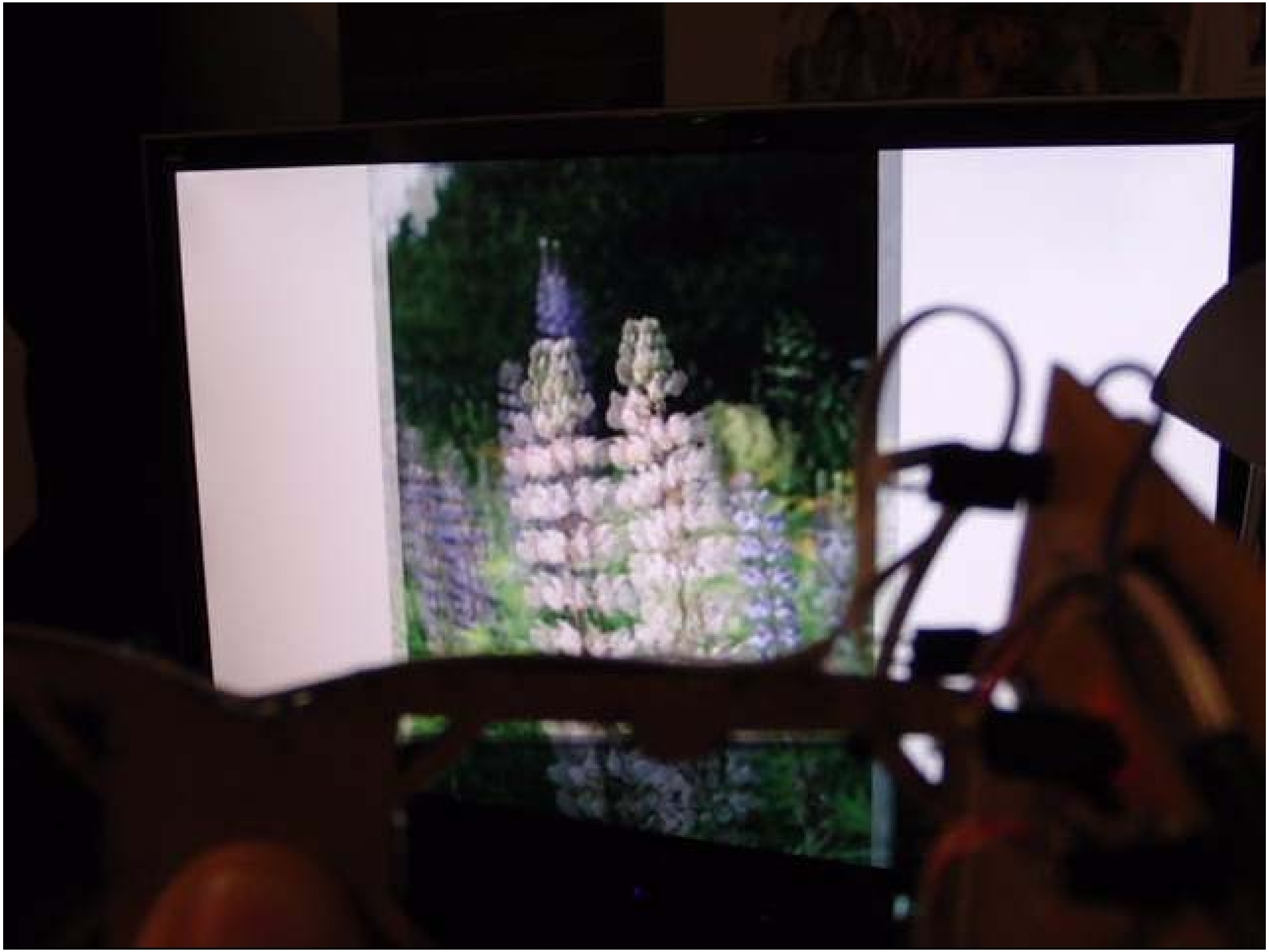
Putting everything together

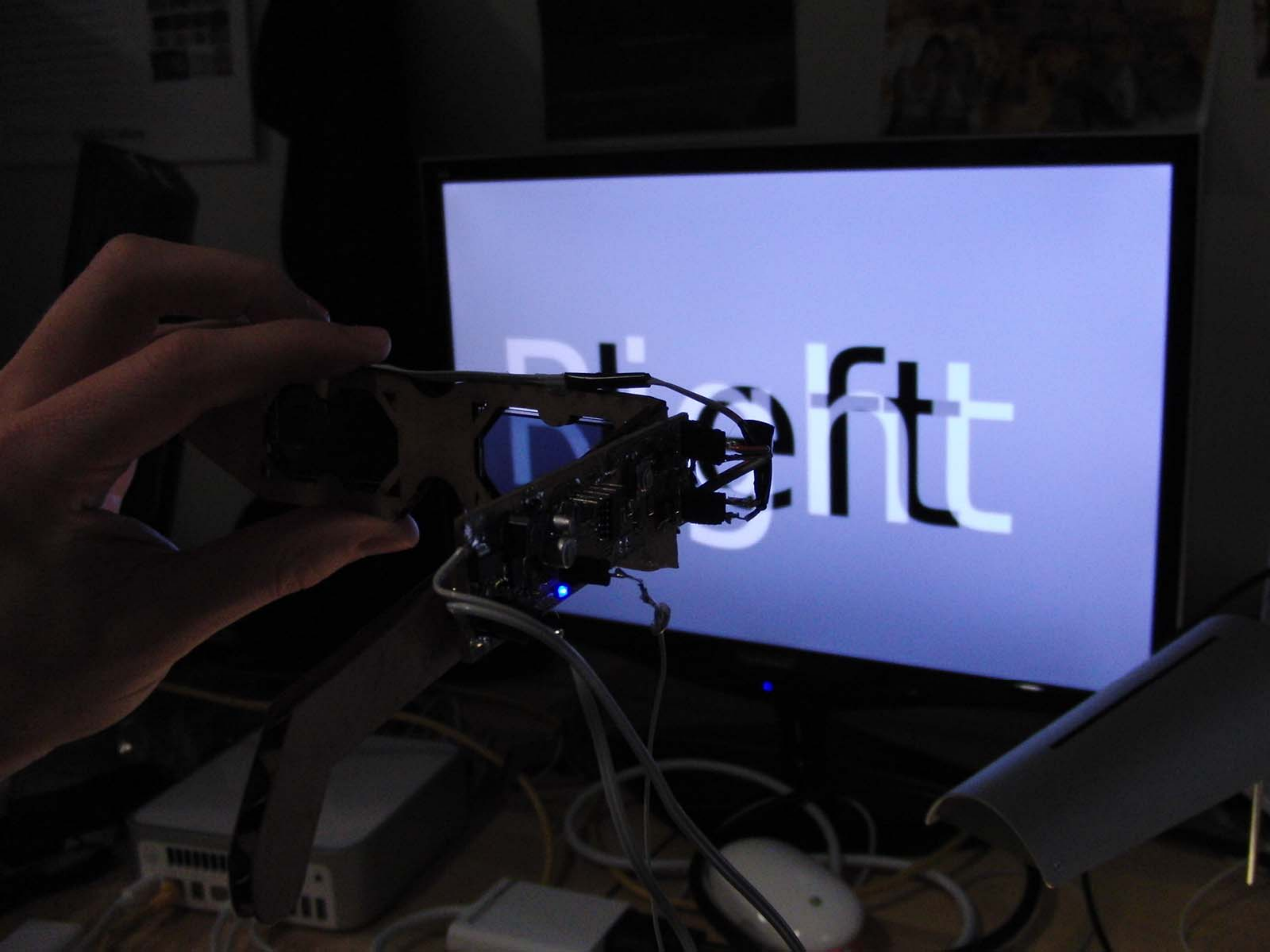
- We use a Viewsonic vx2268wm

- Not only is refresh rate 120Hz, but LC response time is faster than I can measure with 1000fps camera.

User’s view

User's view





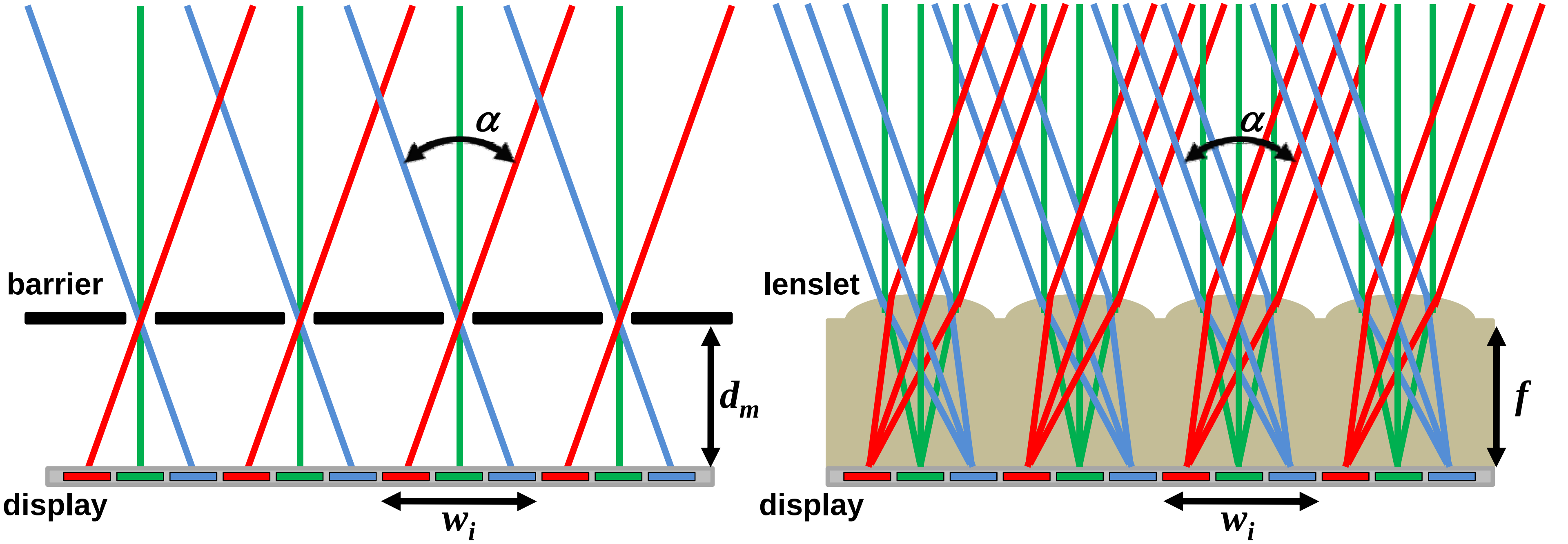
Course Outline

- Introduction: History and Physiology
- Representation and Display
- Glasses-bound Stereoscopic Displays
- ***Unencumbered Automultiscopic Displays***
- Source Material: Rendering and Capture
- Emerging Technology
- Conclusion and Q & A

Course Outline

- Introduction: History and Physiology
- Representation and Display
- Glasses-bound Stereoscopic Displays
- ***Unencumbered Automultiscopic Displays***
- Source Material: Rendering and Capture
- Emerging Technology
- Conclusion and Q & A

Parallax Barriers vs. Lenslet Arrays



Parallax Barrier **Lenselet Array**

Two alternatives for spatially-multiplexed automultiscopic display:

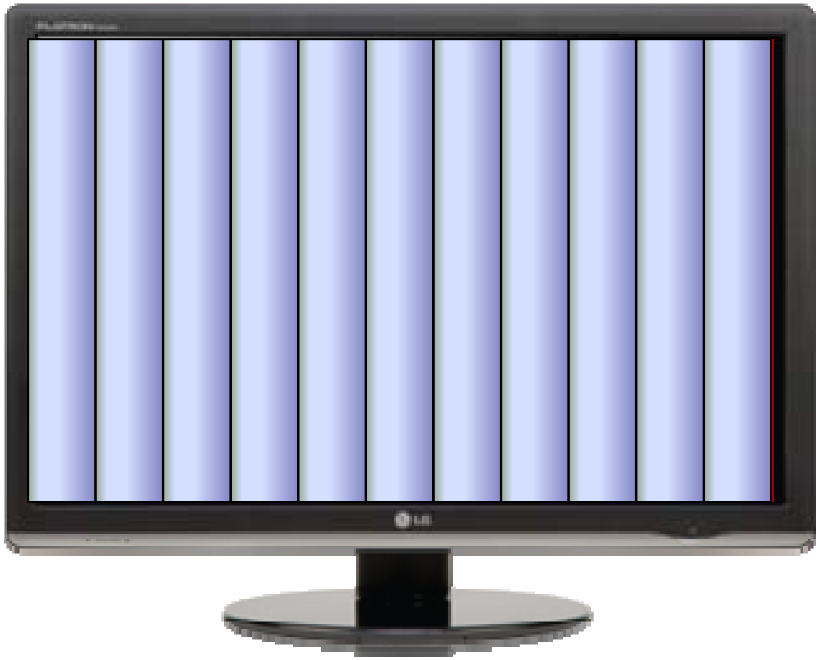
- – Attenuating masks using *parallax barriers* [Ives, 1903]
- – Refracting *lenslet arrays* [Lippmann, 1908]

- Barriers cause severe attenuation → dim displays
- Lenslets impose fixed trade-off between spatial and angular resolution

How to select mask/lenslet properties and generate base images?

Achieving 1D vs. 2D Parallax

1D Parallax Barrier



1D Lenslet Array

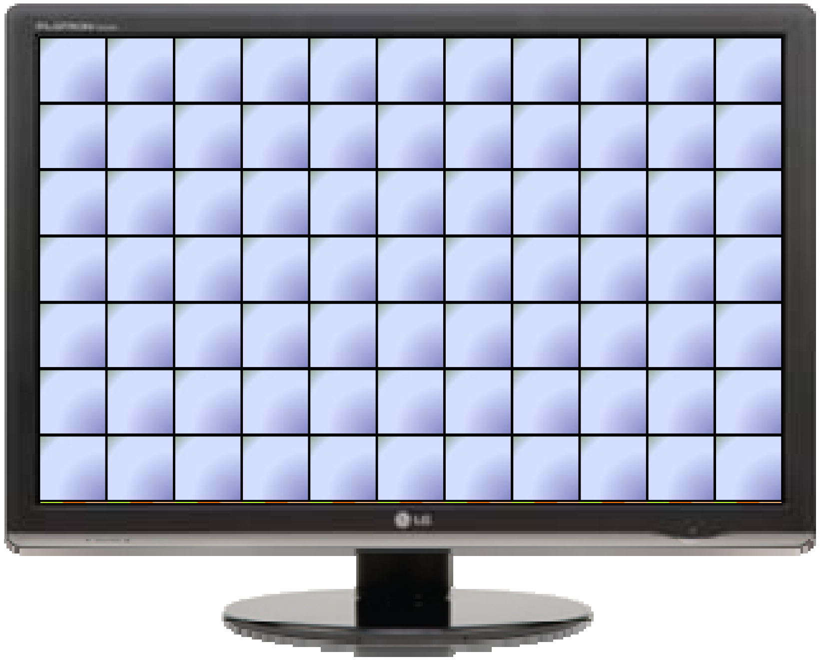
Supporting Horizontal-only Motion Parallax

- Parallax barrier has a vertically-extended base (rear) and slits (front)
- Lenslets are linear array of cylindrical lenses (i.e., a lenticular sheet)

Depth perception not supported when viewed "sideways"

Achieving 1D vs. 2D Parallax

2D Parallax Barrier



2D Lenslet Array

Supporting Horizontal and Vertical Motion Parallax

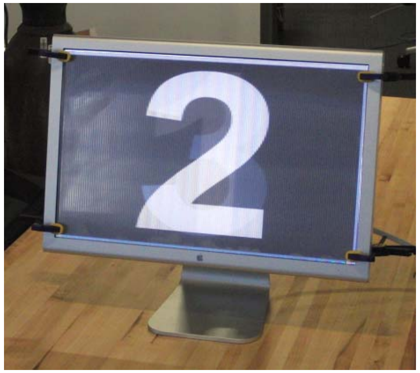
- Parallax barrier has an interlaced base (rear) and pinhole array (front)
- Lenslets consist of a 2D array (i.e., a “fly’s eye" lens array)

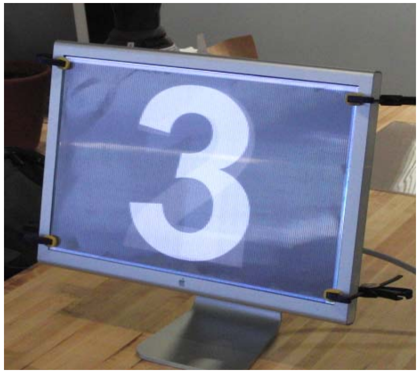
Requires additional views → slower rendering and lower resolution

Pinholes further reduce brightness of parallax barrier displays

Constructing a Lenticular-based 3D Display

Paper Vellum Diffuser Lenticular Sheet

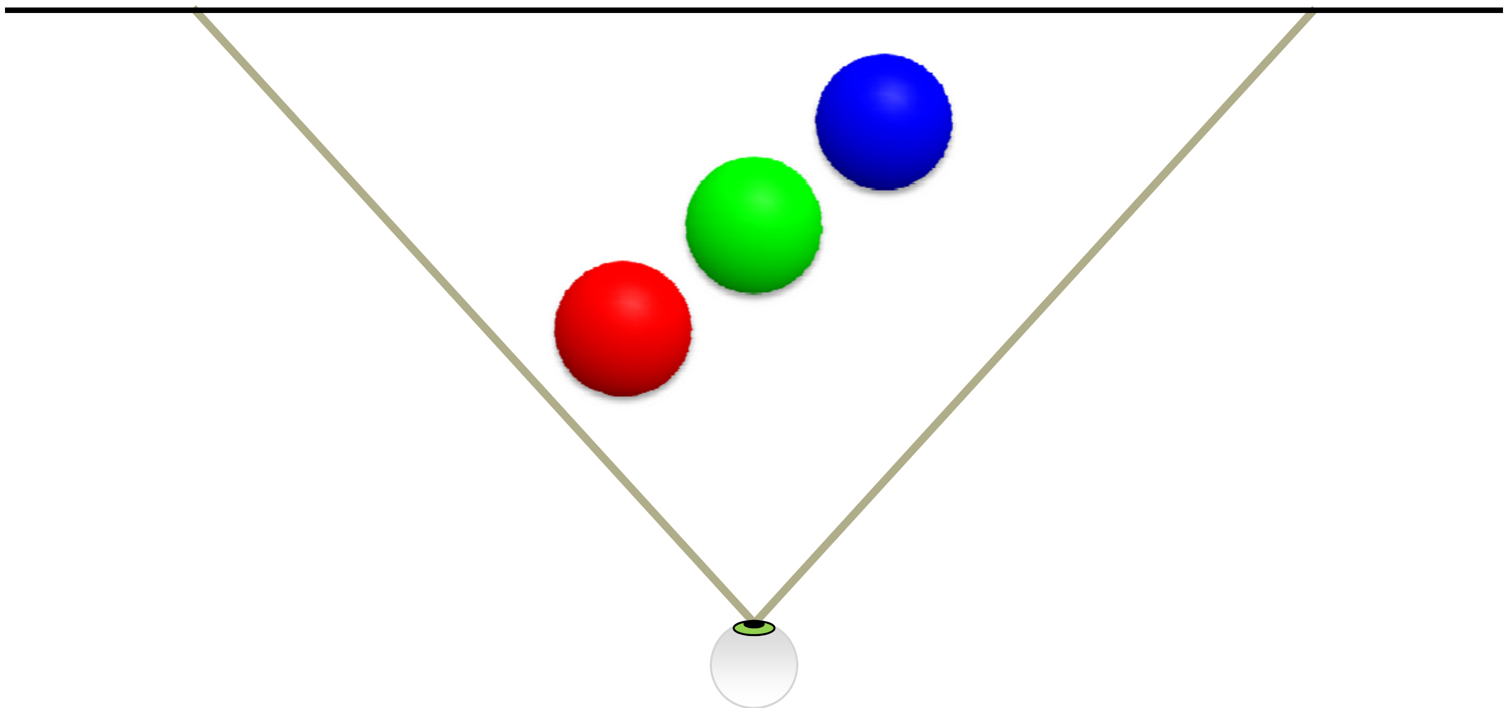




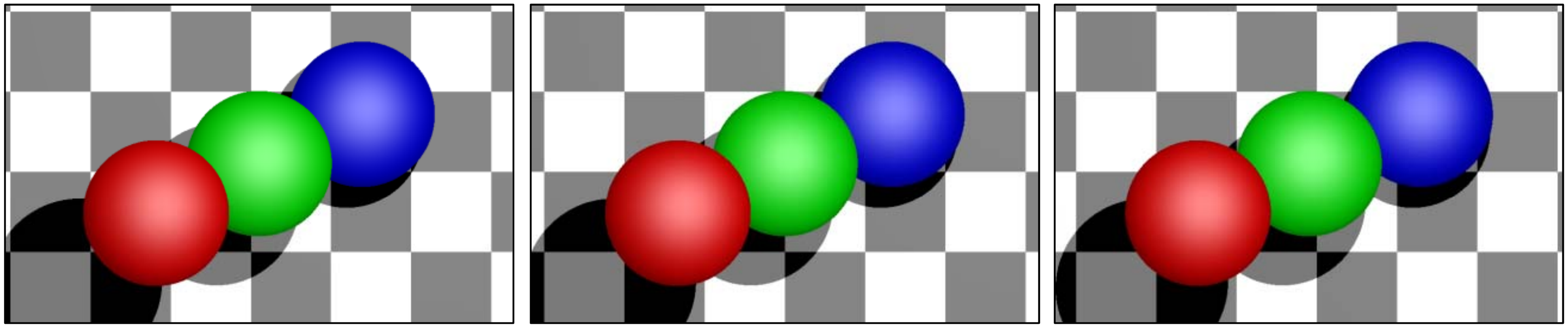
Parts List [$110-$290, but only $110 if an existing LCD monitor is used]

- [1] LCD monitor (e.g, ViewSonic VX2433wm 24") [$180]
- [1] Paper vellum diffuser (e.g., Bee Tracing Roll 68LB) [$25] (see: http://www.pearlpaint.com/)
- [1] Lenticular Sheet (e.g., Micro Lens Technology 22"x28" 10 or 20-3D LPI) [$85] (see: http://www.microlens.com/)
- Additional mounting hardware (tape, clamps, framing, etc.)

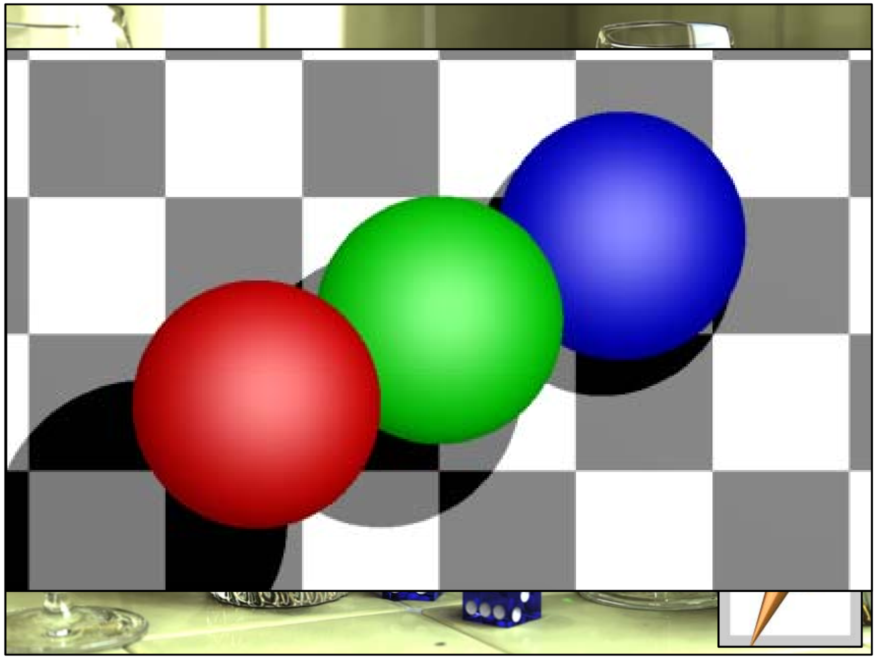
Generating Content:
Input is a Light Field (i.e., 1D Array of Images)



viewer moves right →

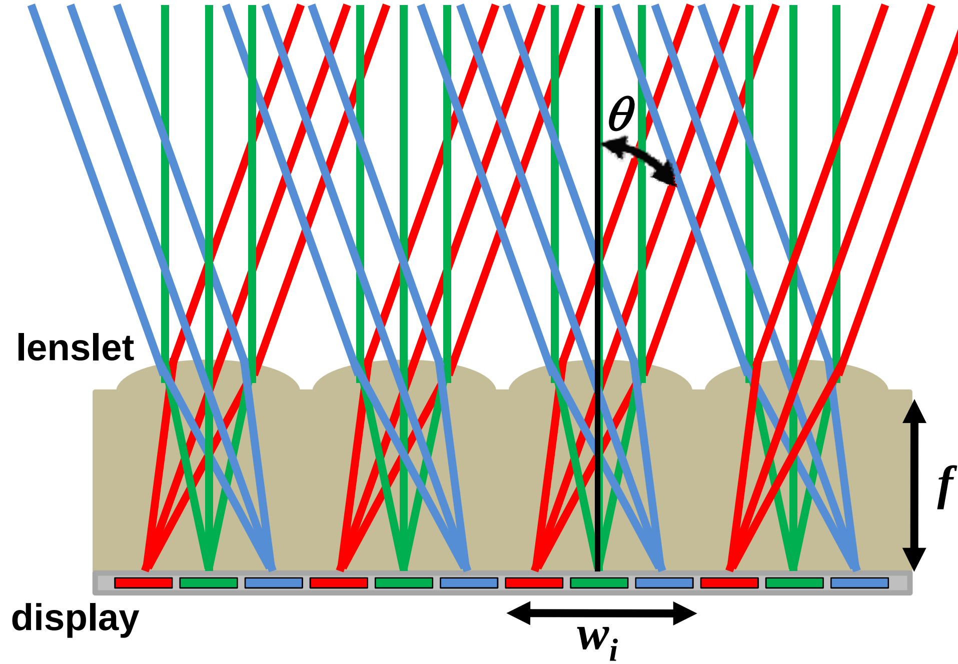


Generating Content:
Ray Tracing using POV-Ray



POV-Ray Example

Oblique Projection

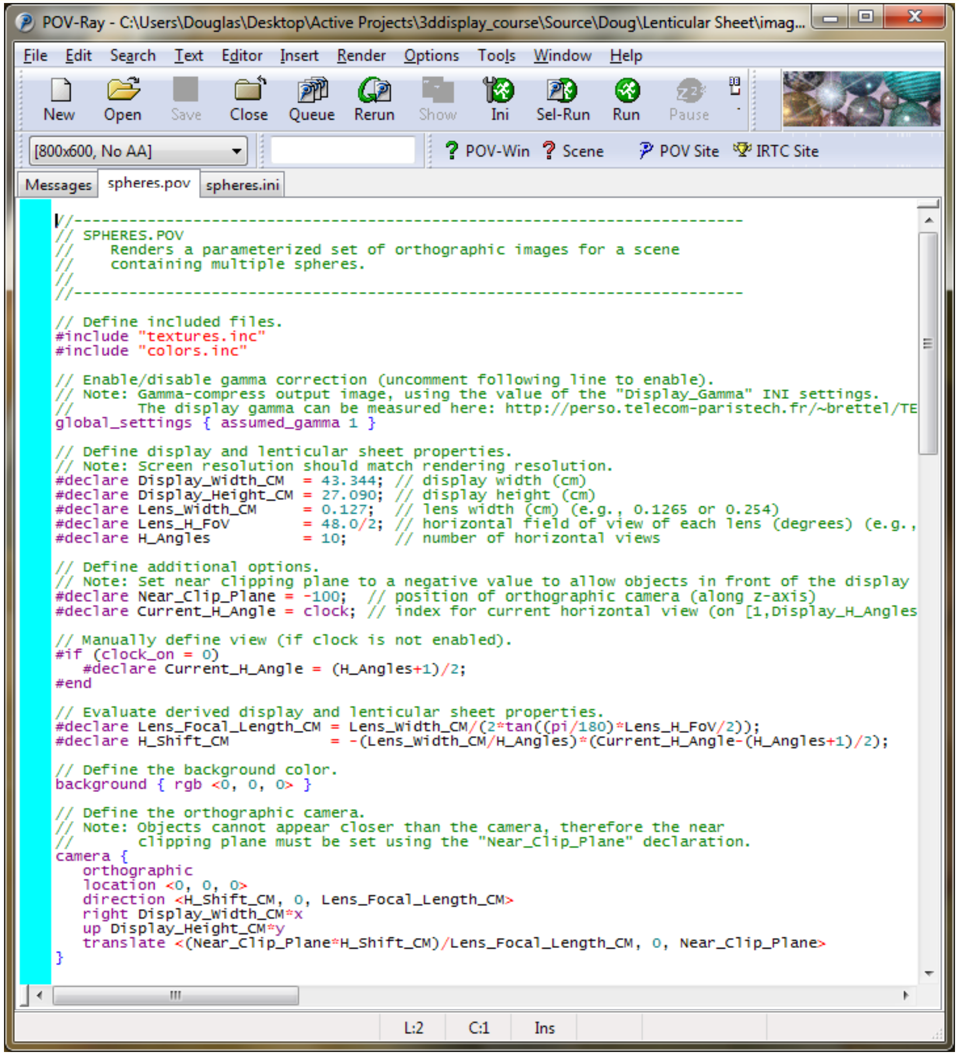


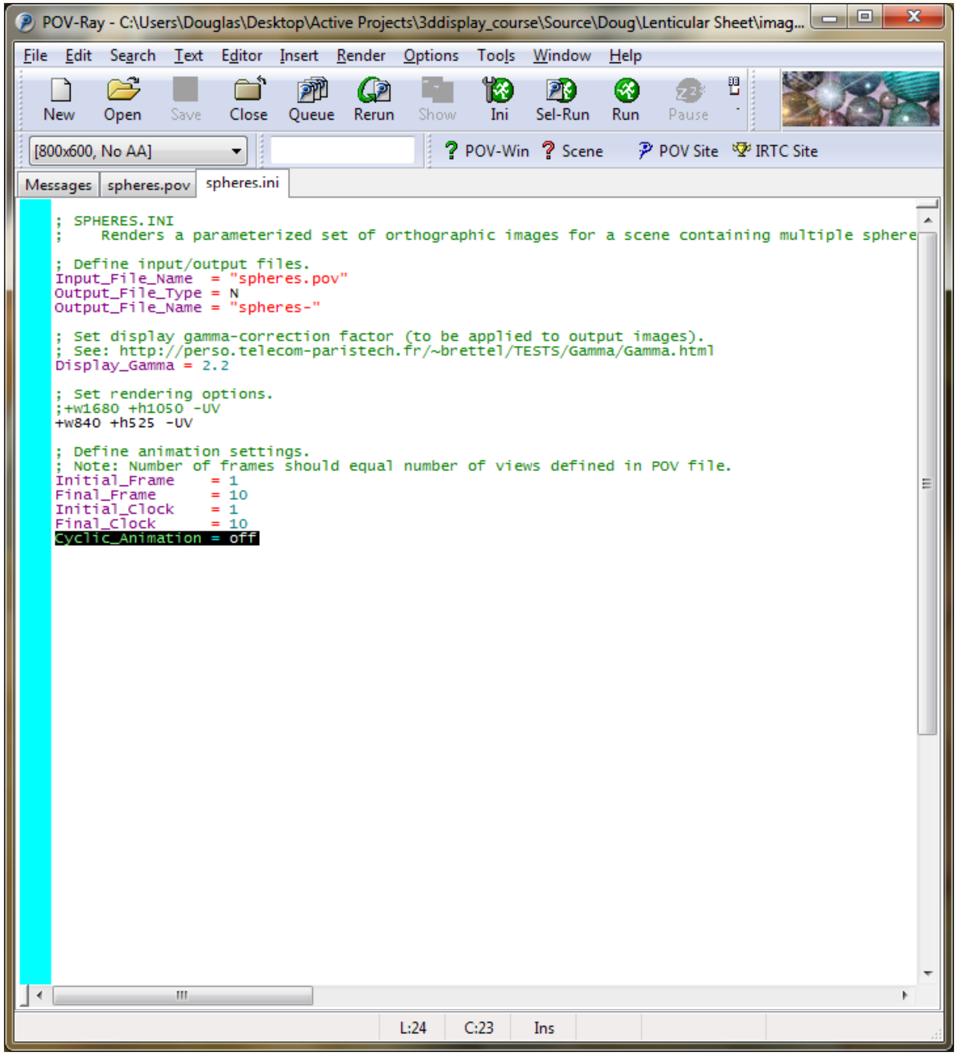
Lenselet Array

Generating Light Fields using POV-Ray

- Freeware ray tracer (see http://www.povray.org/)
- Supports oblique projections (i.e., skewed orthographic cameras)
- Could also use OpenGL, etc. (anything that can generate light fields)

Generating Content:
POV-Ray Demonstration

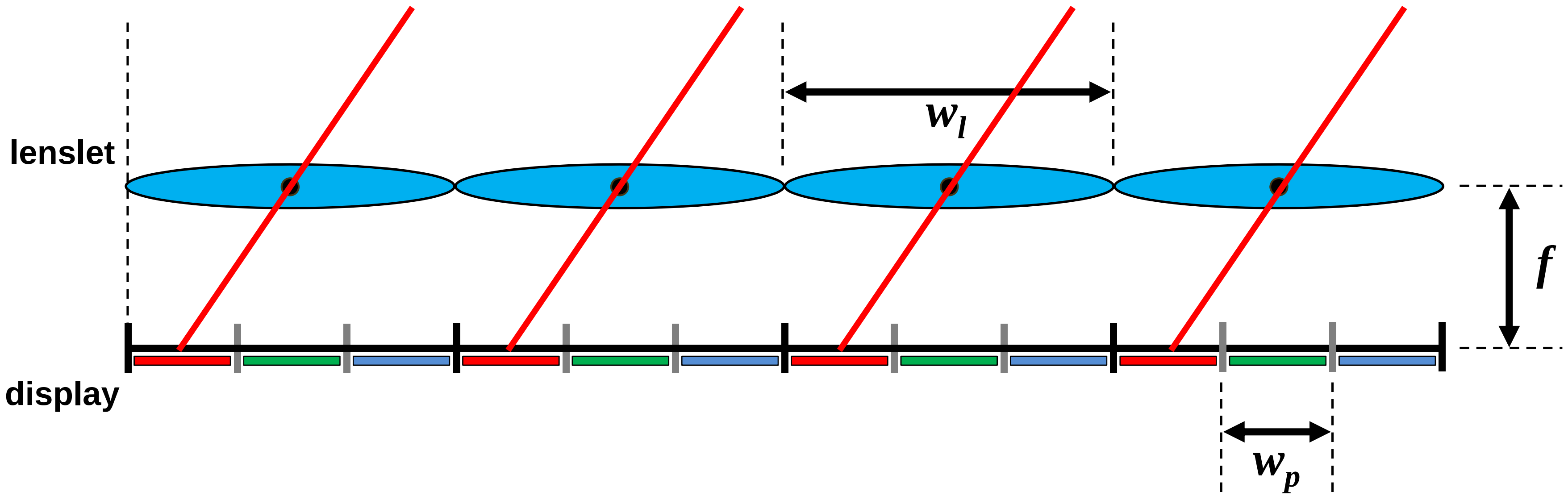




Generating Light Fields using POV-Ray

- Freeware ray tracer (see http://www.povray.org/)

Interlacing Content:
Evaluating Spatially-Multiplexed Base Images



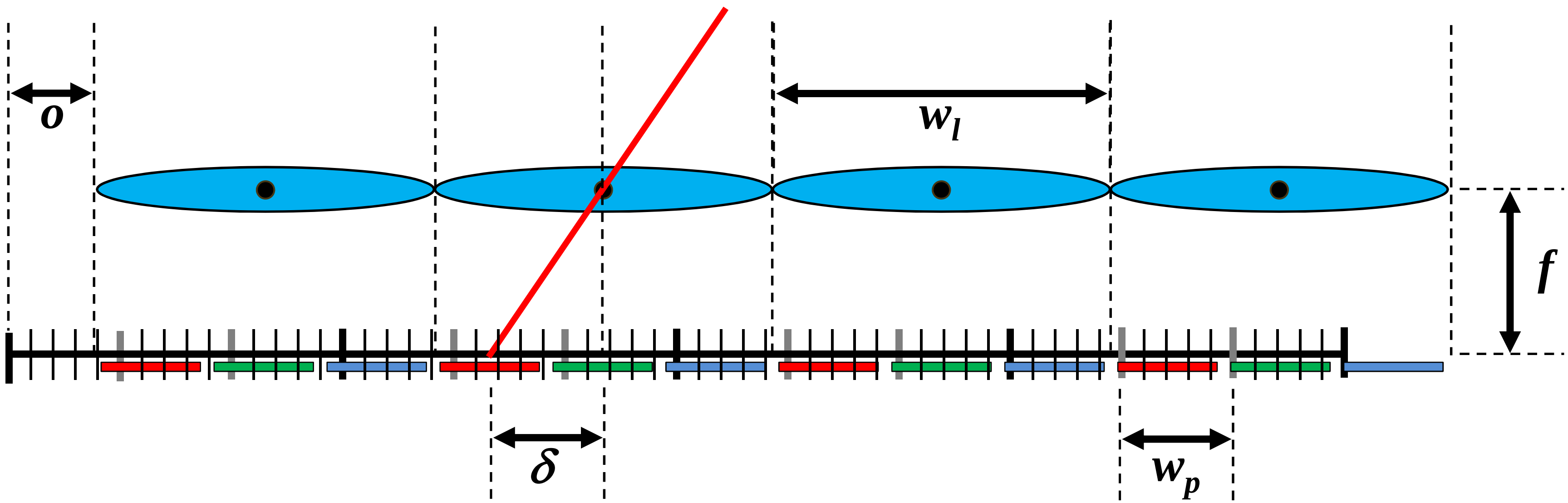
Generating the Interlaced (Base) Image

- Straightforward if lenslet width is an integer multiple of pixel width
- Practically, this is only achieved with custom-manufactured lenslets
- However, could be achieved with custom-printed parallax barrier…

An interlacing algorithm is needed to generate the base image

- Must handle non-integer lens:pixel ratios → spatio-angular antialiasing
- Must accommodate calibration error

Interlacing Content:
Evaluating Spatially-Multiplexed Base Images

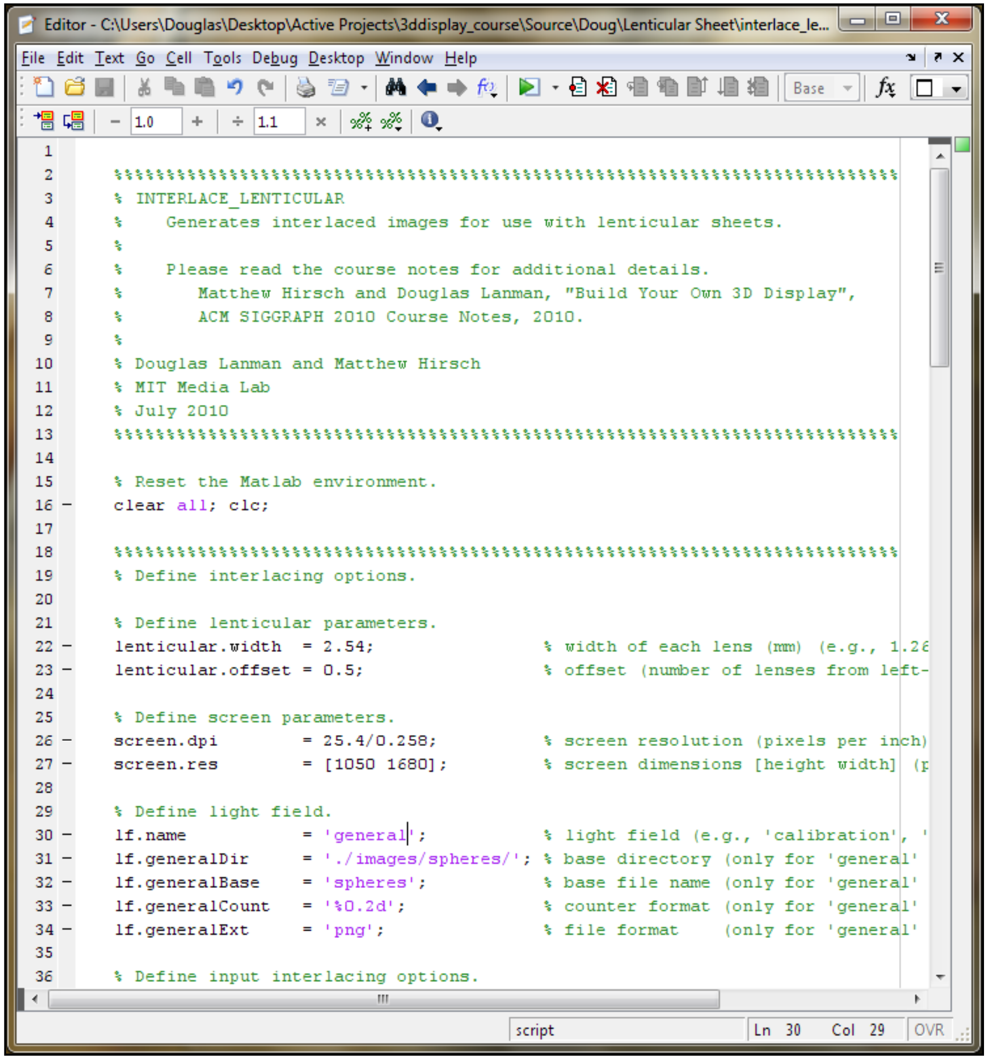


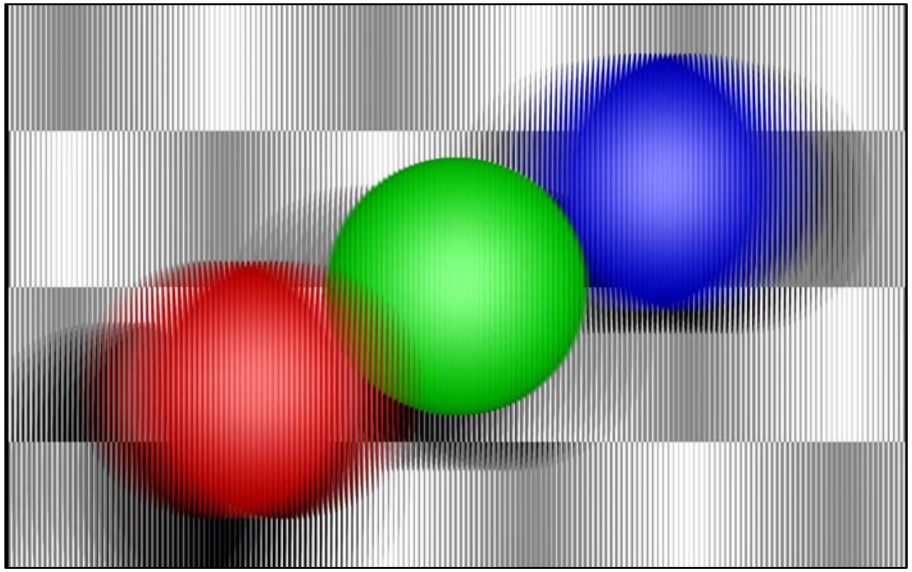
Generating the Interlaced (Base) Image

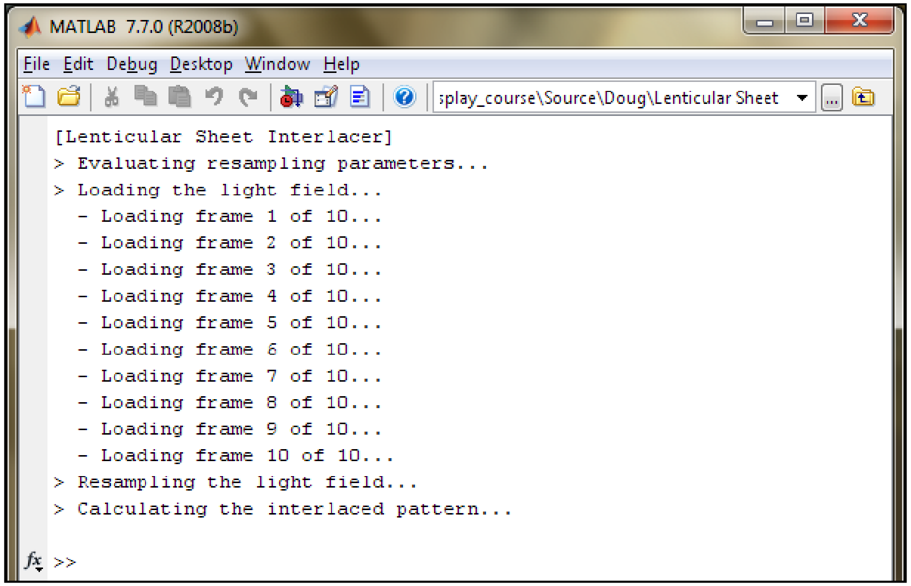
- Pixel pitch and lenslet width must be measured (or found from spec.)
- Must define offset between lenslet array and screen (calibration error)
- First, evaluate closest lenslet for each pixel → spatial image sample
- Second, evaluate offset from lenslet center → angular viewpoint

Antialiasing by oversampling (i.e., average samples in each pixel)

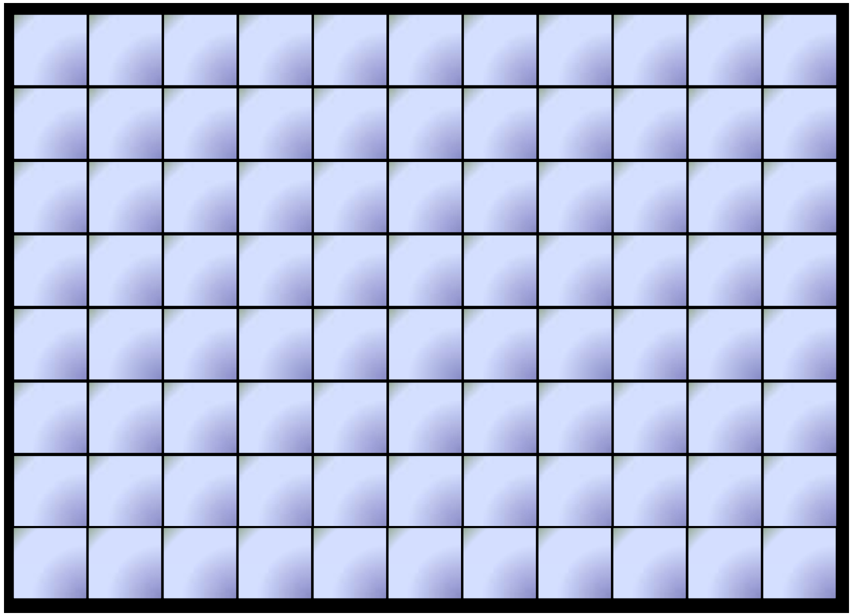
Interlacing Content:
MATLAB Demonstration

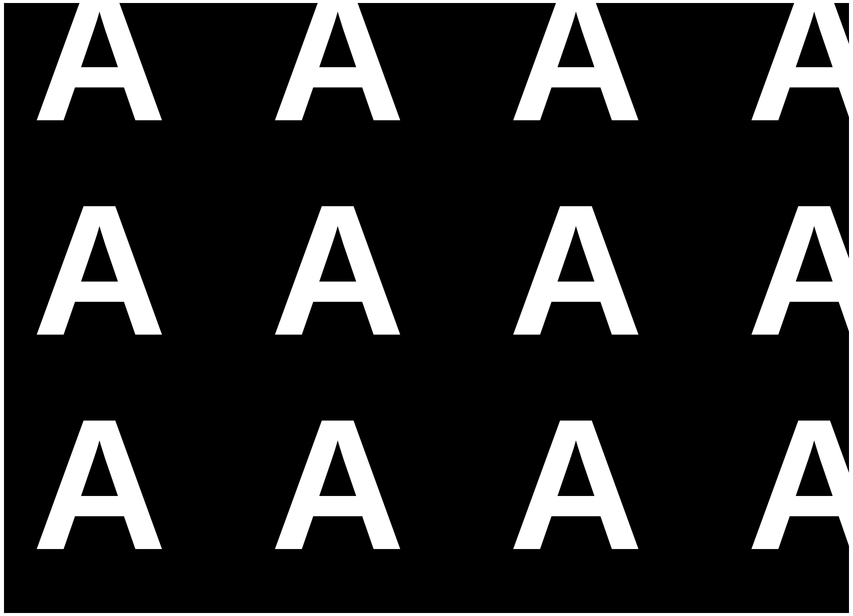






Aligning the Lenticular Sheet:
Using a *Moiré Magnifier* for Calibration





How to align the lenslet array with the screen pixels?

- Interpolation assumes no relative rotation
- Can interpret as a *moiré magnifier* [Hutley et al., 1994]
  - Viewing an array of images through lenslets produces magnified images
  - Relative pitch/orientation determines scaling/rotation of magnified images

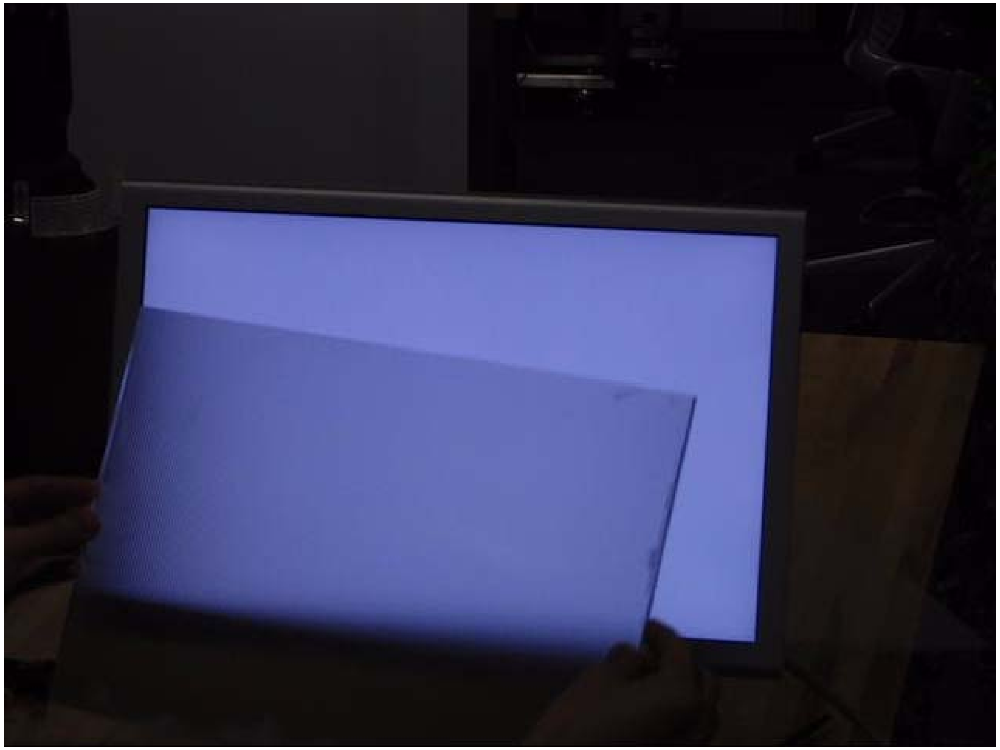
M. C. Hutley , R. Hunt , R. F. Stevens and P. Savander. The Moiré Magnifier. Pure and Applied Optics, 1994

Aligning the Lenticular Sheet: Demonstration

Alignment Procedure

- Display blank white image on screen (color filters emphasized here)
- Place lenticular sheet in direct contact with the screen
- Rotate lenticular sheet until the magnified pixels are vertically aligned

Aligning the Lenticular Sheet: Demonstration

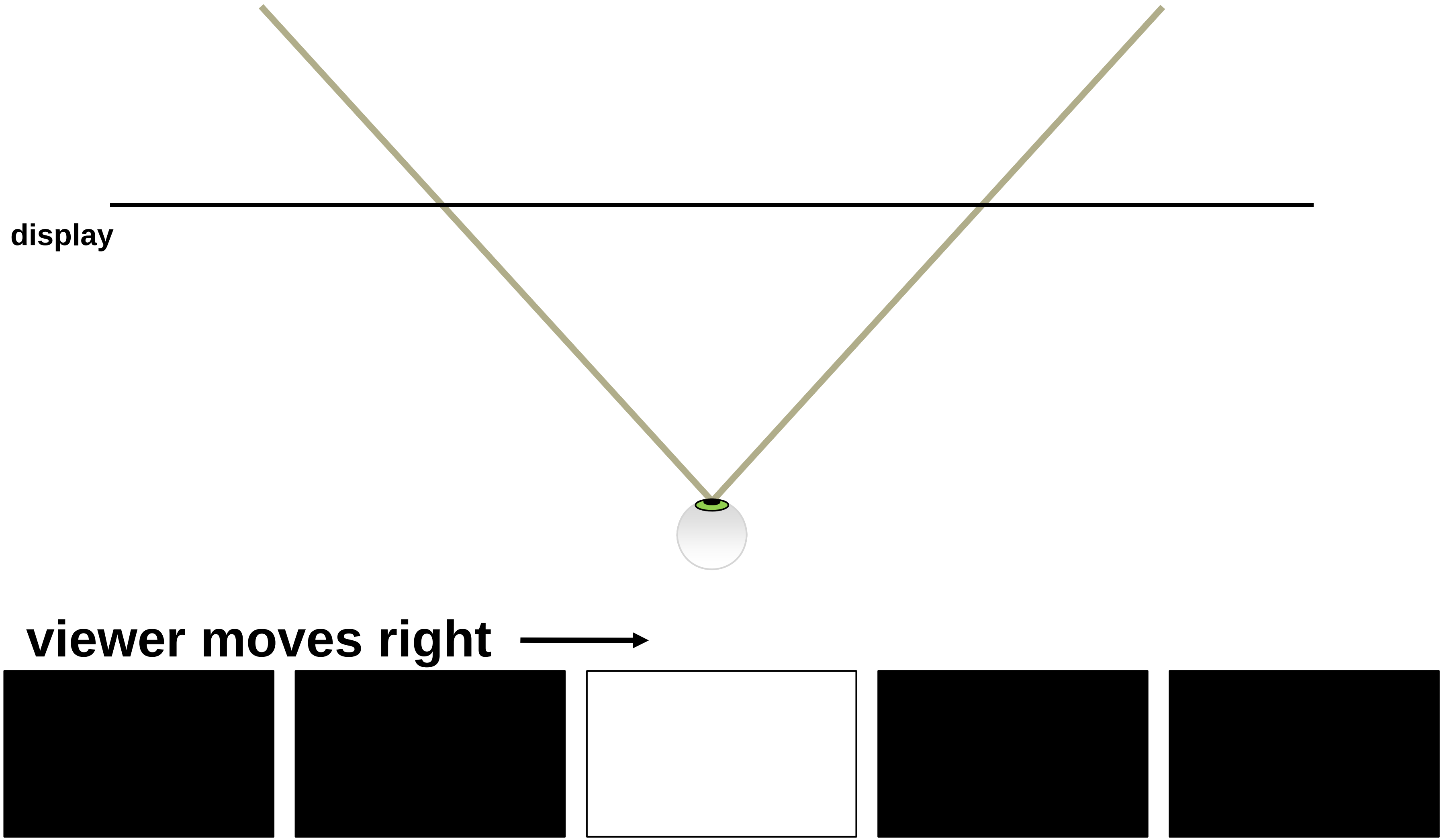


Manual Alignment

Alignment Procedure

- Display blank white image on screen (color filters emphasized here)
- Place lenticular sheet in direct contact with the screen
- Rotate lenticular sheet until the magnified pixels are vertically aligned

Calibrating the Screen DPI and Lenslet Width:
Generating a Calibration Sequence



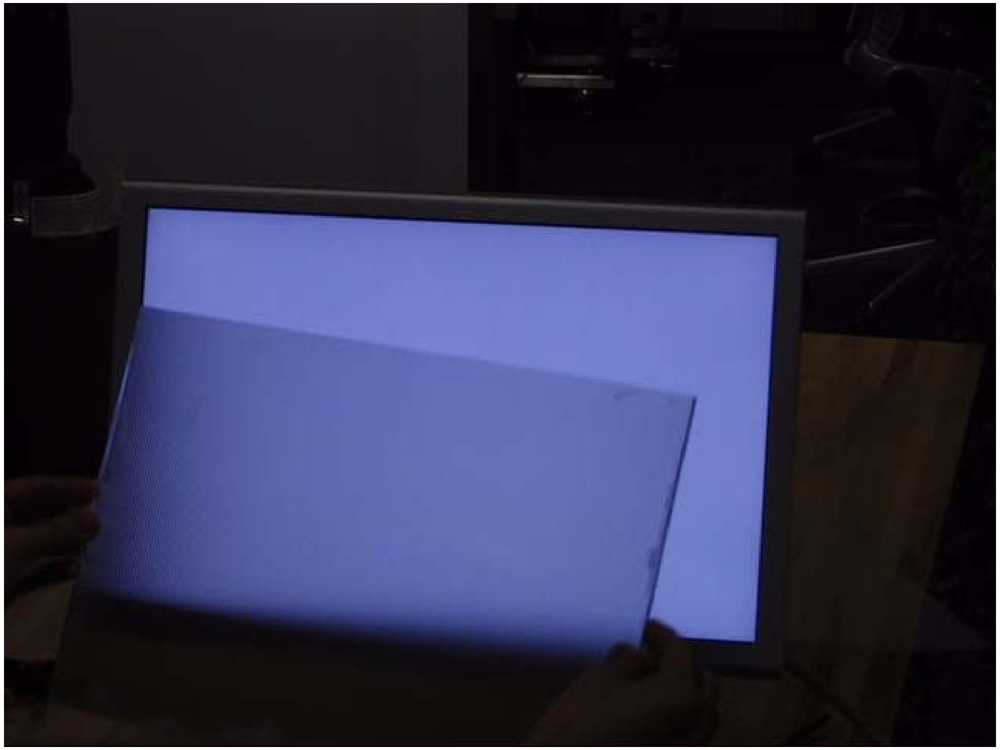
Calibration Light Field
(only the "central view" is visible)

Calibrating the Screen DPI and Lenslet Width: Demonstration

Calibration Procedure

- Assign the screen dots-per-inch (DPI) and lenslet width
- Generate an interlaced image (one white pixel below each lens)
- When calibration is correct, no magnified stripes will be visible (i.e., screen is white when directly in front of display, otherwise black)

Calibrating the Screen DPI and Lenslet Width: Demonstration



Result (assuming pixel size = 245 μm)

Calibration Procedure

- Assign the screen dots-per-inch (DPI) and lenslet width
- Generate an interlaced image (one white pixel below each lens)
- When calibration is correct, no magnified stripes will be visible (i.e., screen is white when directly in front of display, otherwise black)

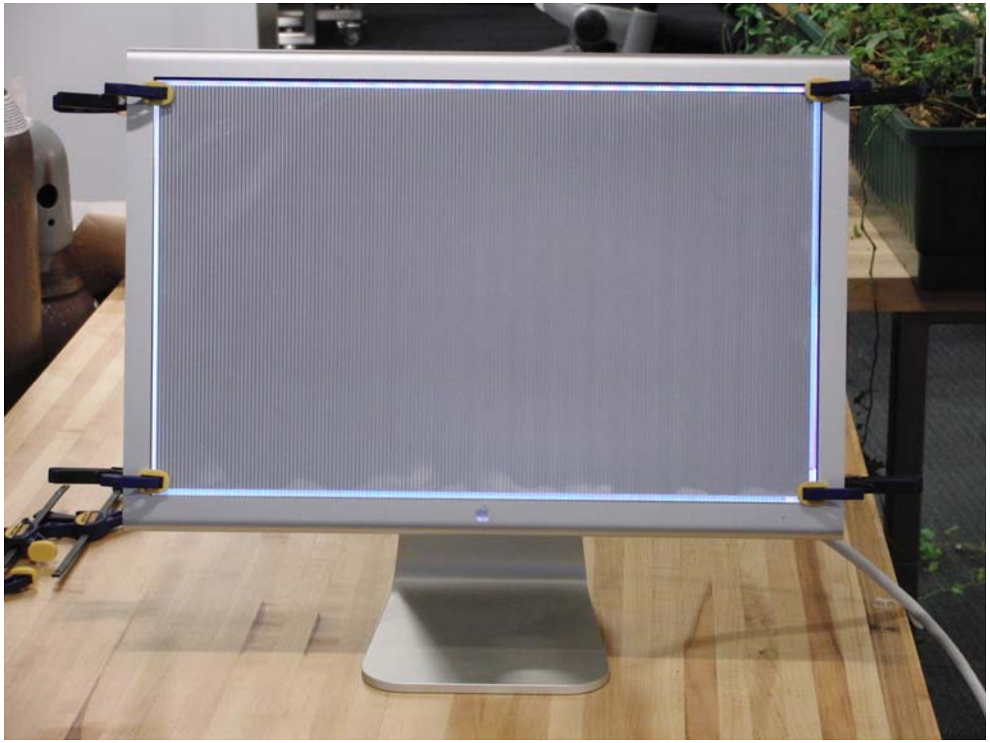
Calibrating the Screen DPI and Lenslet Width: Demonstration

Result (assuming pixel size = 255 μm)

Calibration Procedure

- Assign the screen dots-per-inch (DPI) and lenslet width
- Generate an interlaced image (one white pixel below each lens)
- When calibration is correct, no magnified stripes will be visible (i.e., screen is white when directly in front of display, otherwise black)

Calibrating the Screen DPI and Lenslet Width: Demonstration

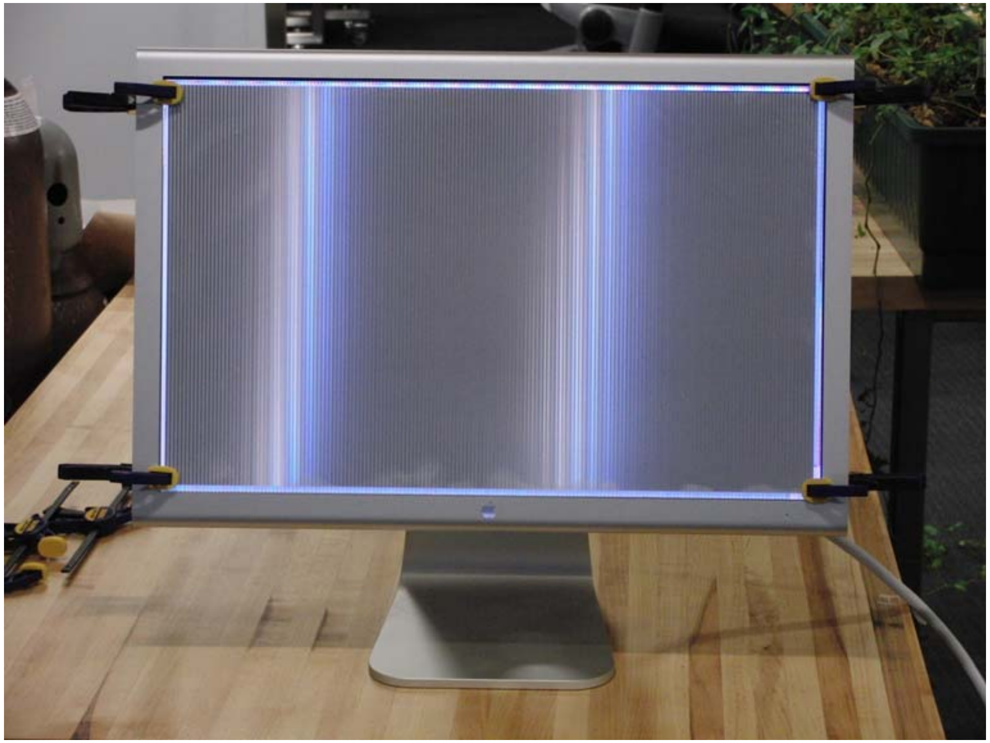


Result (assuming pixel size = 258 μm)

Calibration Procedure

- Assign the screen dots-per-inch (DPI) and lenslet width
- Generate an interlaced image (one white pixel below each lens)
- When calibration is correct, no magnified stripes will be visible (i.e., screen is white when directly in front of display, otherwise black)

Calibrating the Screen DPI and Lenslet Width: Demonstration

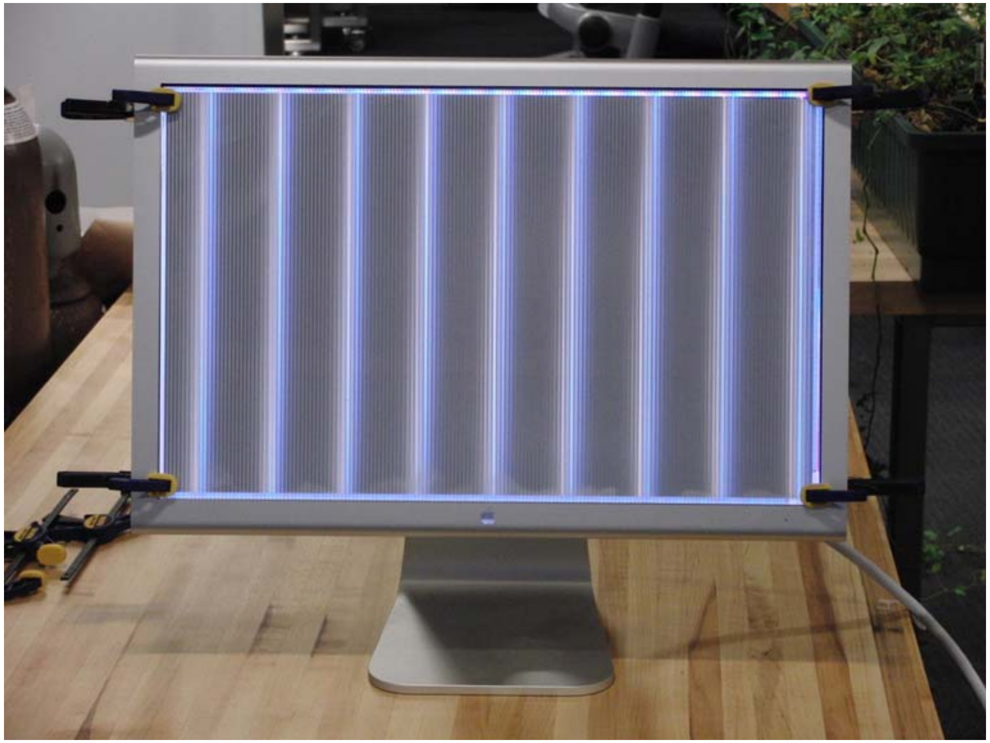


Result (assuming pixel size = 261 μm)

Calibration Procedure

- Assign the screen dots-per-inch (DPI) and lenslet width
- Generate an interlaced image (one white pixel below each lens)
- When calibration is correct, no magnified stripes will be visible (i.e., screen is white when directly in front of display, otherwise black)

Calibrating the Screen DPI and Lenslet Width: Demonstration

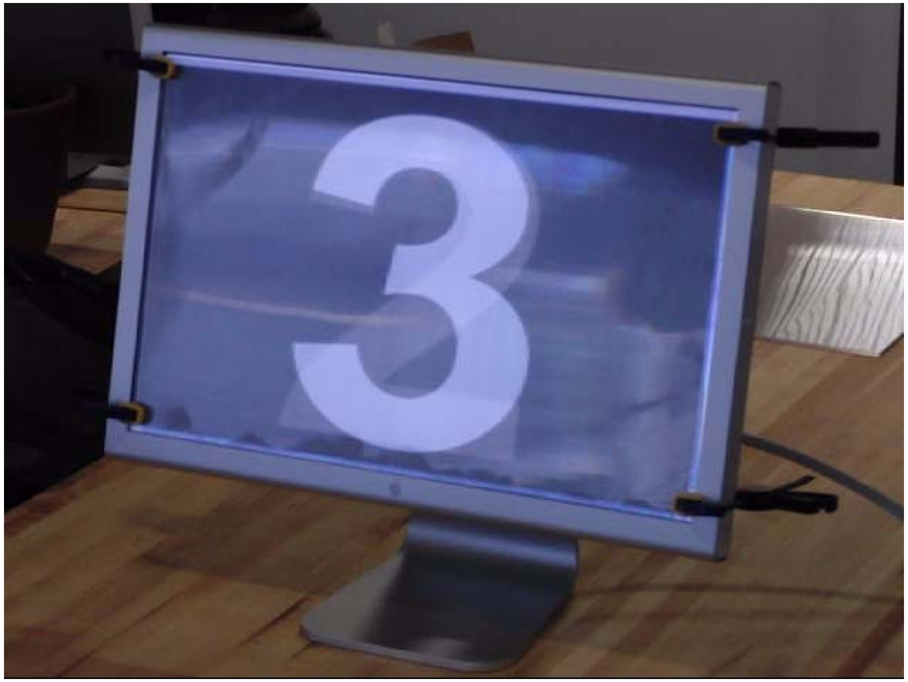


Result (assuming pixel size = 271 μm)

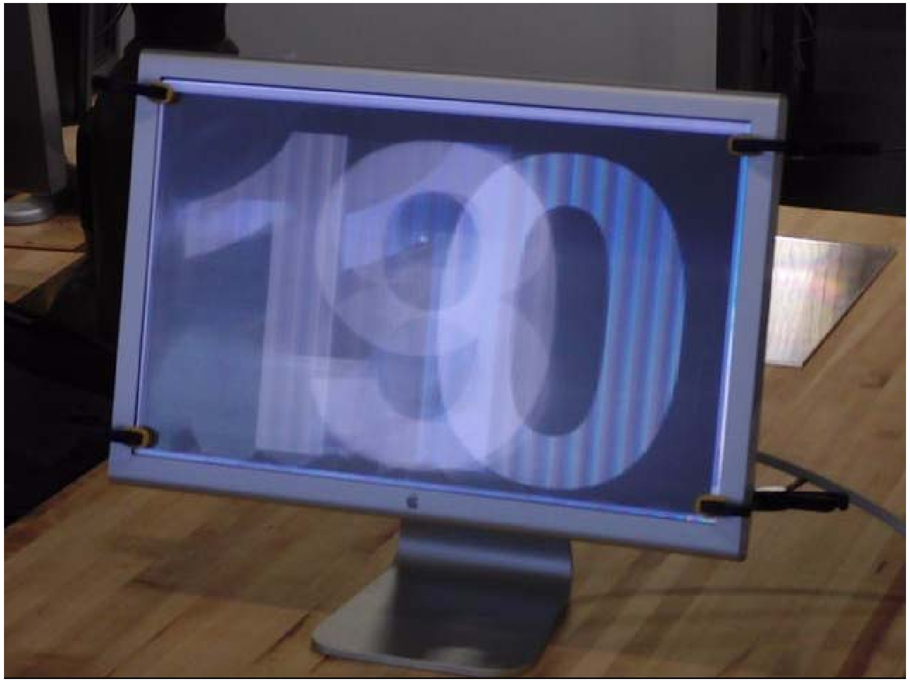
Calibration Procedure

- Assign the screen dots-per-inch (DPI) and lenslet width
- Generate an interlaced image (one white pixel below each lens)
- When calibration is correct, no magnified stripes will be visible (i.e., screen is white when directly in front of display, otherwise black)

Results:
Motion Parallax (Numbers)



Three Views

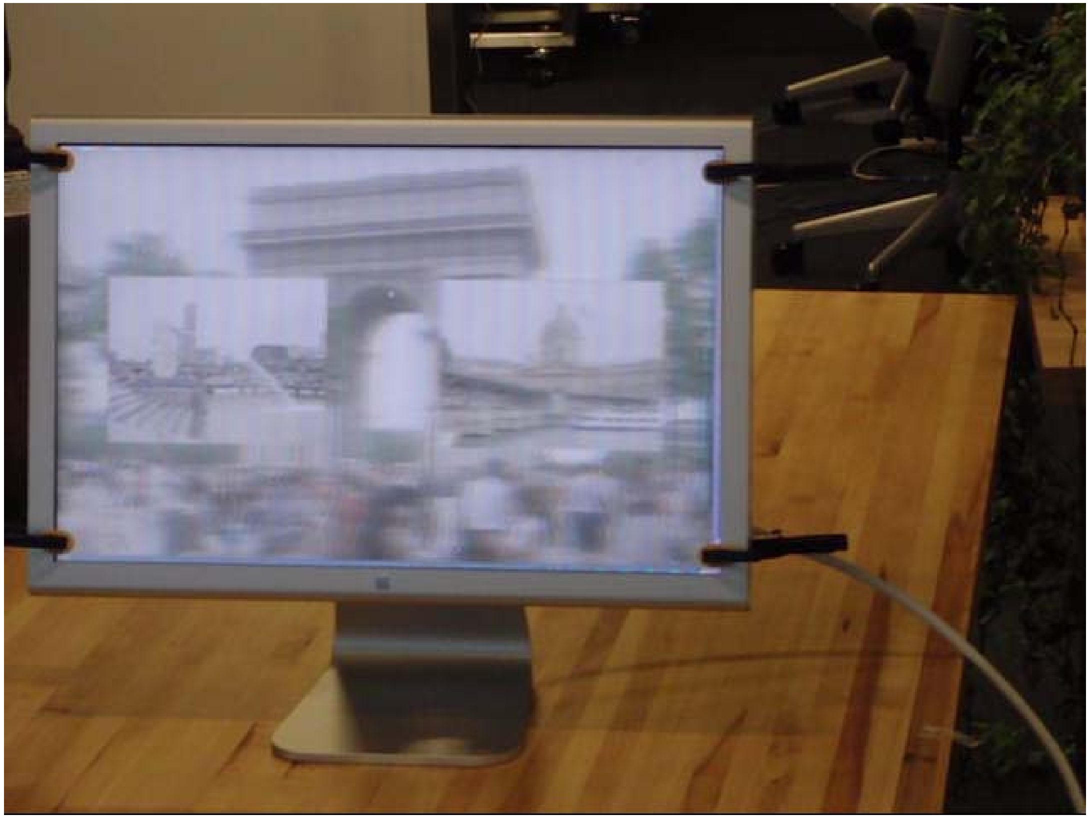


Ten Views

How to demonstrate a 3D display using a 2D display?

- One solution is to generate a “flip” sequence (each view is distinct)
- Interlaced base images were generated for the “numbers” sequence
- Results confirm motion parallax up to ten views with the prototype (i.e., 20 LPI lenticular sheet and 100 DPI screen → 10 views)

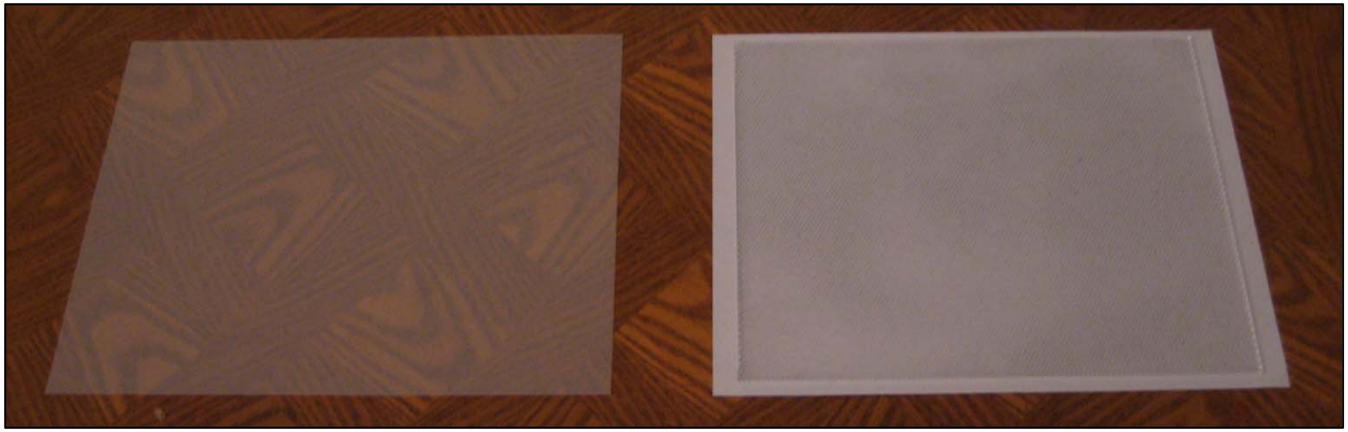
Results:
Motion Parallax (Textured Planes)



How to demonstrate a 3D display using a 2D display?

- Another solution is to generate a sequence with clear motion parallax
- Interlaced base images where generated for the “photos” sequence
- Results confirm motion parallax up to ten views with the prototype (i.e., 20 LPI lenticular sheet and 100 DPI screen → 10 views)

Constructing a Lenslet-based 3D Display:
2D Parallax with Hexagonal Lenslet Arrays

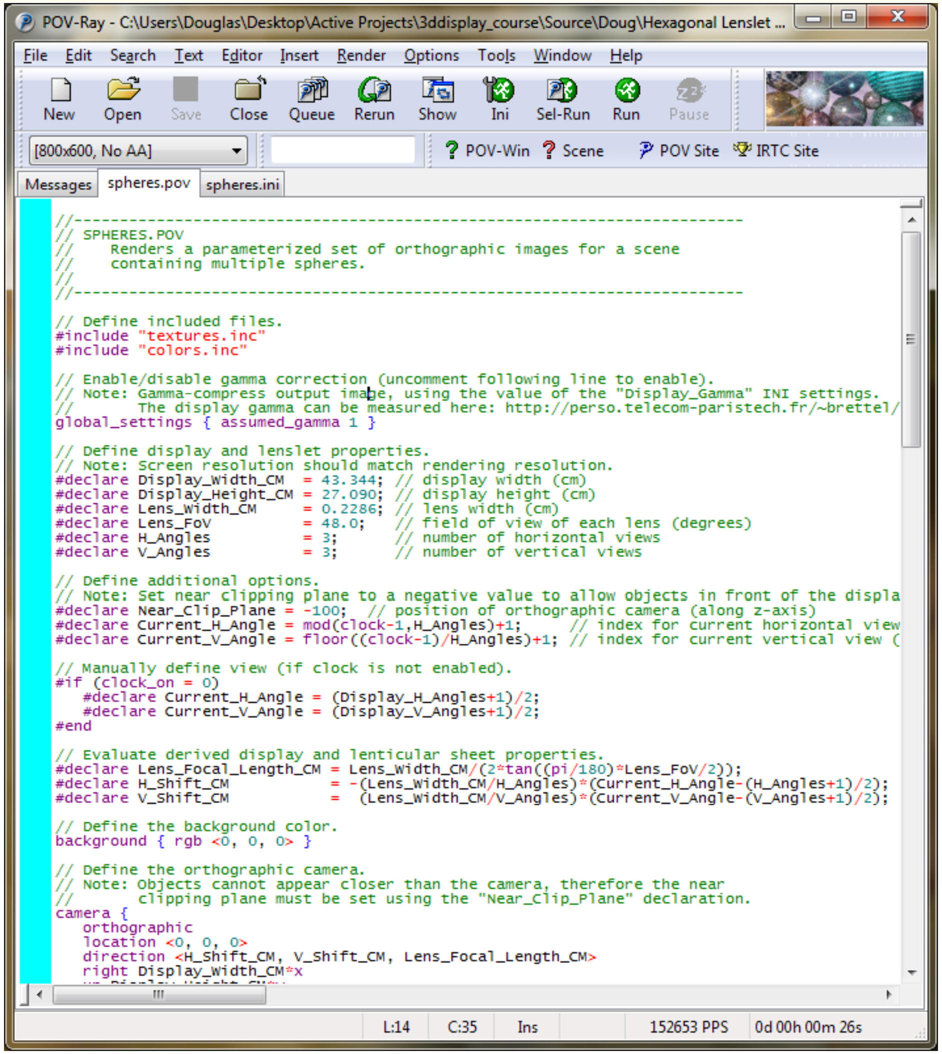


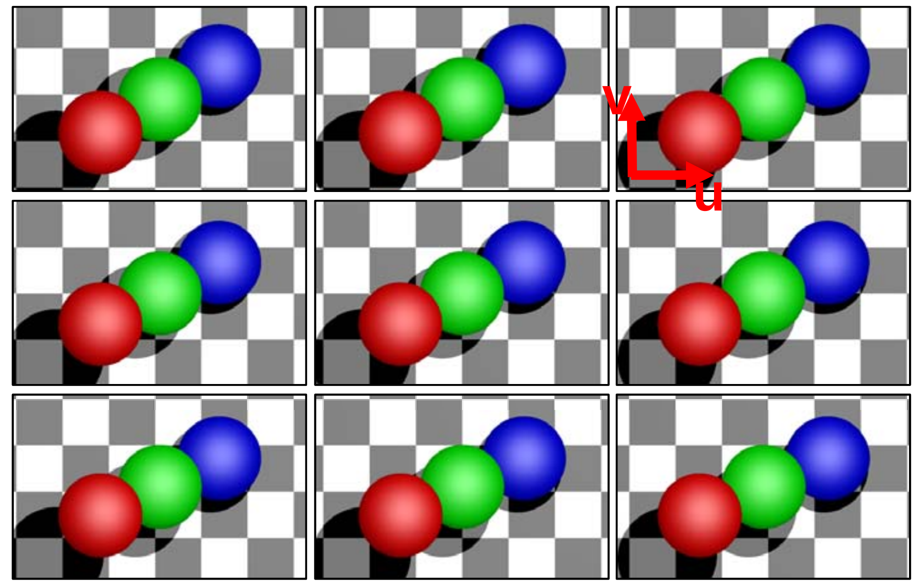
Paper Vellum Diffuser Hexagonal Lenslet Array

Parts List [$70-$250, but only $70 if an existing LCD monitor is used]

- [1] LCD monitor (e.g, ViewSonic VX2433wm 24") [$180]
- [1] Paper vellum diffuser (e.g., ClearPrint 11"x17" Vellum Pad) [$15]
- [1] Fly's Eye Lenslet Array (e.g., Fresnel Technologies #300) [$55]
  (see: http://www.fresneltech.com/)
- Additional mounting hardware (tape, clamps, framing, etc.)

Generating Content:
POV-Ray Demonstration (Revisited in 2D)





Rendered Light Field

Generating Light Fields using POV-Ray

- Freeware ray tracer (see http://www.povray.org/)

Generating Content:
Capturing Light Fields (e.g., *Stanford* Archive)

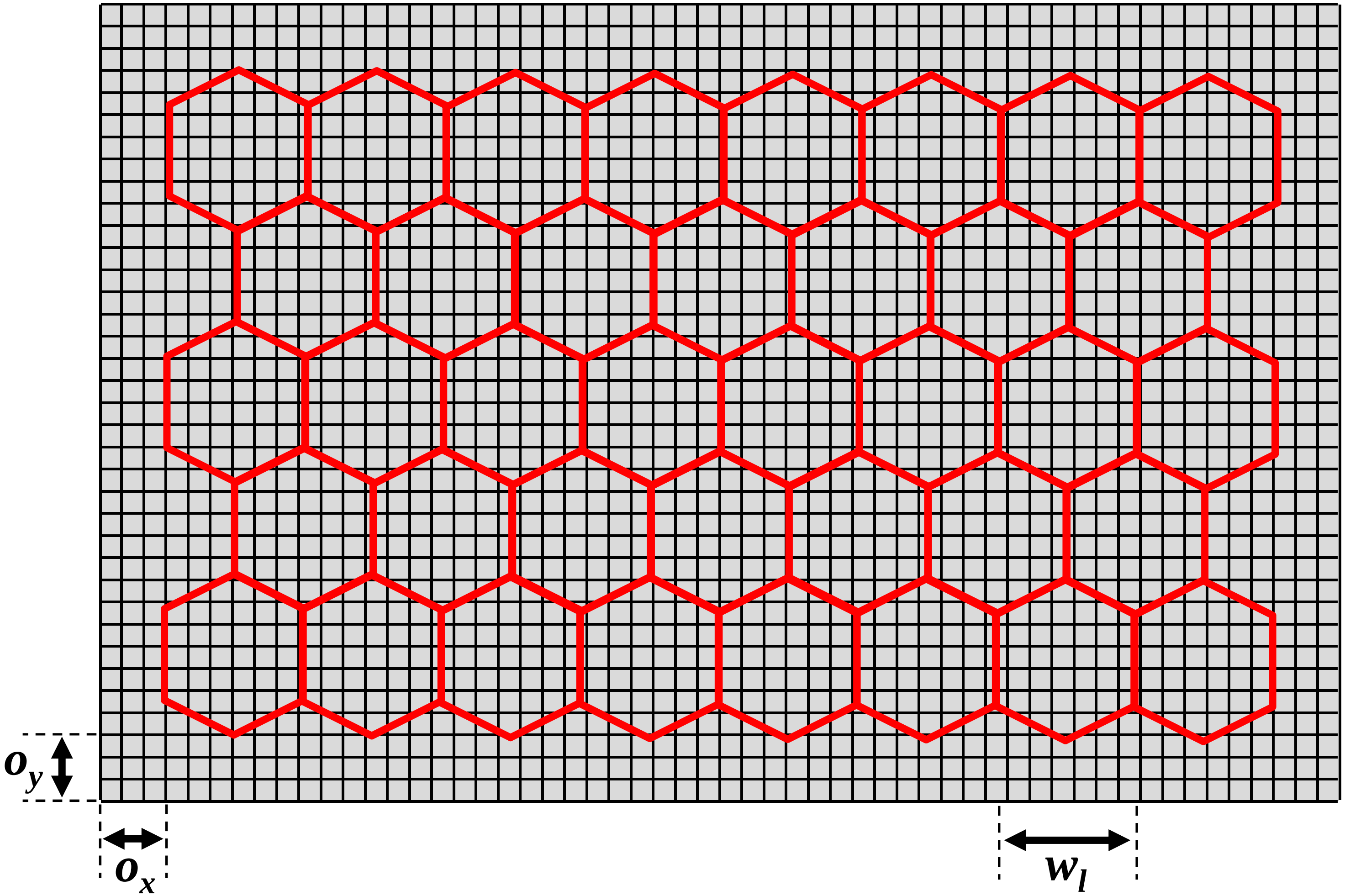
Acquisition Devices

Example Light Field

Light Field Photography

- Examples can be obtained from (New) Stanford Light Field Archive (see http://lightfield.stanford.edu/)
- Images can be resampled to produce oblique projections
- Could be the source of another do-it-yourself project…

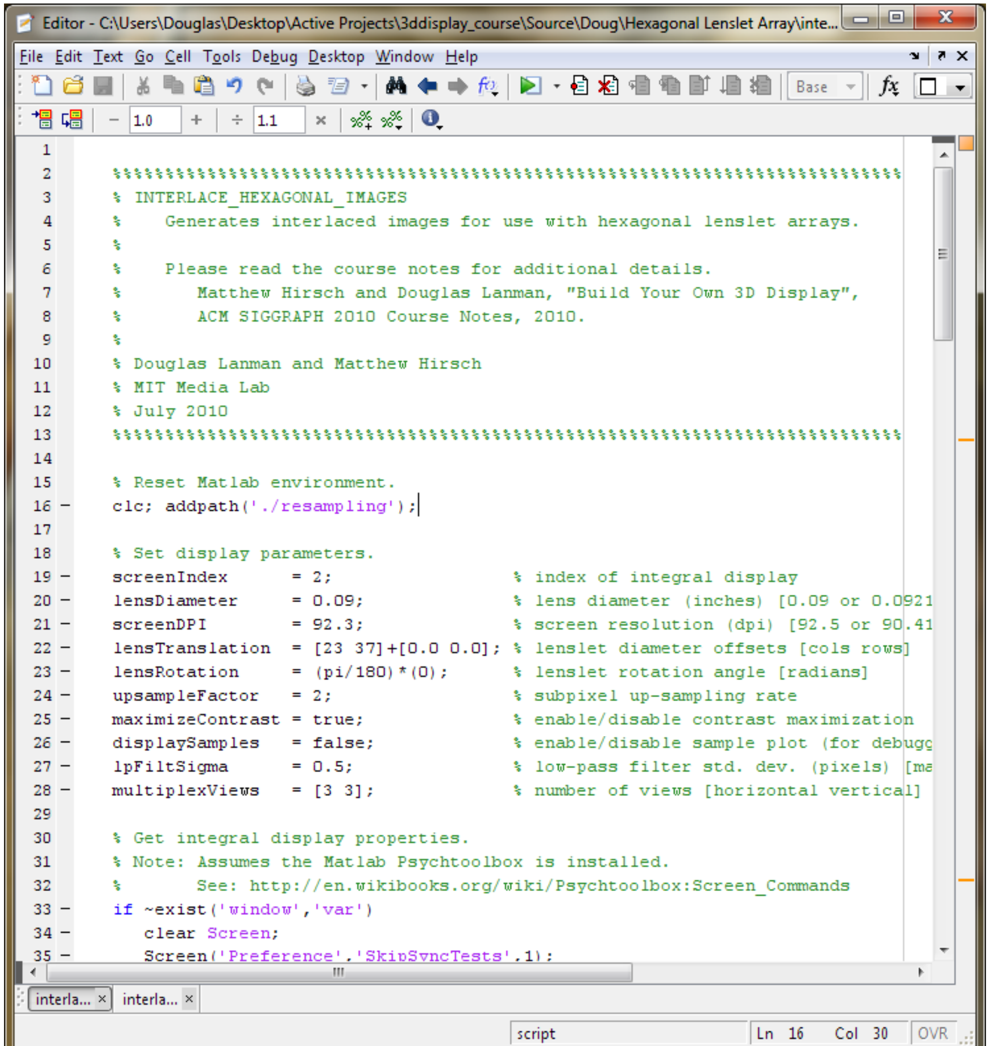
Interlacing Content:
Evaluating Spatially-Multiplexed Base Images



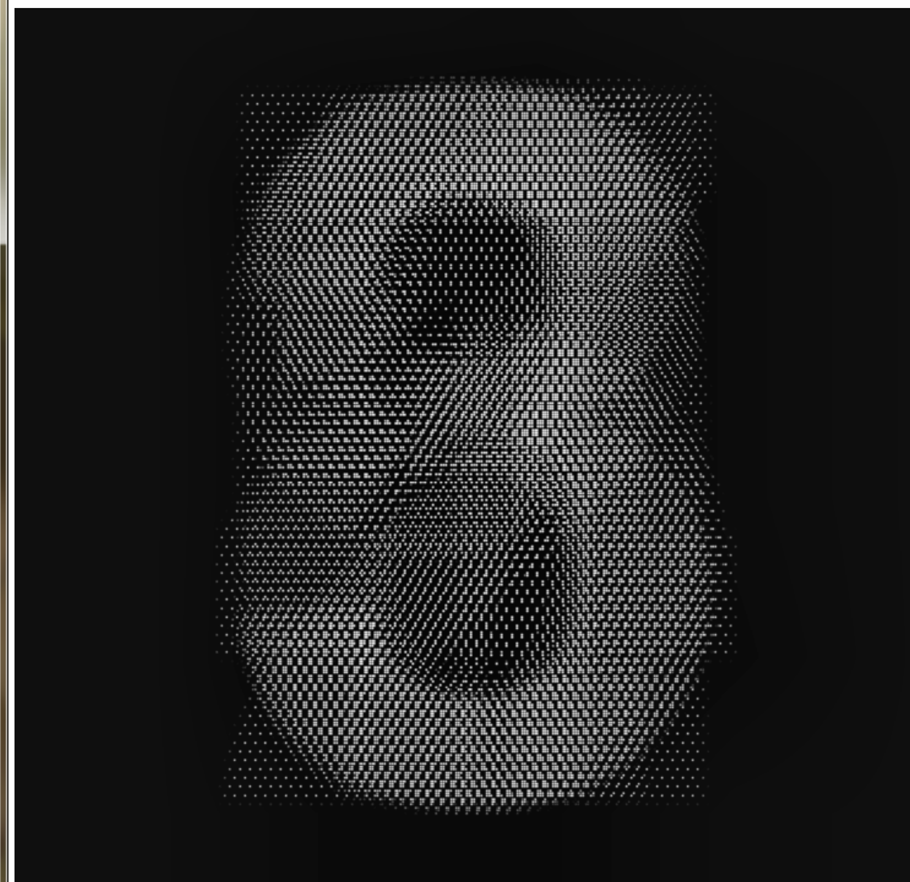
Generating the Interlaced (Base) Image

- First, evaluate closest lenslet for each pixel → spatial image sample
- Second, evaluate offset from lenslet center → angular viewpoint

Interlacing Content:
MATLAB Implementation

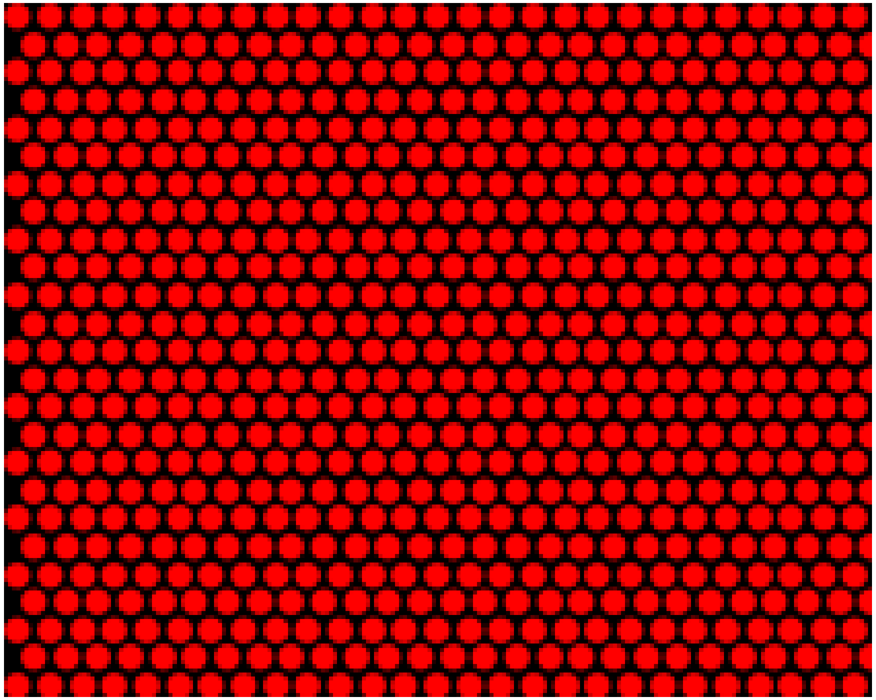



```

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% INTERLACE_HEXAGONAL_IMAGES
%    Generates interlaced images for use with hexagonal lenslet arrays.
%
%    Please read the course notes for additional details.
%       Matthew Hirsch and Douglas Lanman, "Build Your Own 3D Display",
%       ACM SIGGRAPH 2010 Course Notes, 2010.
%
% Douglas Lanman and Matthew Hirsch
% MIT Media Lab
% July 2010
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Reset Matlab environment.
clc; addpath('./resampling');

% Set display parameters.
screenIndex      = 2;                % index of integral display
lensDiameter     = 0.09;             % lens diameter (inches) [0.09 or 0.0921
screenDPI        = 92.3;             % screen resolution (dpi) [92.5 or 90.41
lensTranslation  = [23 37]+[0.0 0.0]; % lenslet diameter offsets [cols rows]
lensRotation     = (pi/180)*(0);     % lenslet rotation angle [radians]
upsampleFactor   = 2;                % subpixel up-sampling rate
maximizeContrast = true;             % enable/disable contrast maximization
displaySamples   = false;            % enable/disable sample plot (for debugg
lpFiltSigma      = 0.5;              % low-pass filter std. dev. (pixels) [ma
multiplexViews   = [3 3];            % number of views [horizontal vertical]

% Get integral display properties.
% Note: Assumes the Matlab Psychtoolbox is installed.
%       See: http://en.wikibooks.org/wiki/Psychtoolbox:Screen_Commands
if ~exist('window','var')
   clear Screen;
   Screen('Preference','SkipSyncTests',1);
```

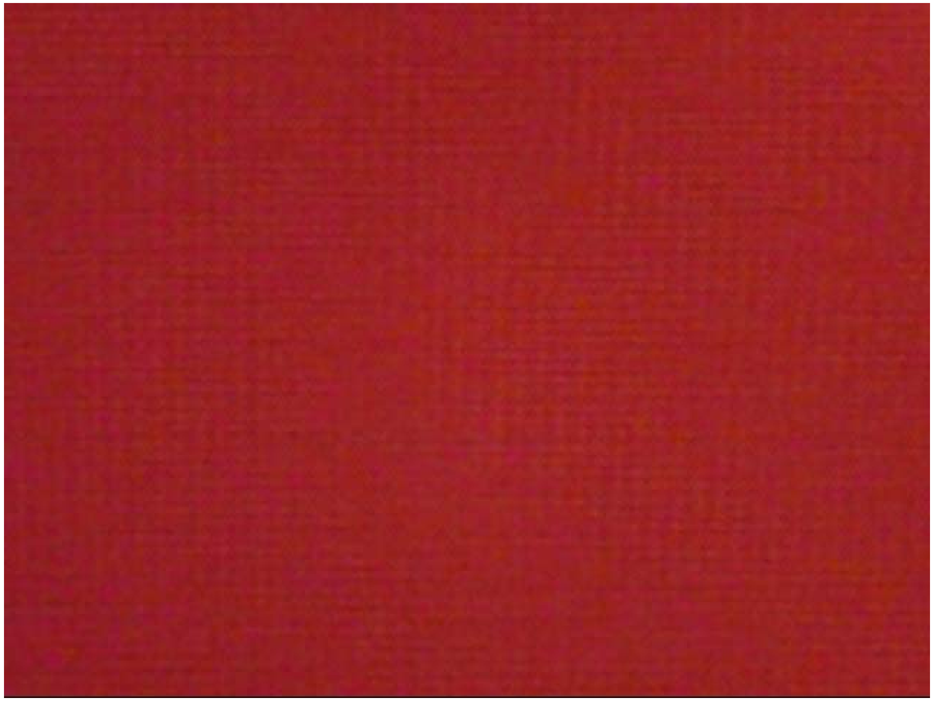


Interlaced "Numbers" Sequence

Aligning/Calibrating the Lenslet Array: Demonstration



Calibration Image

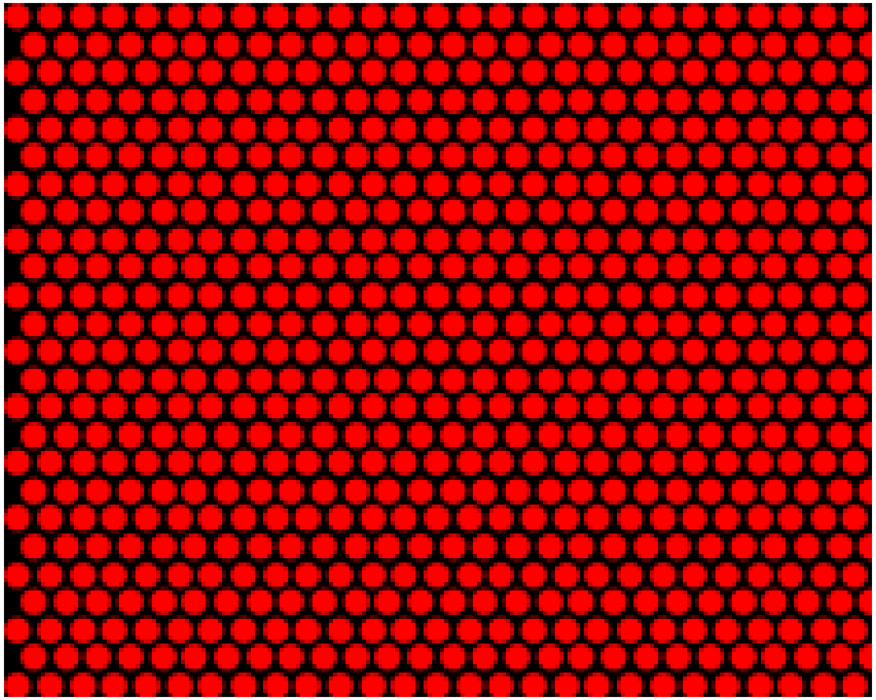


Moiré-based Alignment/Calibration

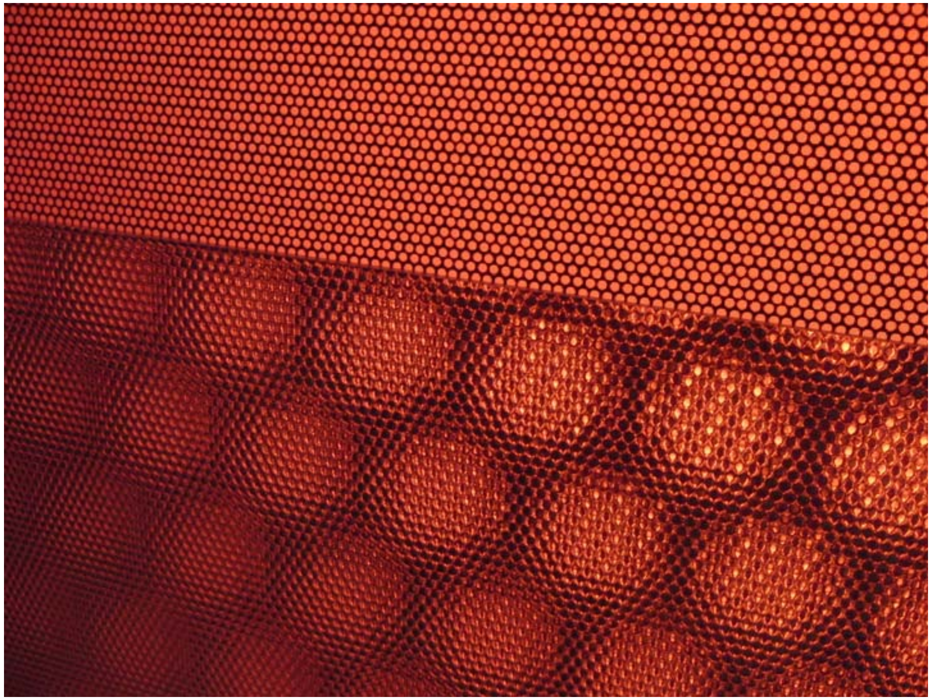
Calibration Procedure

- Assign the screen dots-per-inch (DPI) and lenslet width
- Generate an interlaced image (one “marker” pattern below each lens)
- When calibration is correct, no magnified “markers” will be visible (i.e., screen is uniform color when directly in front of display)

Aligning/Calibrating the Lenslet Array: Demonstration



Calibration Image

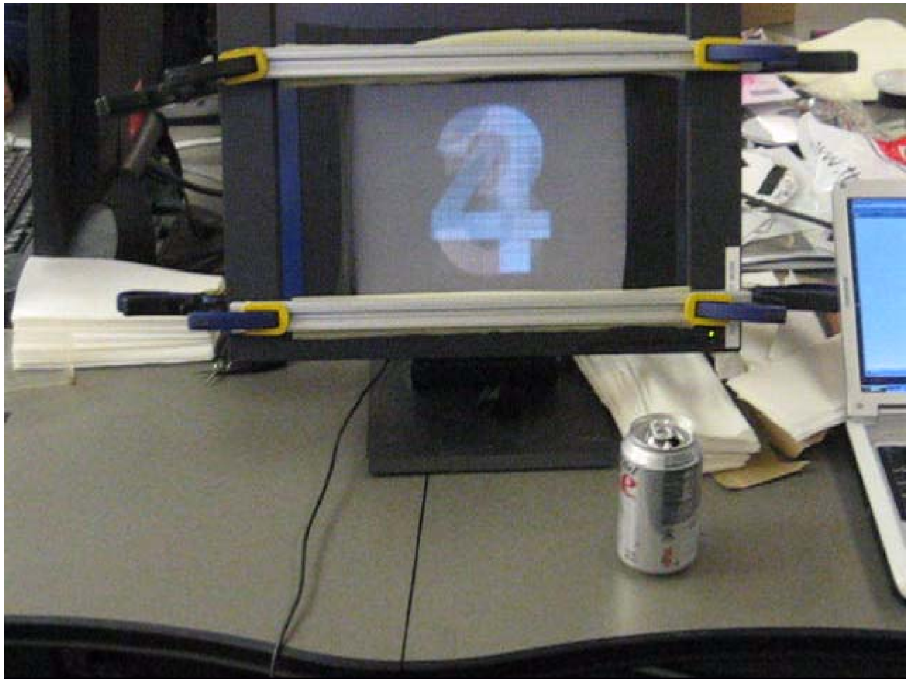


Moiré-based Alignment/Calibration

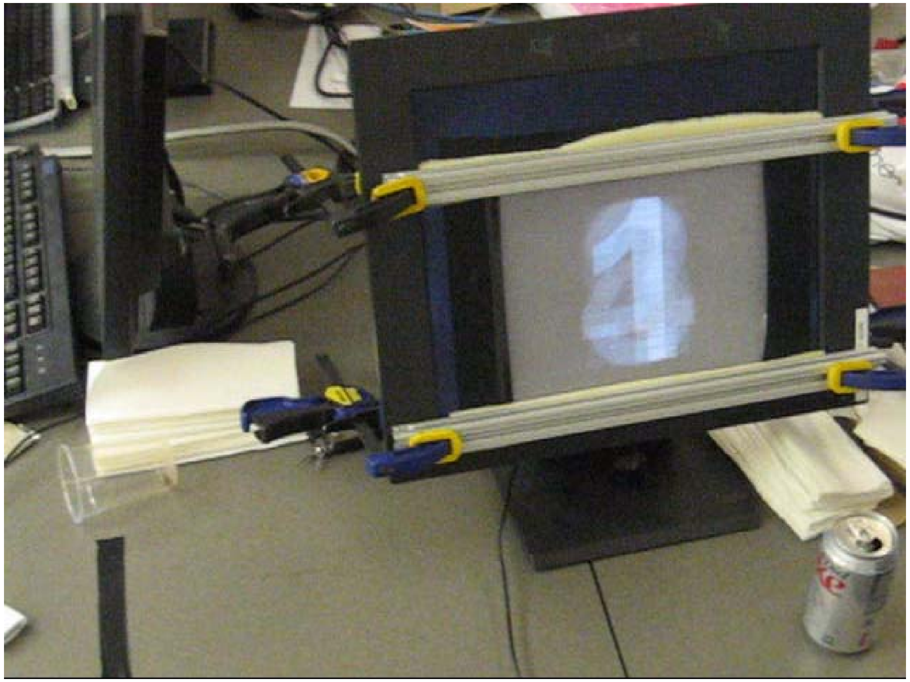
Calibration Procedure

- Assign the screen dots-per-inch (DPI) and lenslet width
- Generate an interlaced image (one “marker” pattern below each lens)
- When calibration is correct, no magnified “markers” will be visible (i.e., screen is uniform color when directly in front of display)

Results:
Motion Parallax (Numbers)



Four Views



Nine Views

Demonstrating Motion Parallax

- Interlaced base images were generated for the “numbers” sequence
- Results confirm motion parallax up to 8x8 views with the prototype (i.e., 0.09 inch lenslet diameter and 90 DPI screen → 8x8 views)

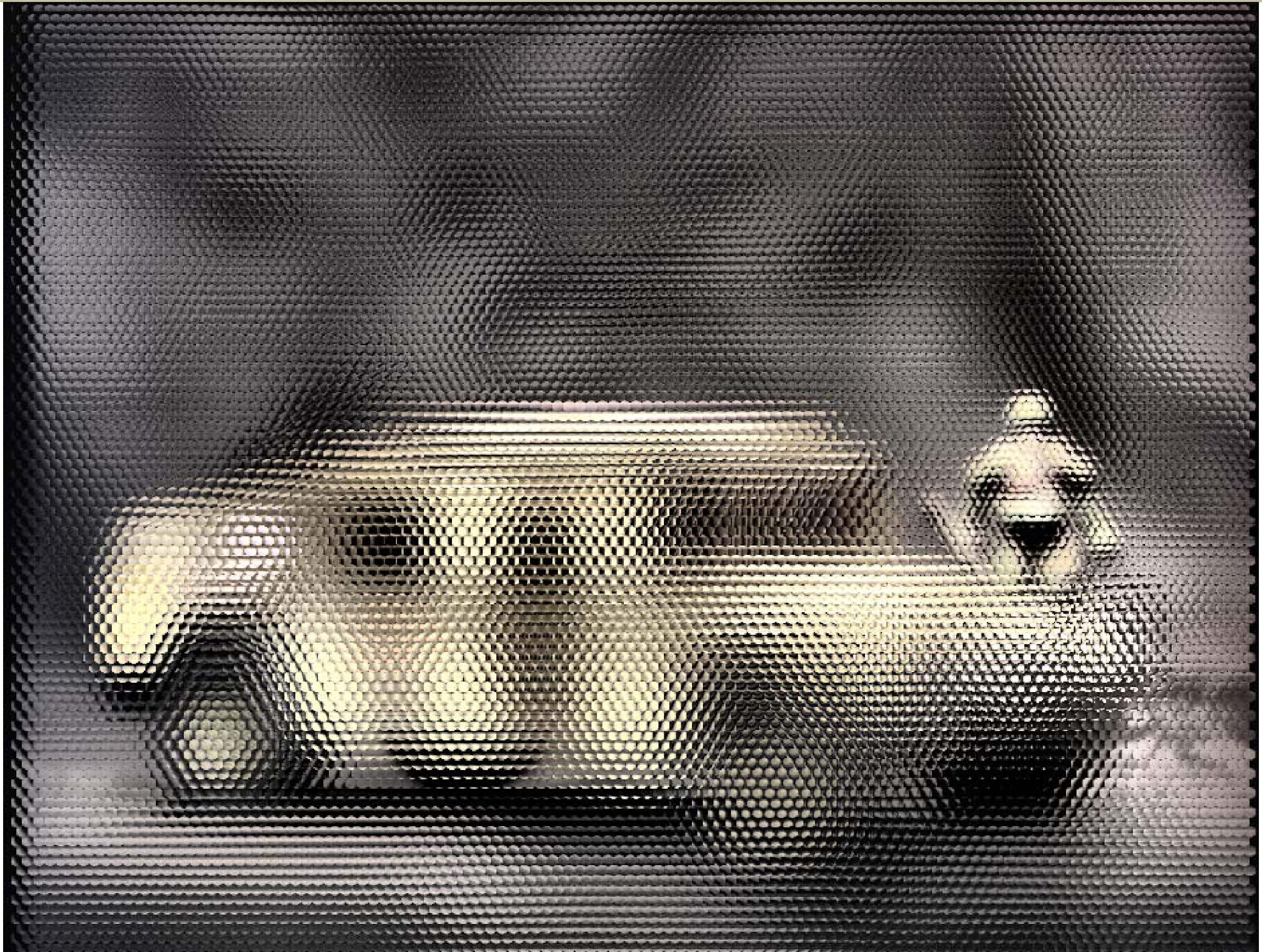
Results:
Light Field (Toy Humvee and Soldier)

viewer moves right

viewer moves up

Sample Image

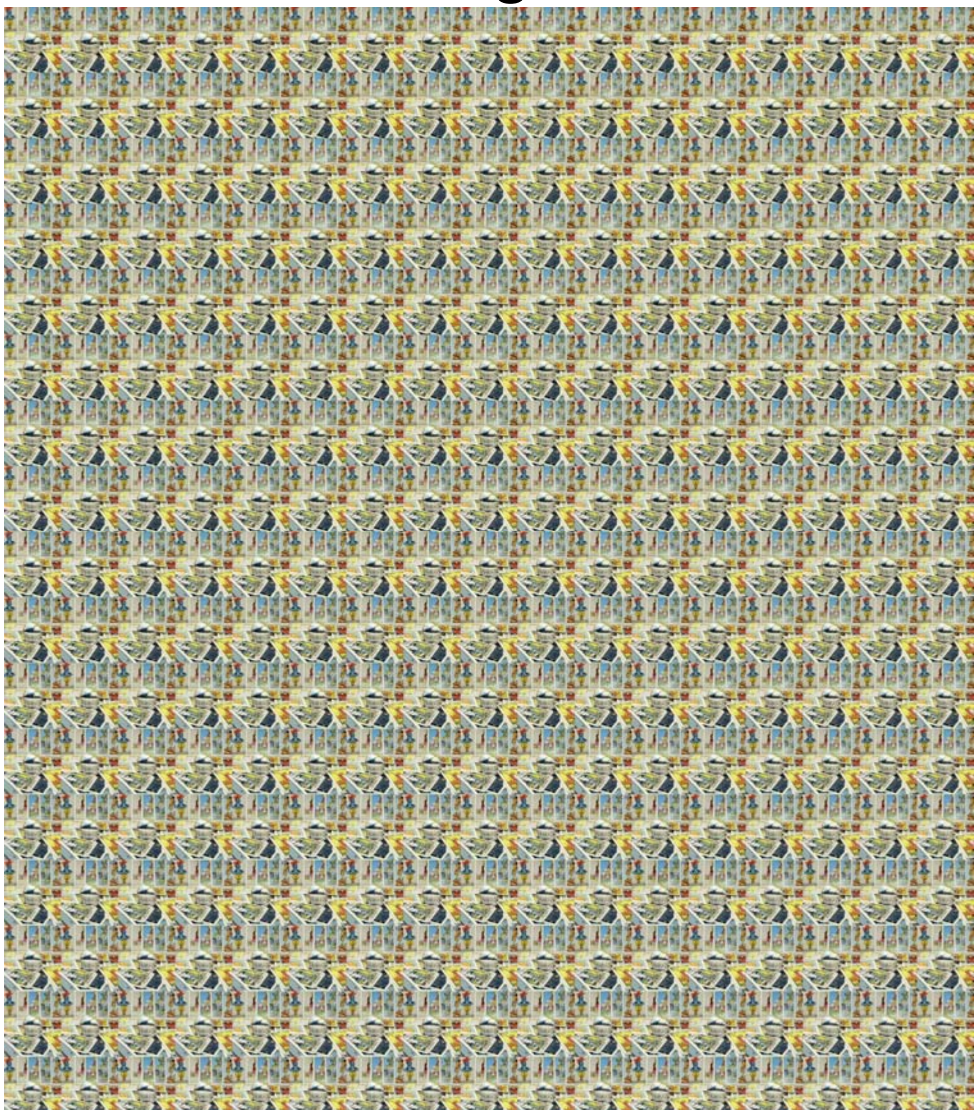
Results:
Interlaced Image (Toy Humvee and Soldier)



Results:
Light Field (Tarot Cards and Crystal Ball)

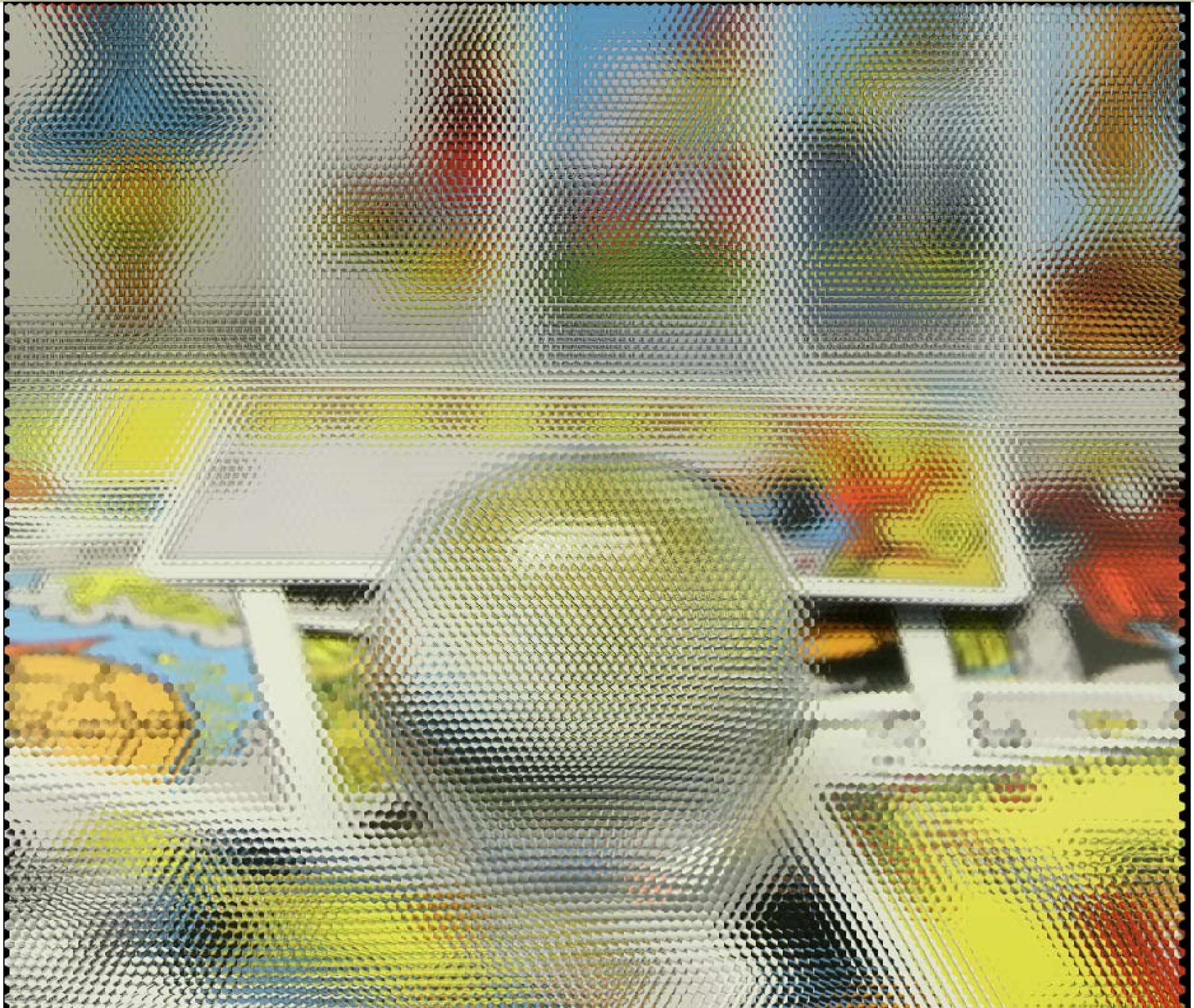
viewer moves right

viewer moves up

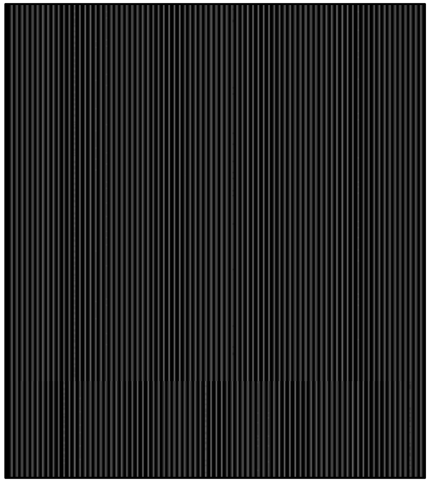


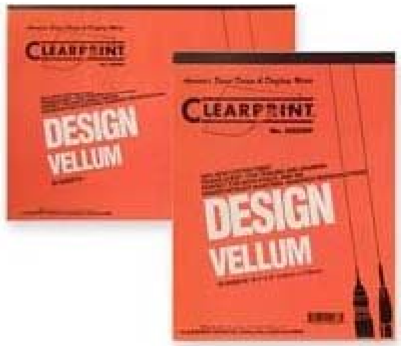
Sample Image

Results:
Interlaced Image (Tarot Cards and Crystal Ball)



Constructing a (Static) Parallax Barrier Display

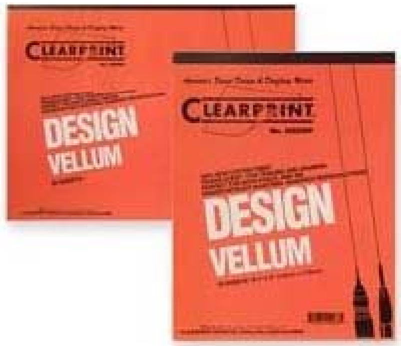


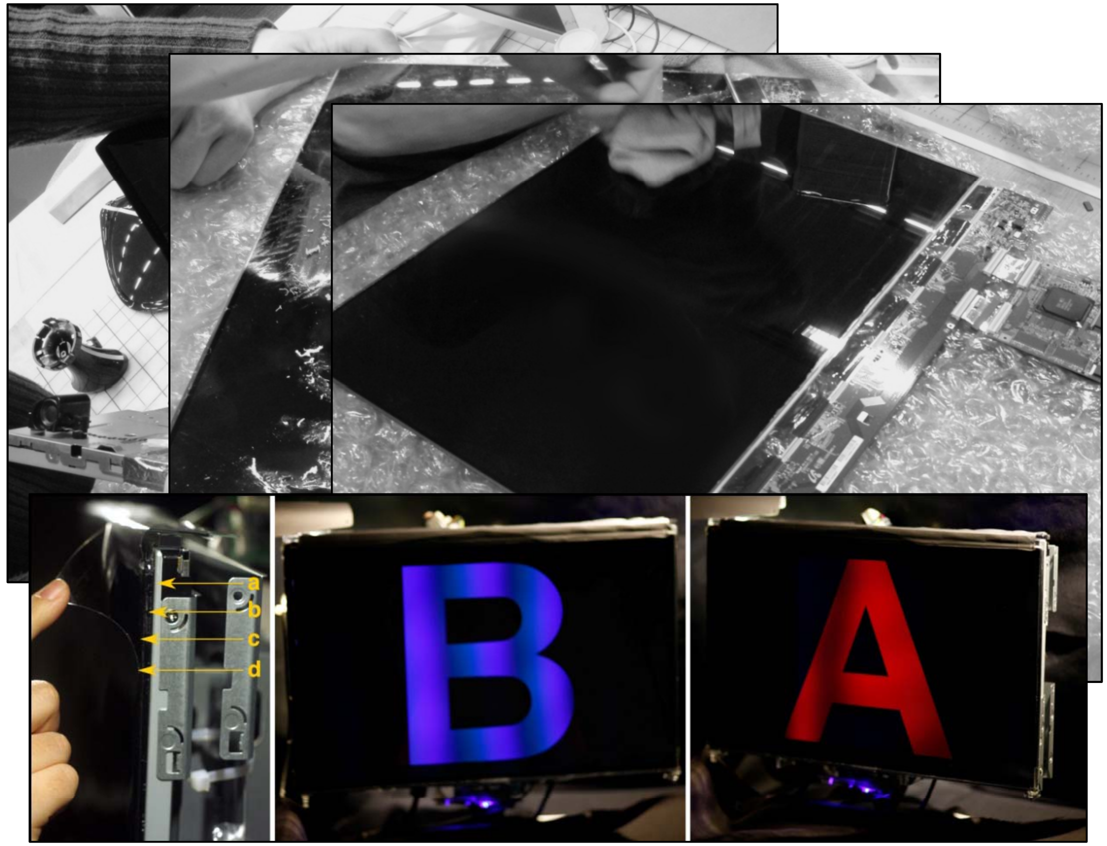


Parts List [$25-$400, but only $25 with existing monitor and laser printer]

- [1] LCD monitor (e.g, ViewSonic VX2433wm 24") [$180]
- [1] Paper vellum diffuser (e.g., ClearPrint 11"x17" Vellum Pad) [$15]
- [1] Printed parallax barrier (e.g., emulsion-based transparency) [$10-$200]
  (see: http://www.pageworks.com/transparencymasks.html/)
- Additional mounting hardware (plastic spacer, clamps, framing, etc.)

Constructing a (Dynamic) Parallax Barrier Display

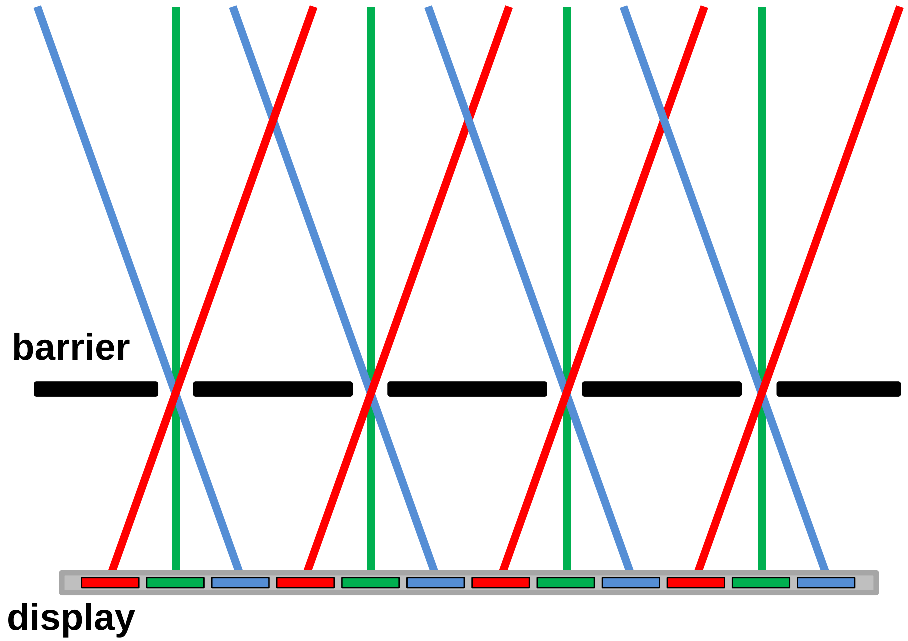




Parts List [$515, possibly $515+$250*n*, where *n* = # of broken LCDs]

- [2] **High-speed LCD monitor (e.g, ViewSonic VX2265wm FuHzion 22") [$250]**
- [1] **Paper vellum diffuser (e.g., ClearPrint 11"x17" Vellum Pad) [$15]**
- **Additional mounting hardware (plastic spacer, clamps, framing, etc.)**

Dual-Stacked LCDs:
Full-resolution Display using Dynamic Barriers

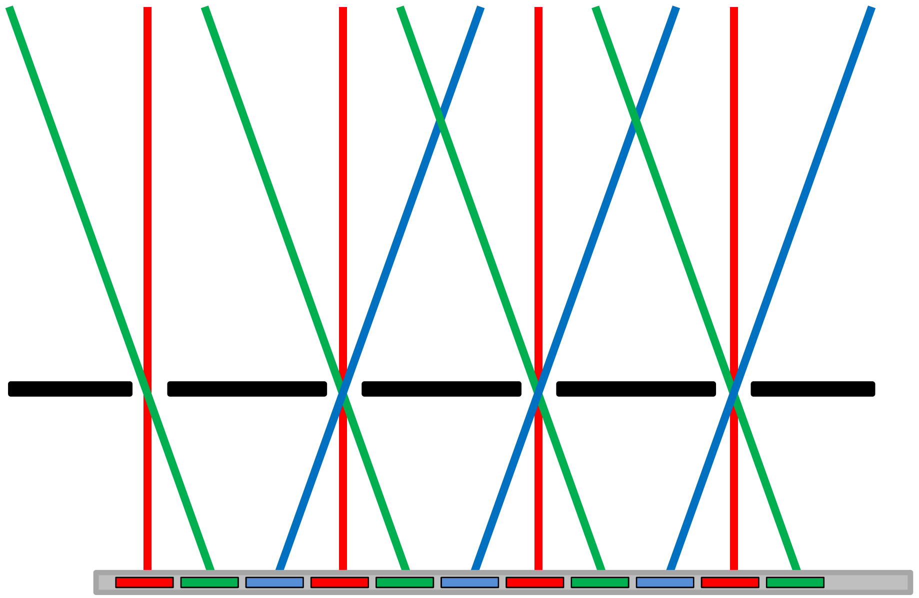


Parallax Barrier

Static vs. Dynamic Parallax Barrier Displays

- Static barriers result in reduced (spatial) resolution and brightness

Dual-Stacked LCDs:
Full-resolution Display using Dynamic Barriers

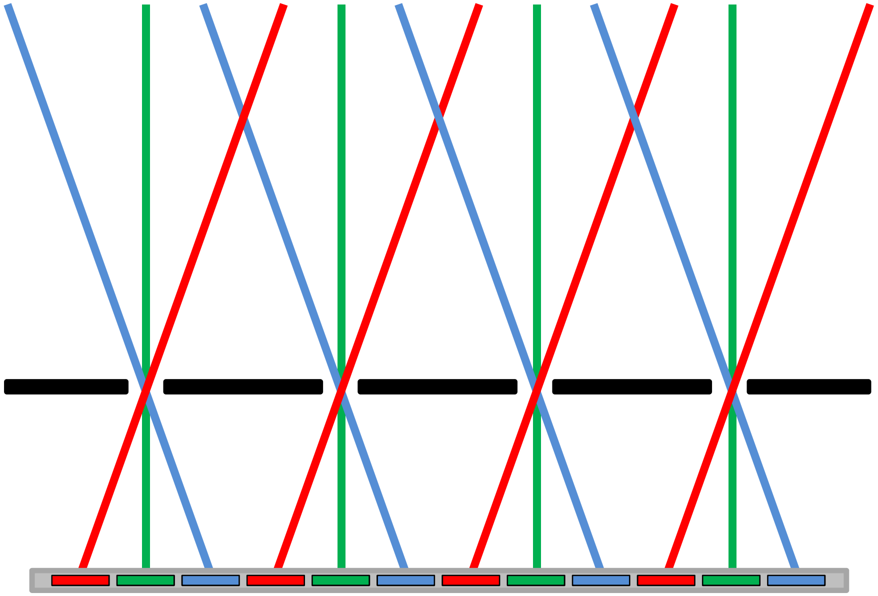


Parallax Barrier

Static vs. Dynamic Parallax Barrier Displays

- Static barriers result in reduced (spatial) resolution and brightness
- Dynamic barriers can eliminate resolution loss
  - Must translate faster than flicker fusion threshold (i.e., 60 Hz)

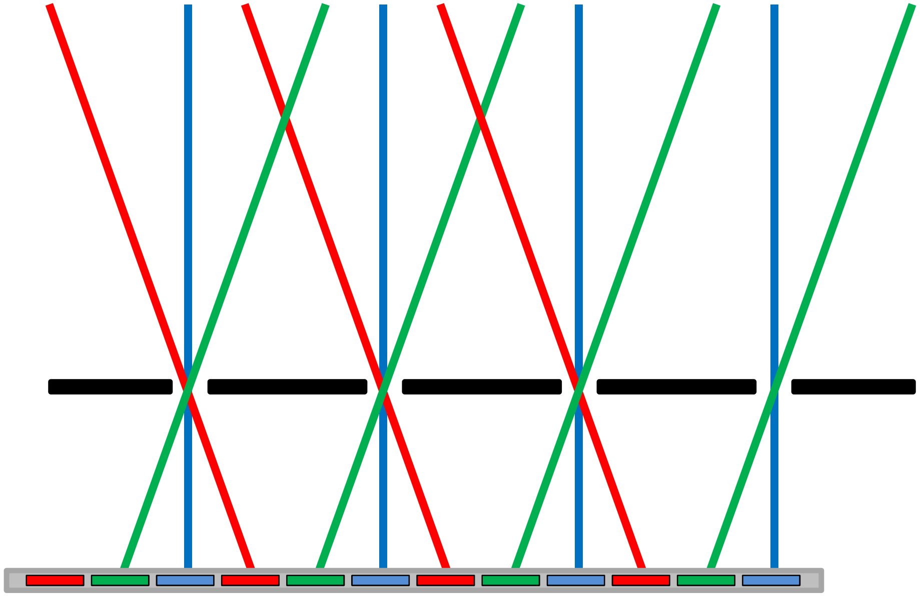
Dual-Stacked LCDs:
Full-resolution Display using Dynamic Barriers



Parallax Barrier

Static vs. Dynamic Parallax Barrier Displays
- Static barriers result in reduced (spatial) resolution and brightness
- Dynamic barriers can eliminate resolution loss
  - Must translate faster than flicker fusion threshold (i.e., 60 Hz)

Dual-Stacked LCDs:
Full-resolution Display using Dynamic Barriers



Parallax Barrier

Static vs. Dynamic Parallax Barrier Displays

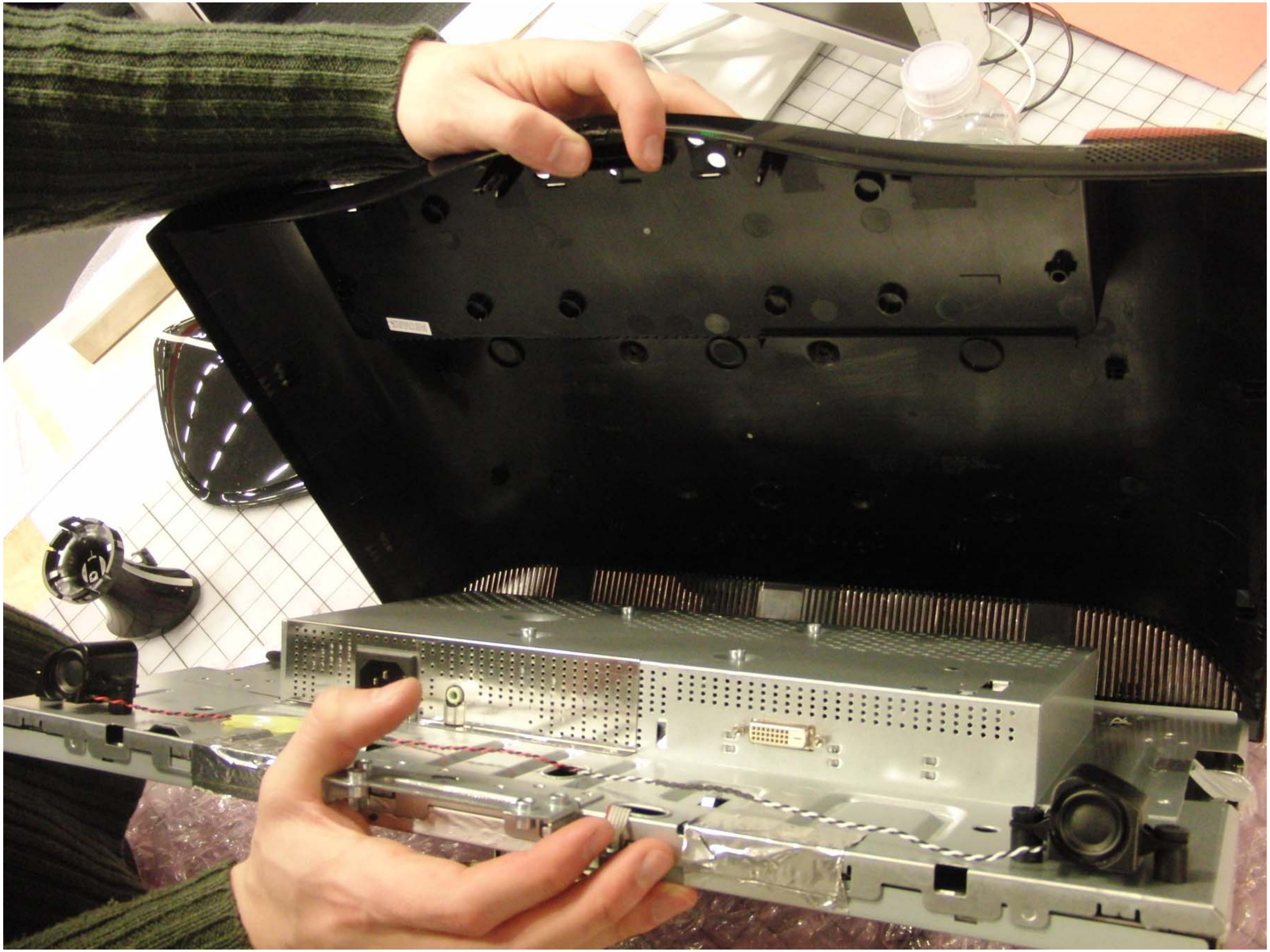
- Static barriers result in reduced (spatial) resolution and brightness
- Dynamic barriers can eliminate resolution loss
  - Must translate faster than flicker fusion threshold (i.e., 60 Hz)

While eliminating resolution loss, display is still dim

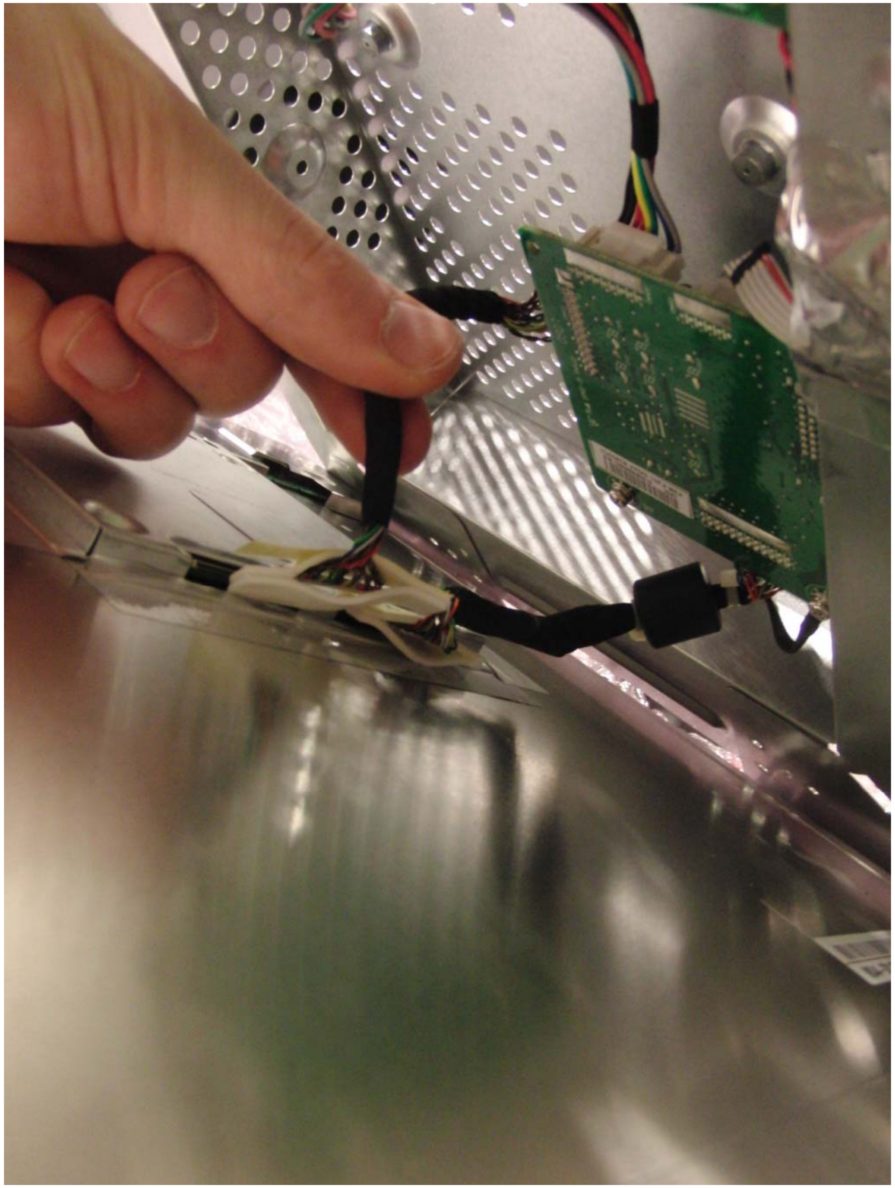
LCD Disassembly:
Removing the Case

LCD Disassembly:
Removing the Case

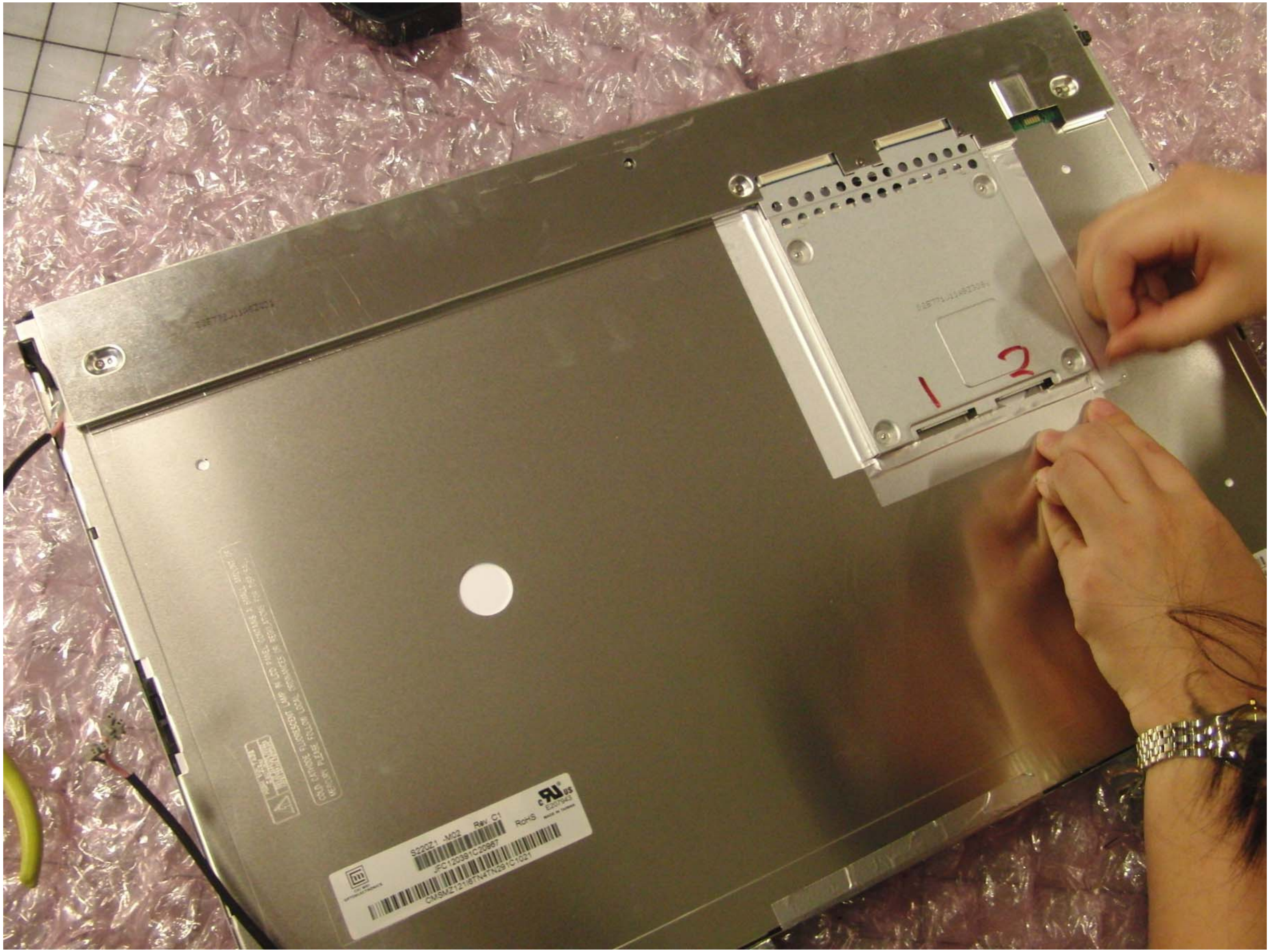
LCD Disassembly:
Removing the Case



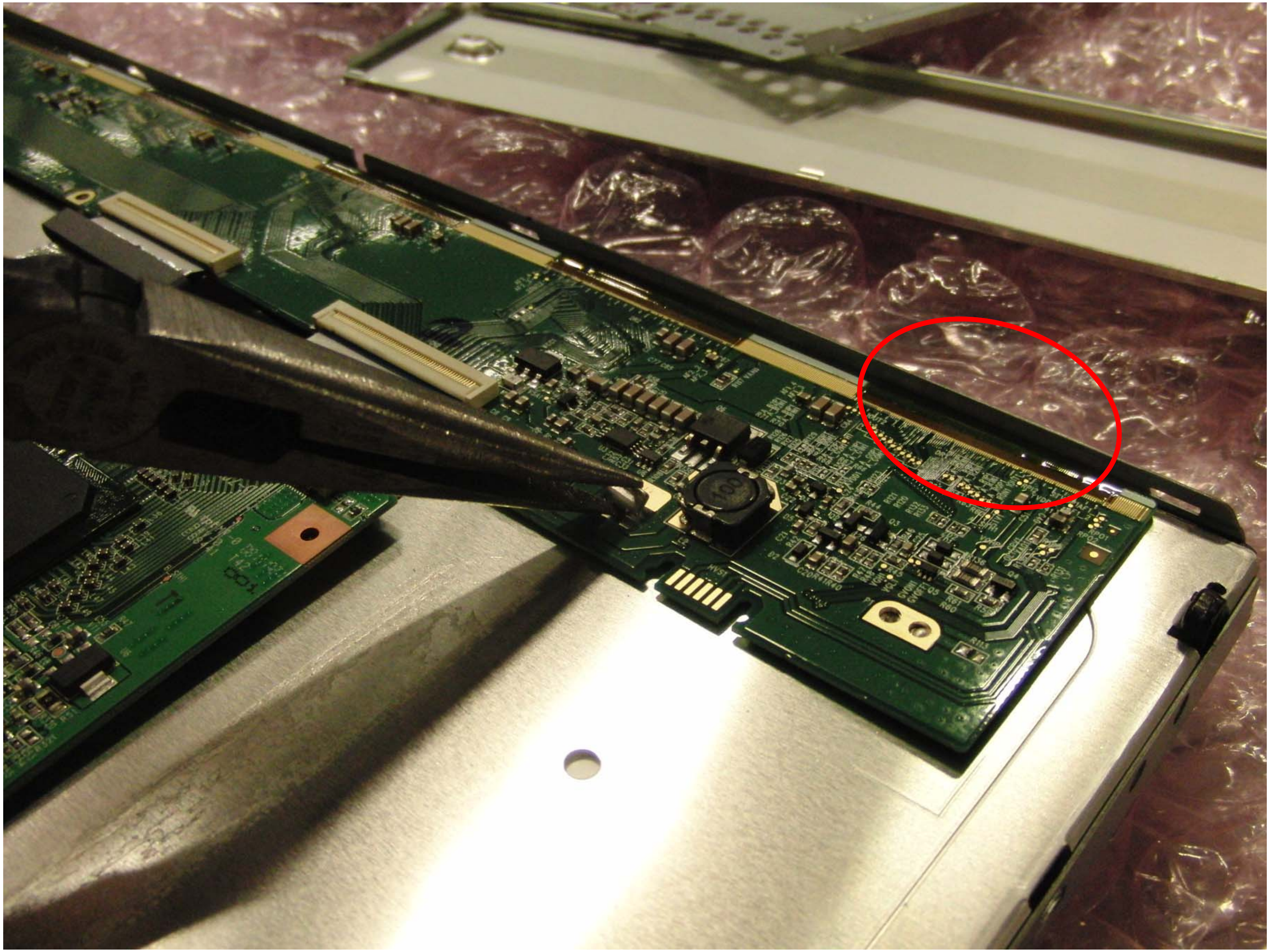
LCD Disassembly:
Separating the Power Supply



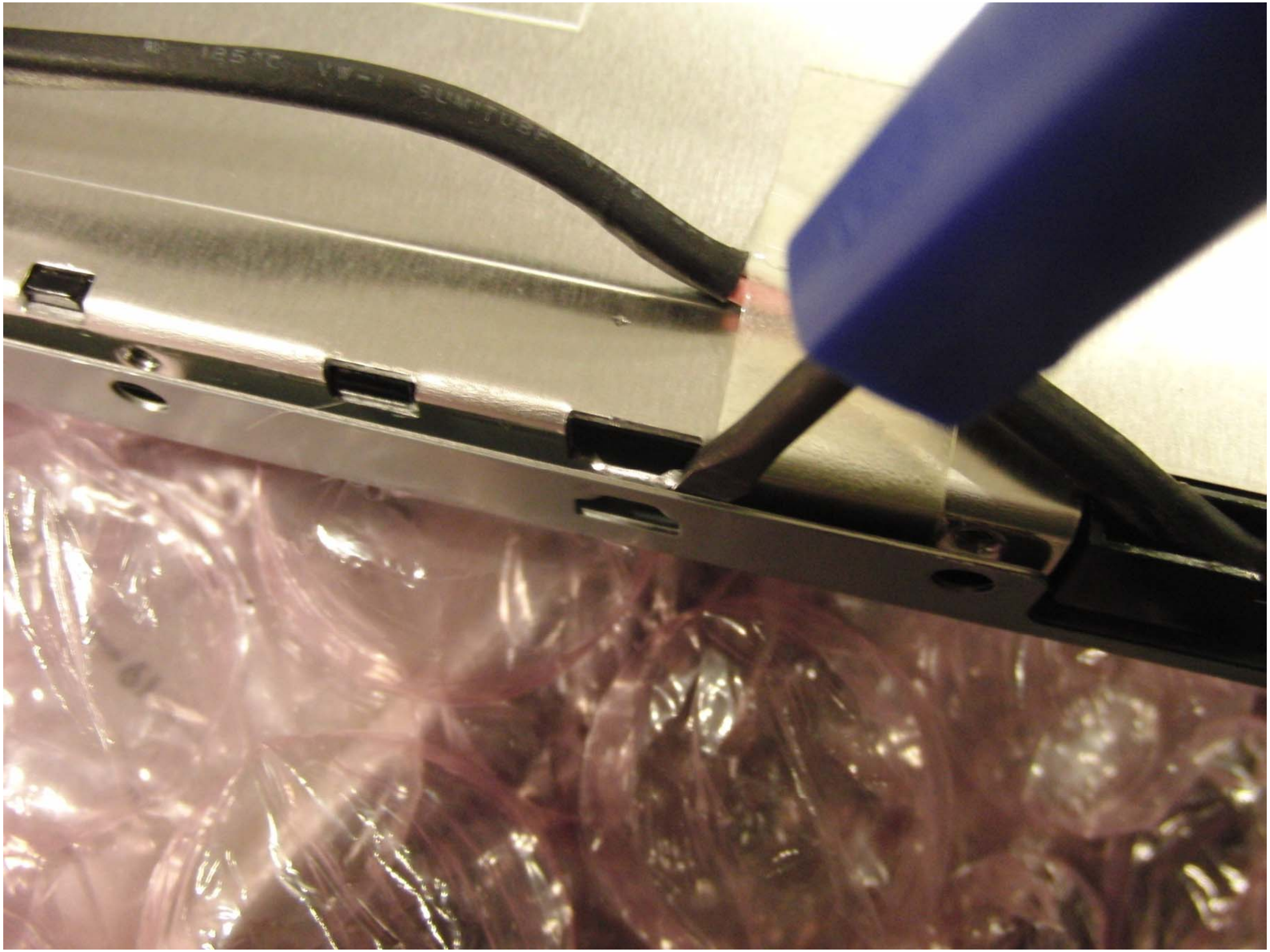
LCD Disassembly:
Separating the Power Supply



LCD Disassembly:
Separating the Controller Board

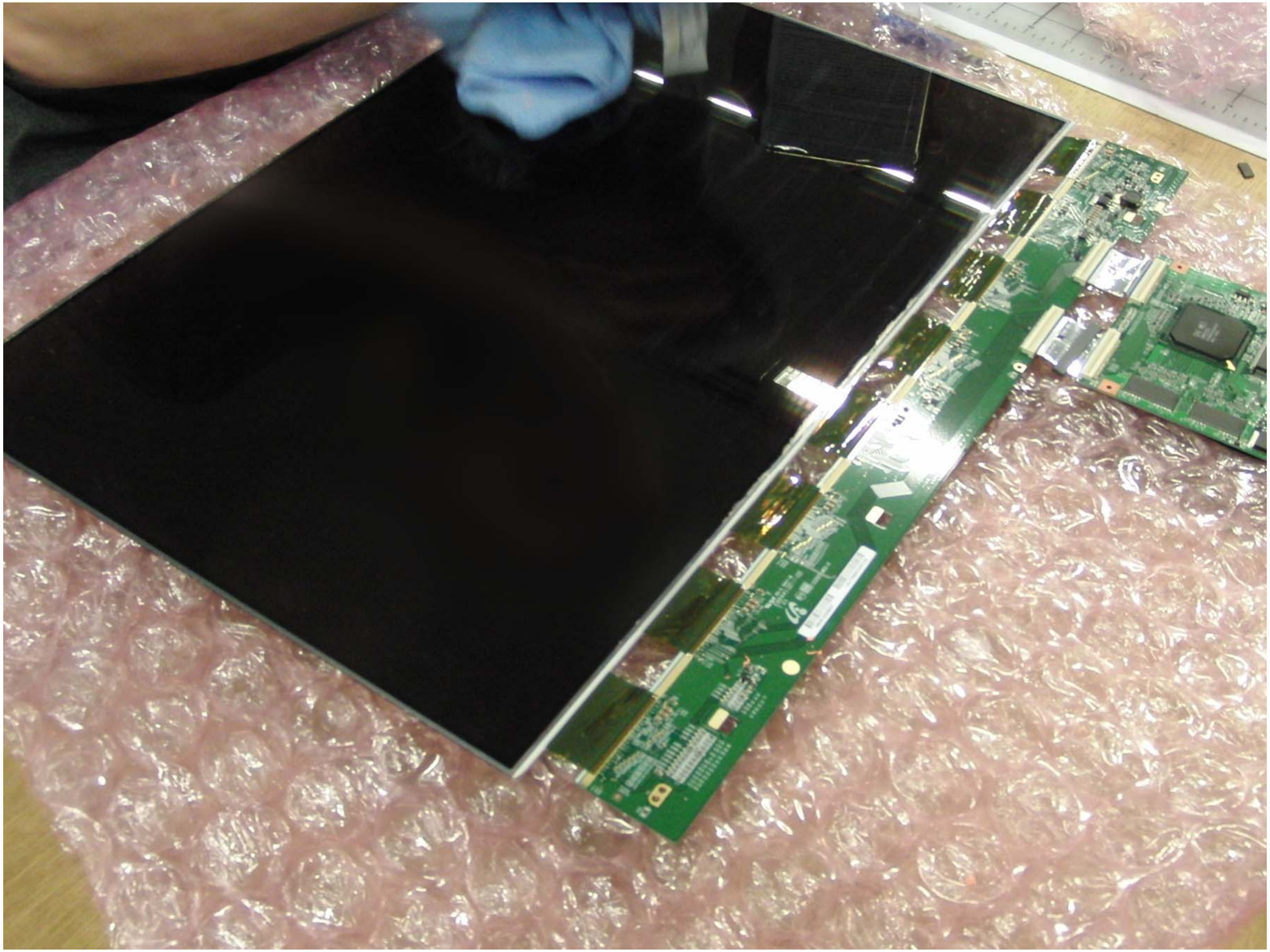


LCD Disassembly:
Removing the Backlight



LCD Disassembly:
Removing the Diffusing/Polarizing Films

LCD Disassembly:
Cleaning the Spatial Light Modulator



Assembled Dual-Stacked LCD Barrier Display

Dual-Stacked LCD Construction

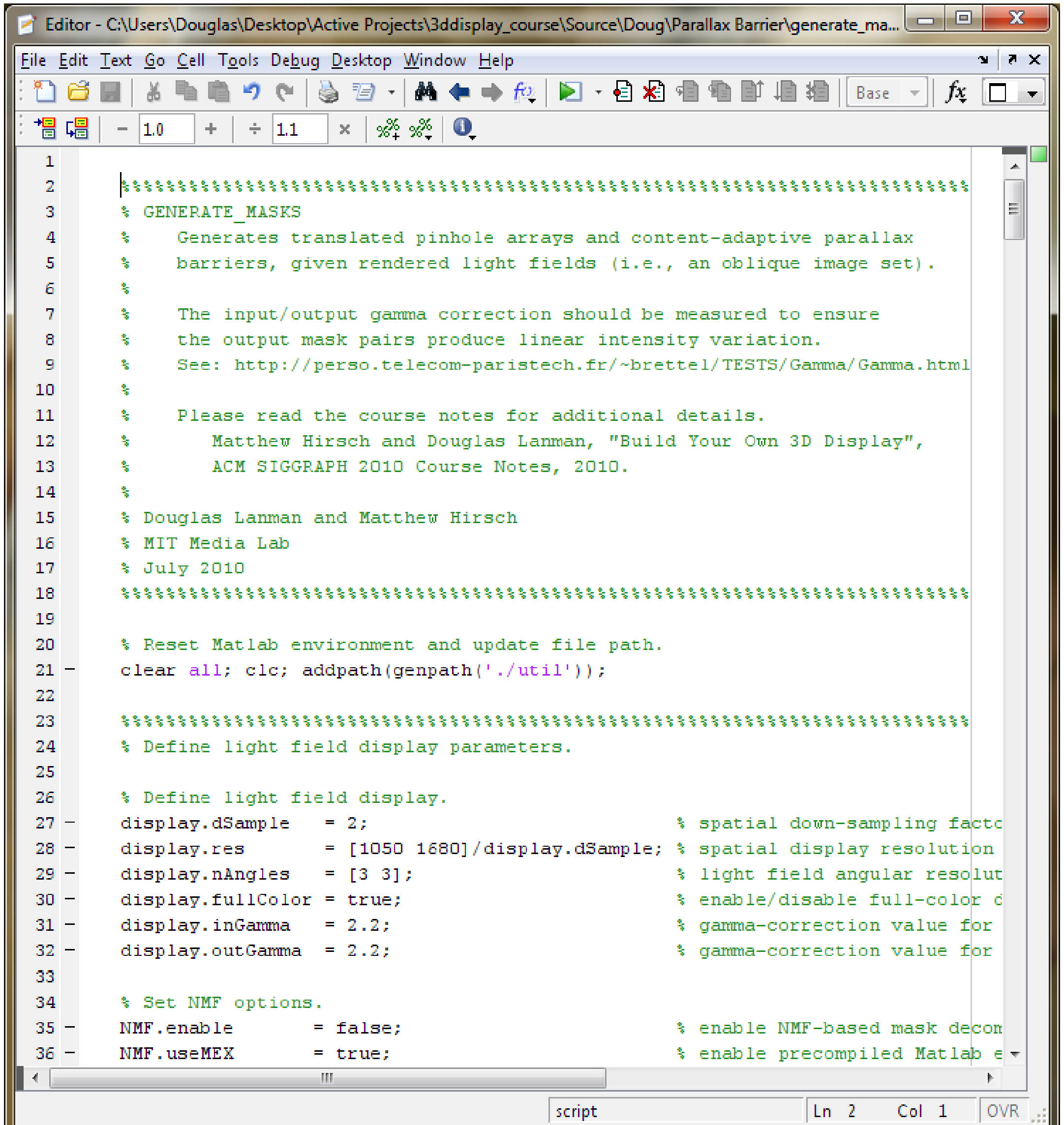
a) Rear LCD panel and backlight (unmodified)

b) Plastic spacer

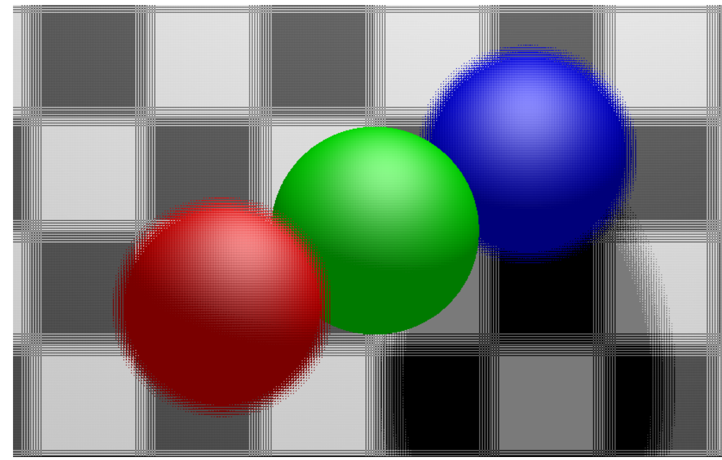
c) Front LCD panel (modified)

d) Replacement linear polarizing sheet

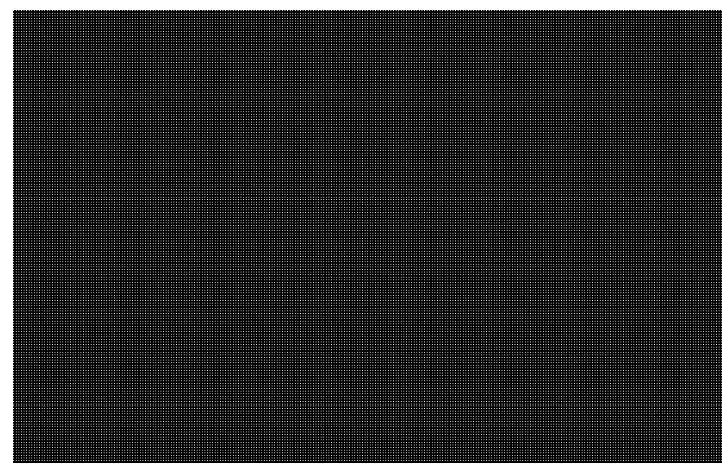
Interlacing Content:
MATLAB Demonstration



```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% GENERATE_MASKS
%    Generates translated pinhole arrays and content-adaptive parallax
%    barriers, given rendered light fields (i.e., an oblique image set).
%
%    The input/output gamma correction should be measured to ensure
%    the output mask pairs produce linear intensity variation.
%    See: http://perso.telecom-paristech.fr/~brettel/TESTS/Gamma/Gamma.html
%
%    Please read the course notes for additional details.
%       Matthew Hirsch and Douglas Lanman, "Build Your Own 3D Display",
%       ACM SIGGRAPH 2010 Course Notes, 2010.
%
% Douglas Lanman and Matthew Hirsch
% MIT Media Lab
% July 2010
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Reset Matlab environment and update file path.
clear all; clc; addpath(genpath('./util'));

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Define light field display parameters.

% Define light field display.
display.dSample   = 2;                          % spatial down-sampling facto
display.res       = [1050 1680]/display.dSample; % spatial display resolution
display.nAngles   = [3 3];                      % light field angular resolut
display.fullColor = true;                       % enable/disable full-color d
display.inGamma   = 2.2;                        % gamma-correction value for
display.outGamma  = 2.2;                        % gamma-correction value for

% Set NMF options.
NMF.enable        = false;                      % enable NMF-based mask decom
NMF.useMEX        = true;                       % enable precompiled Matlab e
```

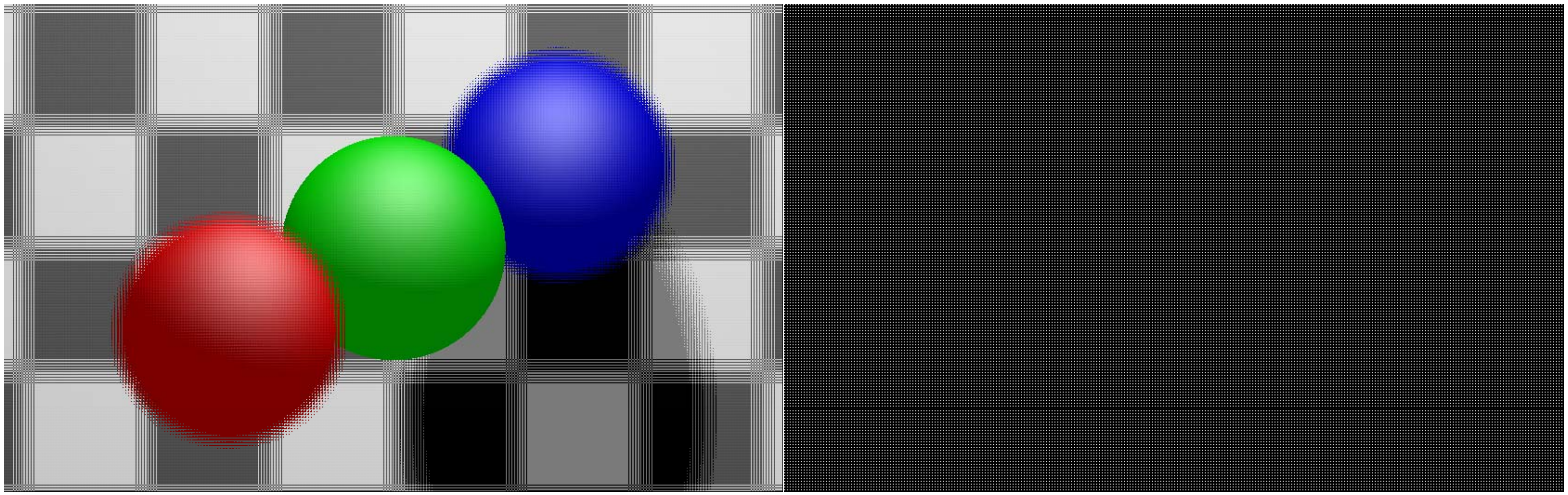


Interlaced (Rear) Image (1 of 9)



Pinhole Array (Front) Image (1 of 9)

Synchronizing the Display Updates: OpenGL Implementation

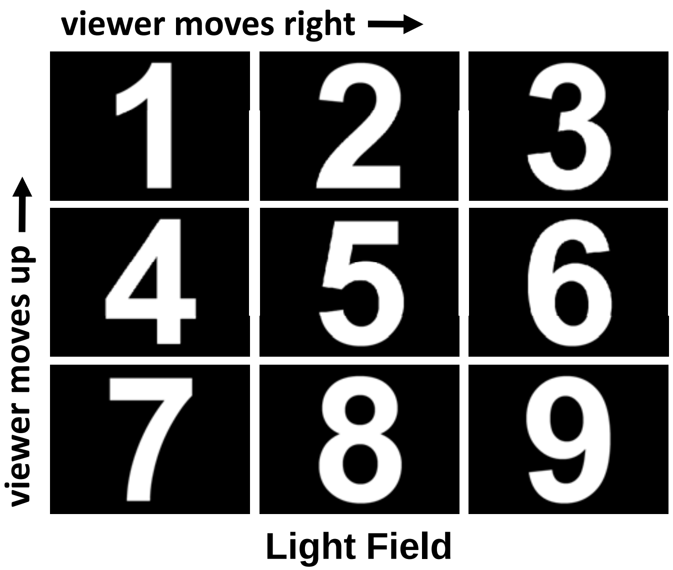


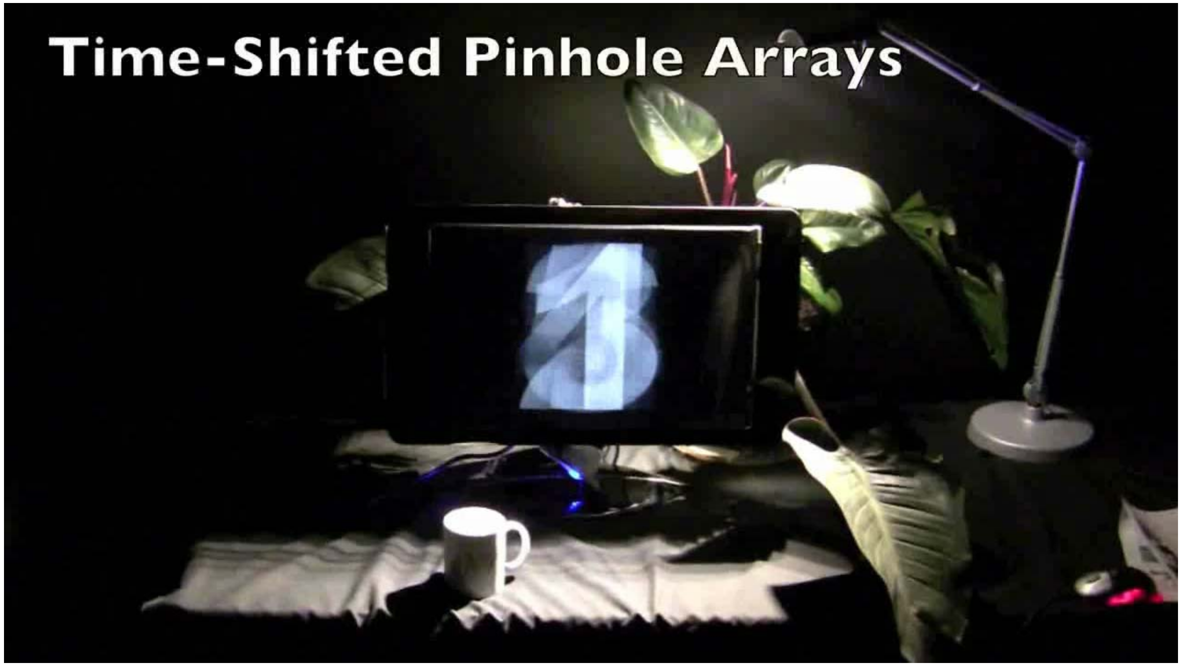
Texture Displayed on “Spanned” Display

Mask Synchronization Procedure

- Dual-head NVIDIA Quadro FX 570 display adapter
- Each panel connected via DVI (driver ensures synchronization)
- OpenGL application refreshes front and rear panels

Results:
Motion Parallax (Numbers)





Demonstrating Motion Parallax

- Interlaced base images were generated for the "numbers" sequence
- A sequence of nine time-shifted pinhole arrays were displays
- Results confirm motion parallax with 3x3 views for the prototype (effective refresh rate is 120 Hz / 9 = 13.3 Hz)

Course Outline

- Introduction: History and Physiology
- Representation and Display
- Glasses-bound Stereoscopic Displays
- Unencumbered Automultiscopic Displays
- ***Source Material: Rendering and Capture***
- Emerging Technology
- Conclusion and Q & A

Course Outline

- Introduction: History and Physiology
- Representation and Display
- Glasses-bound Stereoscopic Displays
- Unencumbered Automultiscopic Displays
- ***Source Material: Rendering and Capture***
- Emerging Technology
- Conclusion and Q & A

Source Data

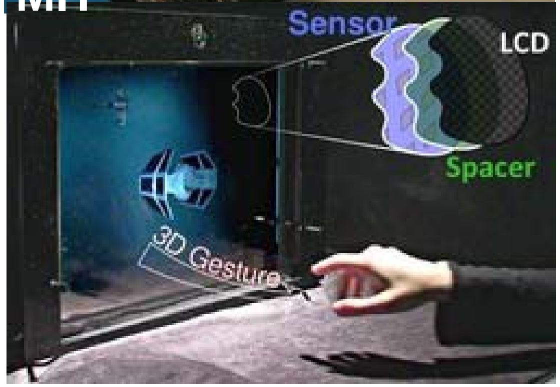
- Stereo cameras (commercial and improvised) are common

Light Field Cameras

- Many researchers/hobbiests have built their own solutions to capture light fields
- The PointGrey ProFusion is one of the few commercially available

PointGrey ProFusion

MIT

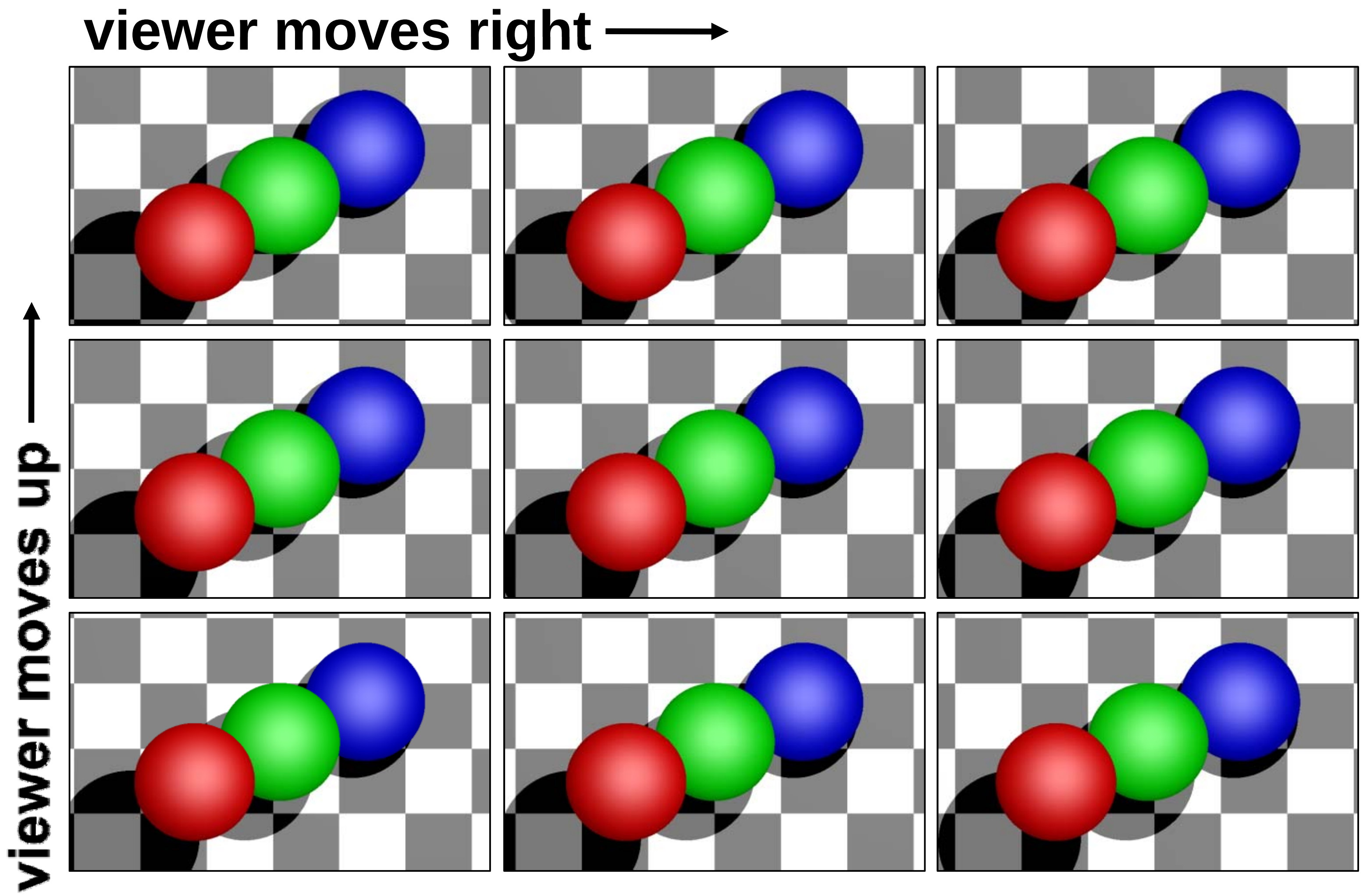


Stanford

Make Magazine

Rendering Synthetic Light Fields

- Matlab and POVRay covered in Section 4



Stereo 3D in OpenGL

- Some graphics cards have some support for stereo 3D
- Double buffered stereo = Quad buffered

```
int
main(int argc, char **argv)
{
  glutInit(&argc, argv);
  glutInitDisplayMode(GLUT_DOUBLE |
GLUT_RGB | GLUT_STEREO);
  glutCreateWindow("stereo example");
  glutDisplayFunc(display);
  glutMainLoop();
  return 0;           /* ANSI C requires main
to return int. */
}
```

```
void
display(void)
{
  glDrawBuffer(GL_BACK_LEFT);

  <Draw left eye here>

  glDrawBuffer(GL_BACK_RIGHT);

  <Draw right eye here>

  glutSwapBuffers();
}
```

The bad news…

- Only professional cards (e.g. Nvidia Quadro line) support quad buffered rendering

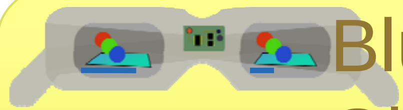
- Even if supported, what the card does with the data in each buffer is hardware and driver specific
- Range of options is overwhelming

An Example: Current Nvidia Drivers

- Modes supported on Quadro cards:

DDC Glasses

Shutter glasses synced using monitor communication bus



Blueline Glasses

Length of blue line at the bottom of the frame sends image to correct LCD

DIN Connector

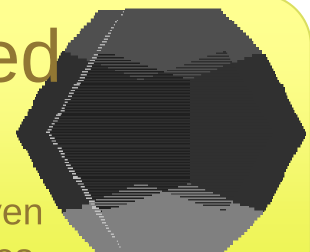
Shutter glasses synced using special video card connector

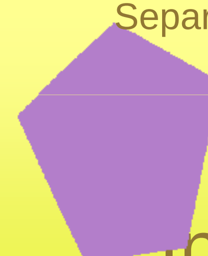
Clone Mode

Right and left images are shown on identically configured displays

Interlaced

Separate the right and left channels into even and odd scanlines





Color Interleaved

Separate views in color channels
e.g. Sharp 3D

Checkerboard

Views separated in checkerboard pattern for 3D DLP Projectors

NVIDIA 3D Vision

NVIDIA

NVIDIA's own system; DIN connector with polarity sent over IR via USB tower

http://us.download.nvidia.com/XFree86/Linux-x86/195.36.31/README/xconfigoptions.html

When quadbuffering isn't supported

- Most systems will not have a high end graphics card
- Still possible to render for some stereo 3D displays
- Must manually multiplex views as device requires
- Example: code provided to run the shutter glasses in Section 3

Example: flipping for shutter glasses

```
void onRender() {
  static char which=0;

  glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);

  switch(which){
  case 0:
     <Render left eye scene>
    break;
  case 1:
    <Render right eye scene>
    break;
  default:
    break;

  glFlush();
  glutSwapBuffers();

  which=!which;
  }
```

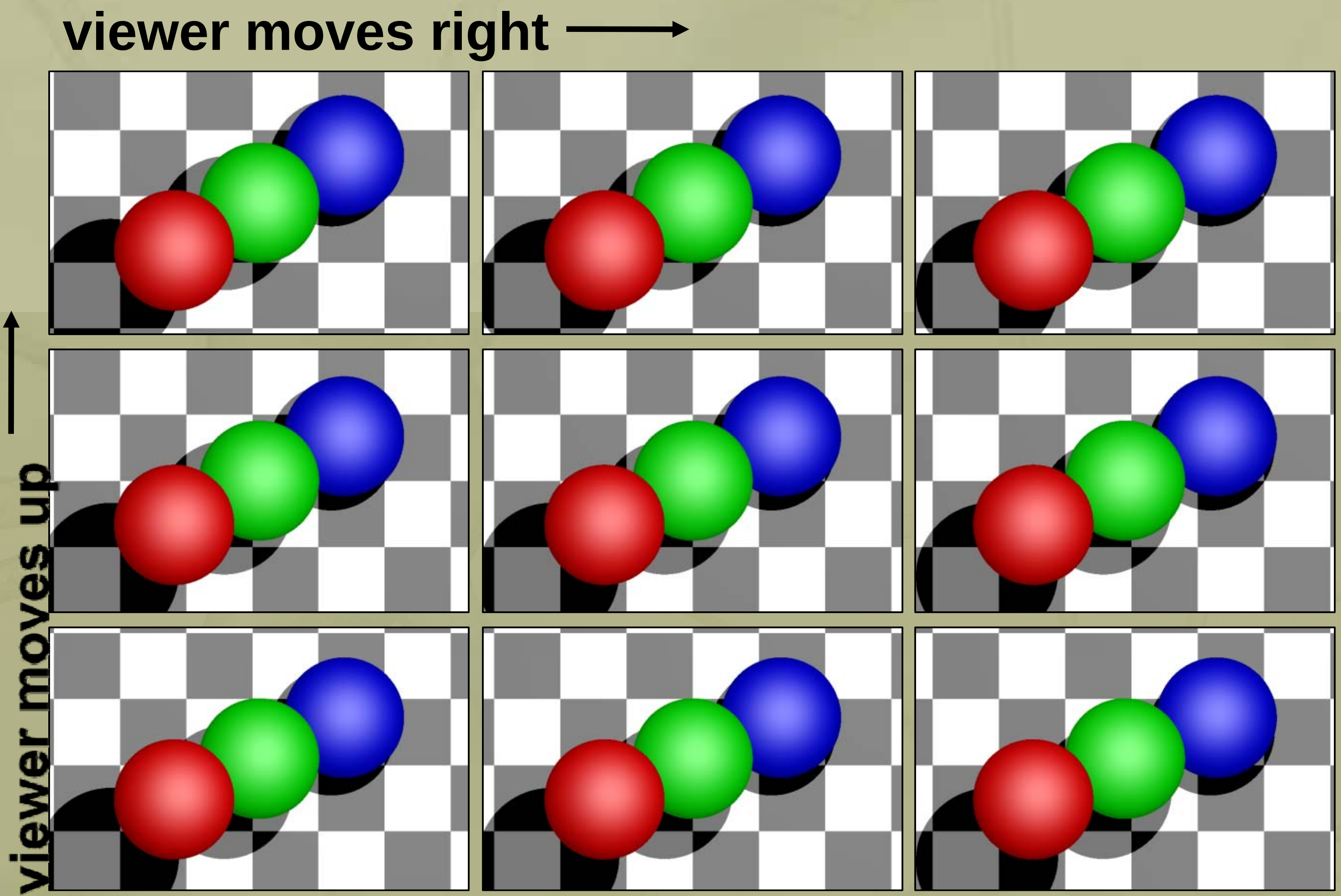
Note: must render in vertically synced mode!

Long history

- The above only works for simple programs
  - Can never miss a frame
- Possibly more robust methods
  - http://www.gali-3d.com/archive/articles/StereoOpenGL/StereoscopicOpenGLTutorial.php
  - http://sourceforge.net/projects/stereogl/files/
- Historical device info
  - http://www.stereo3d.com/3dhome.htm
- Anaglyph Rendering
  - Many examples, does not required quad buffering
  - See quake3 source code (engine is opensource)

Beyond Stereo

- Multiview OpenGL rendering requires shader/vertex programs on modern GPUs
- No explicit hardware support
- Some work has been done in this area
  - Annen et. al. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.72.6756&rep=rep1&type=pdf
  - Boev et. al. http://sp.cs.tut.fi/publications/archive/Boev2008-GPU.pdf
  - Hübner et. al. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.89.5141&rep=rep1&type=pdf



Source code for rendering 4D light fields is available on the course website:

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

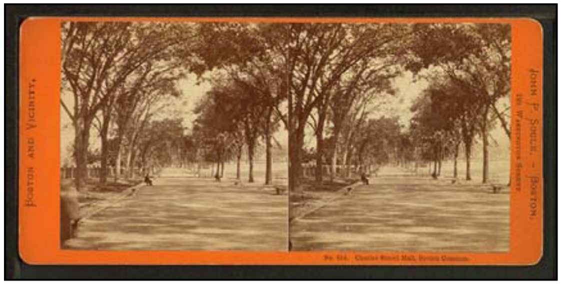
Course Outline

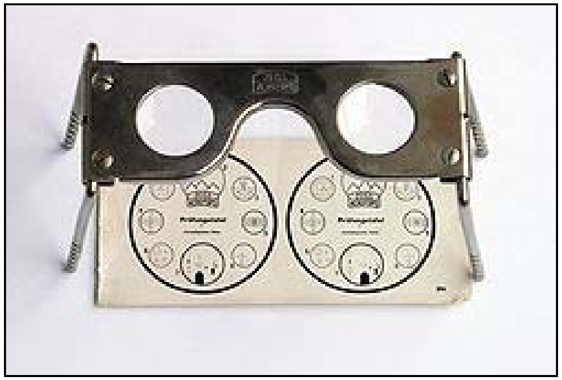
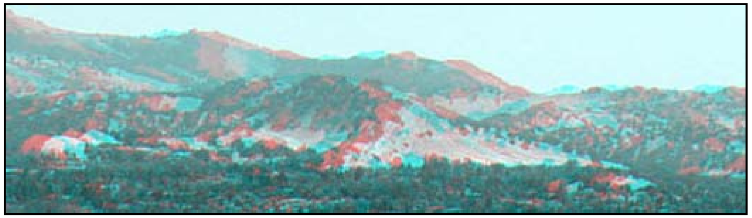
- Introduction: History and Physiology
- Representation and Display
- Glasses-bound Stereoscopic Displays
- Unencumbered Automultiscopic Displays
- Source Material: Rendering and Capture
- ***Emerging Technology***
- Conclusion and Q & A

Course Outline

- Introduction: History and Physiology
- Representation and Display
- Glasses-bound Stereoscopic Displays
- Unencumbered Automultiscopic Displays
- Source Material: Rendering and Capture
- ***Emerging Technology***
- Conclusion and Q & A

Summary:
Glasses-bound Stereoscopic Displays

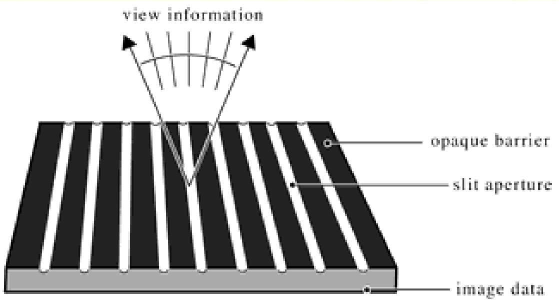


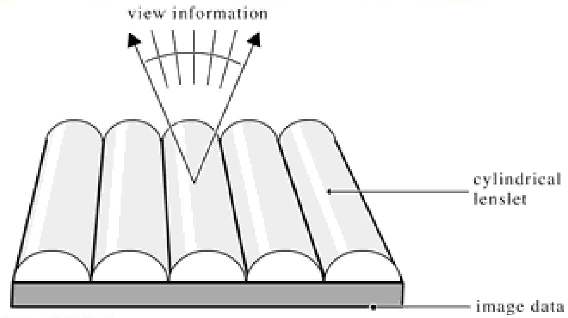




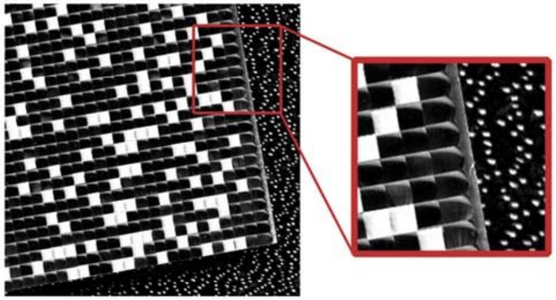

Glasses-bound Stereoscopic

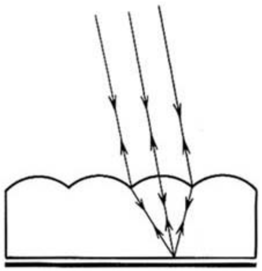
- **Head-mounted**
  (eyepiece-objective and microdisplay)
  - Immersive
    (blocks direct-viewing of real world)
  - See-through
    (superimposes synthetic images onto real world)
- **Multiplexed**
  (stereo pair with same display surface)
  - Spatially-multiplexed (field-concurrent)
    (color filters, polarizers, autostereograms, etc.)
  - Temporally-multiplexed (field-sequential)
    (LCD shutter glasses)

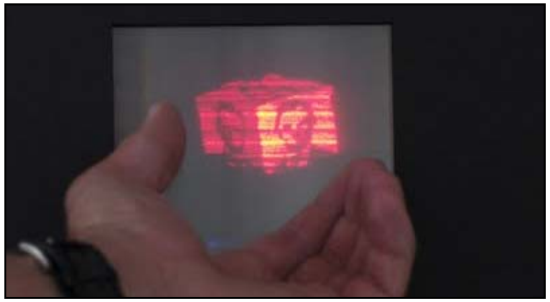
Summary:
Unencumbered Automultiscopic Displays







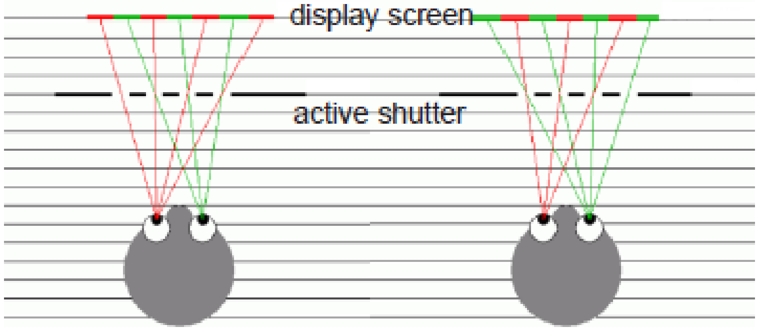




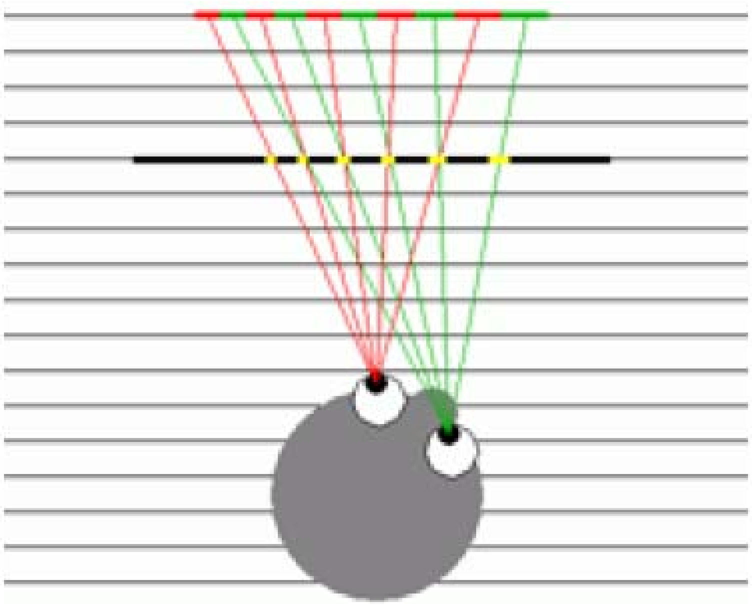
Unencumbered Automultiscopic

- **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)

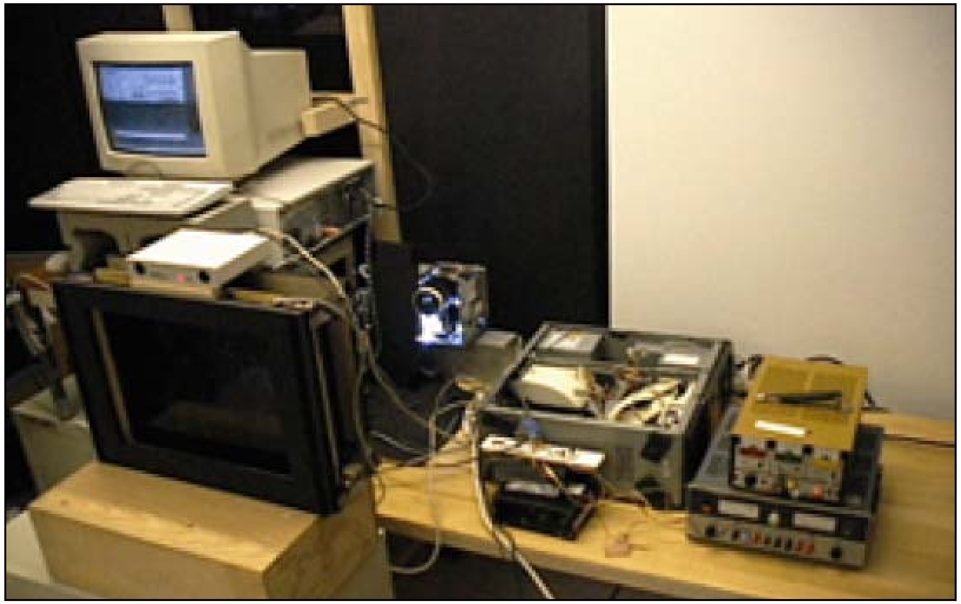
Recent Work:
NYU Autostereoscopic Display

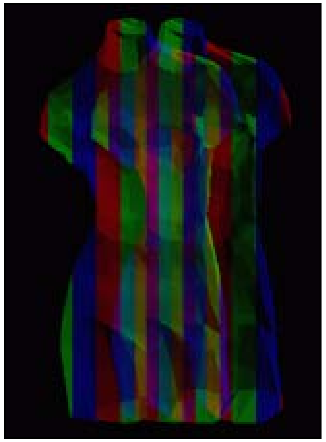


Time-shifted Parallax Barriers



Varying-width Parallax Barriers

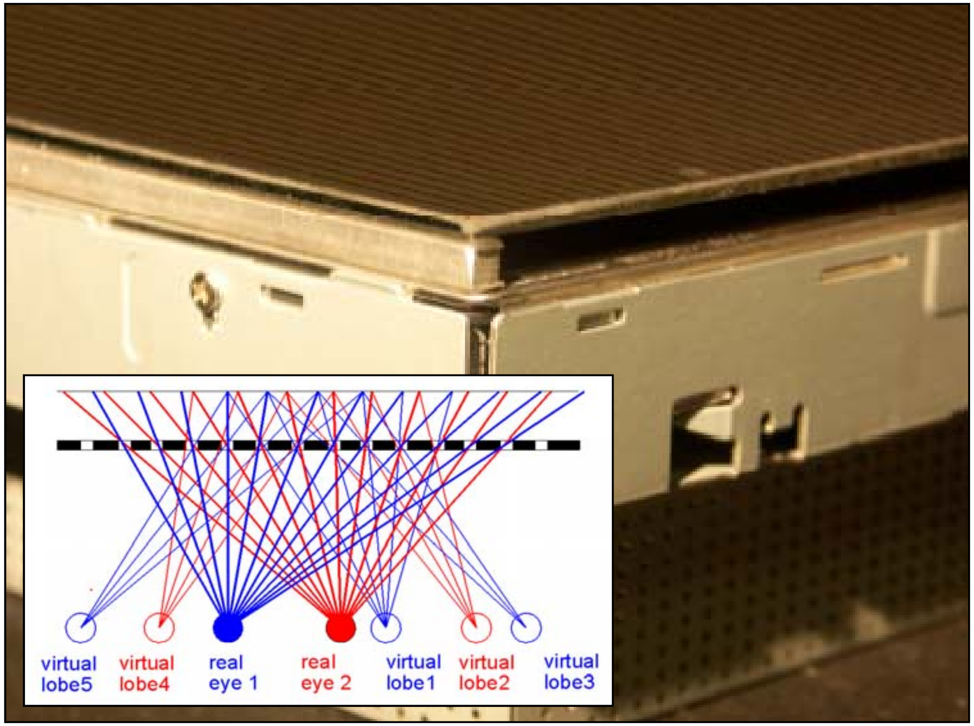


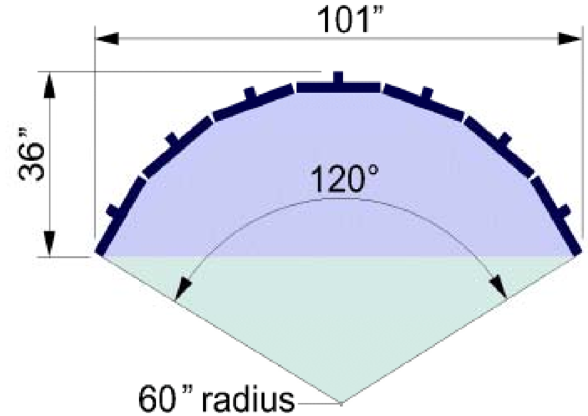


K. Perlin, S. Paxia, J. Kollin. An Autostereoscopic Display. ACM SIGGRAPH, 2000

K. Perlin, C. Poultney, J. Kollin, D. Kristjansson, S. Paxia. Recent Advances in the NYU Autostereoscopic Display. Proceedings of the SPIE, 2001

Recent Work:
Dynallax and Cylindrical Varrier Displays

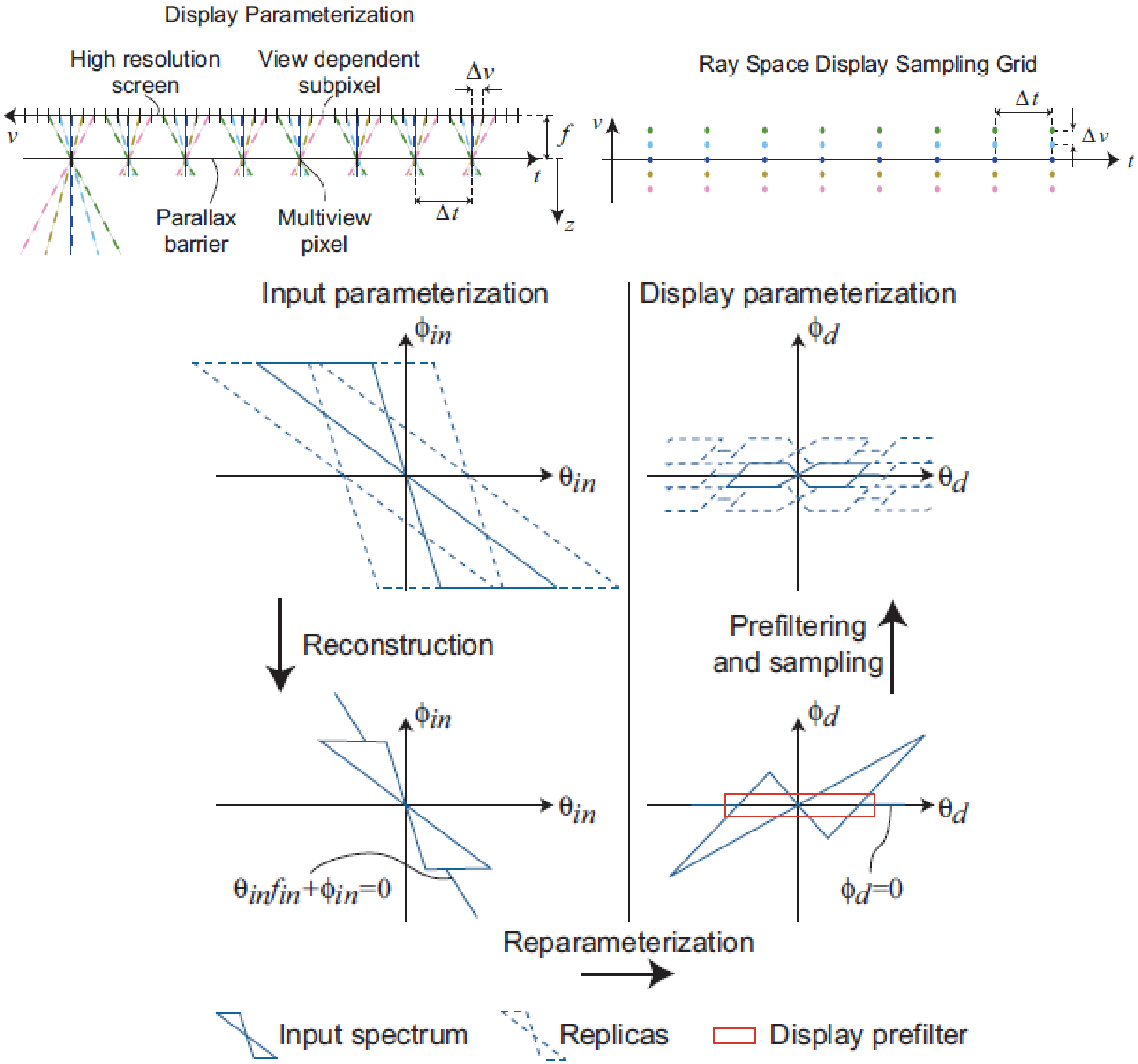




D. J. Sandin et al. The Varrier Autostereoscopic Virtual Reality Display. ACM SIGGRAPH, 2005

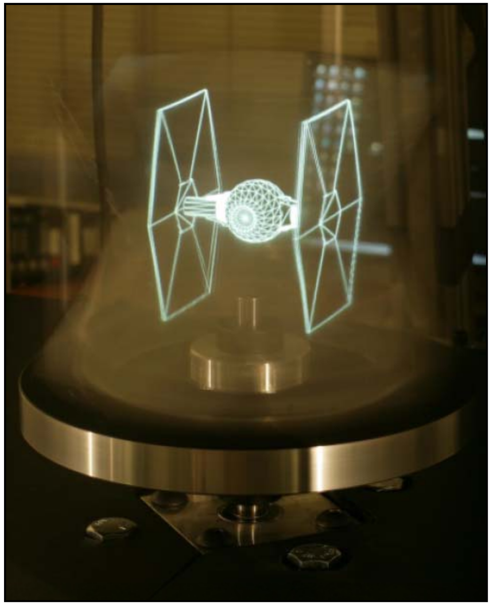
T. Peterka et al. Dynallax: Solid State Dynamic Parallax Barrier Autostereoscopic VR Display. IEEE Virtual Reality, 2007

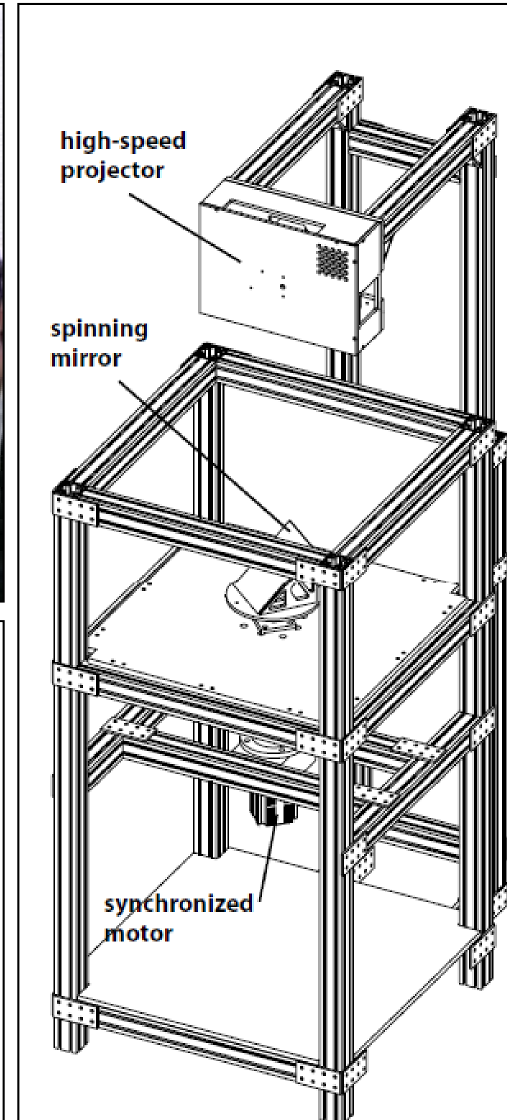
Recent Work:
Antialiasing for Automultiscopic 3D Displays

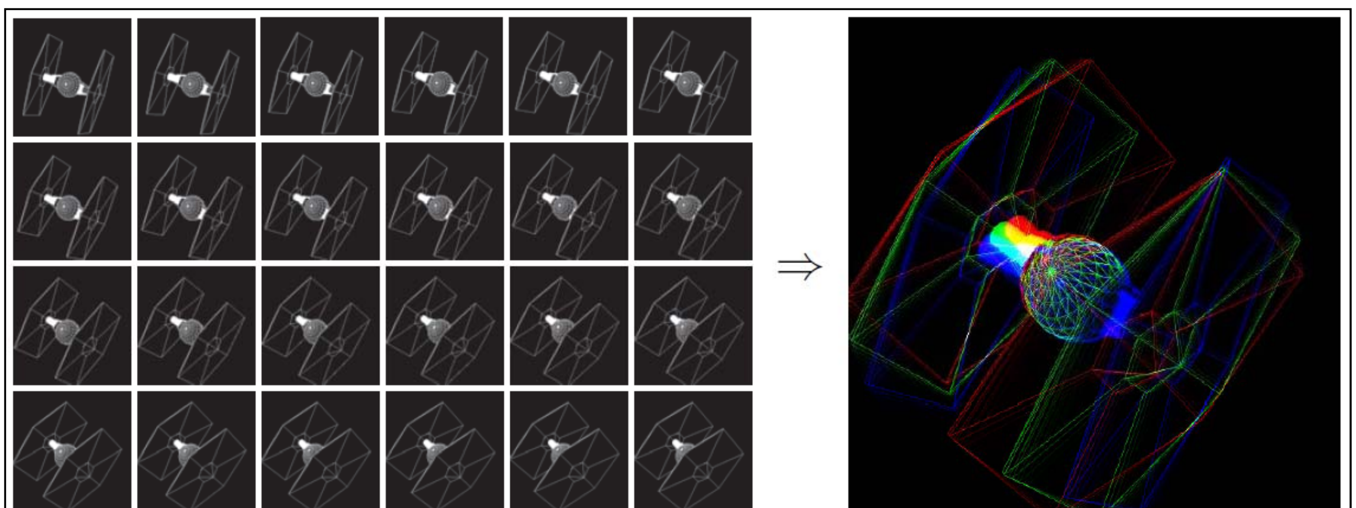


M. Zwicker, W. Matusik, F. Durand, H. Pfister. Antialiasing for Automultiscopic 3D Displays. EGSR, 2006

Recent Work:
An Interactive 360º Light Field Display



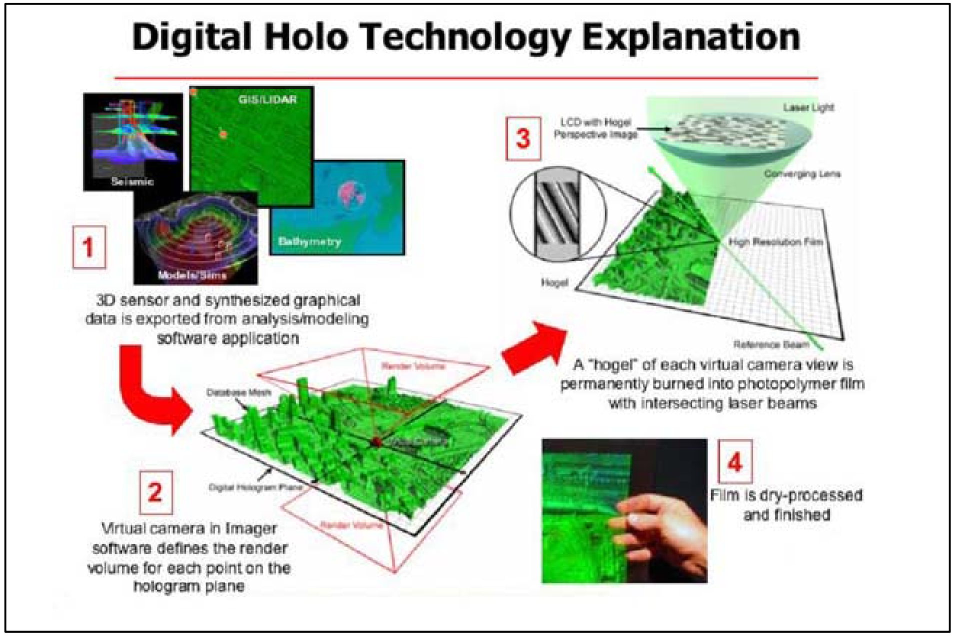




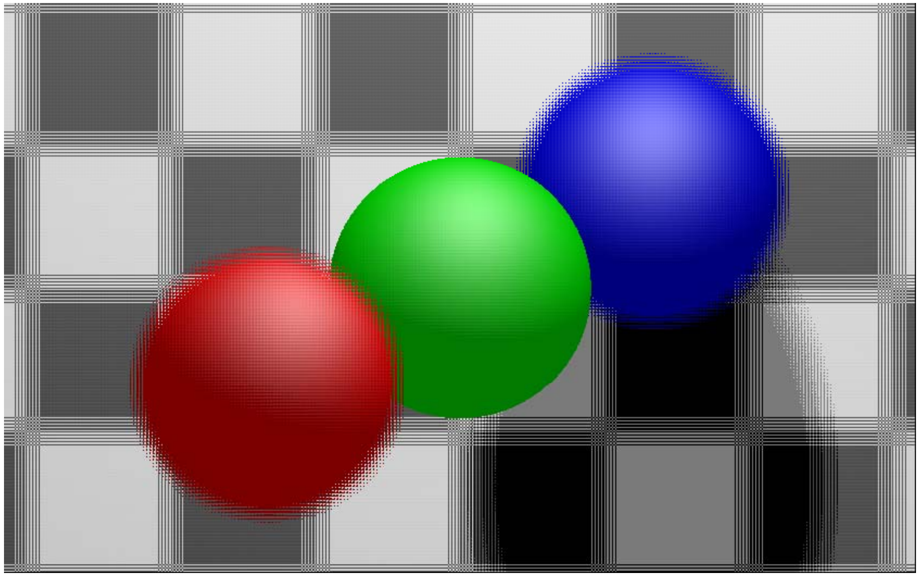
A. Jones, I. McDowall, H. Yamada, M. Bolas, P. Debevec. Rendering for an Interactive 360º Light Field Display. ACM SIGGRAPH, 2007

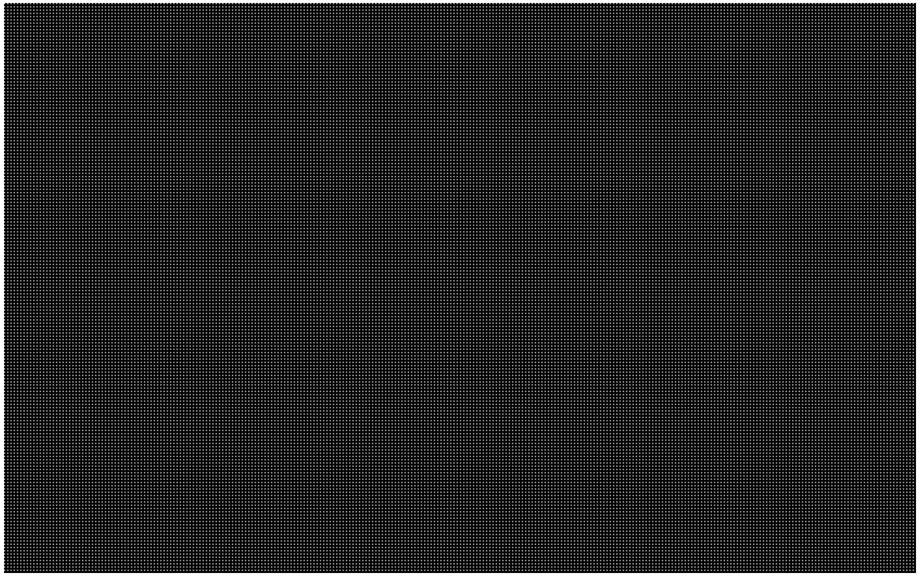
Recent Work:

Zebra Imaging, Inc. and RabbitHoles Holdings Corp.

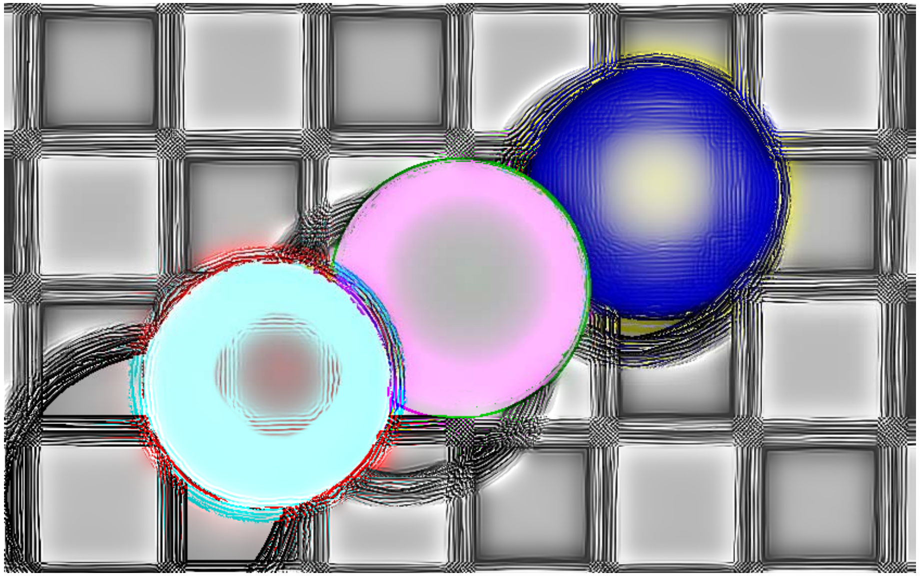


Recent Work:
Conventional Parallax Barriers [Ives, 1903]

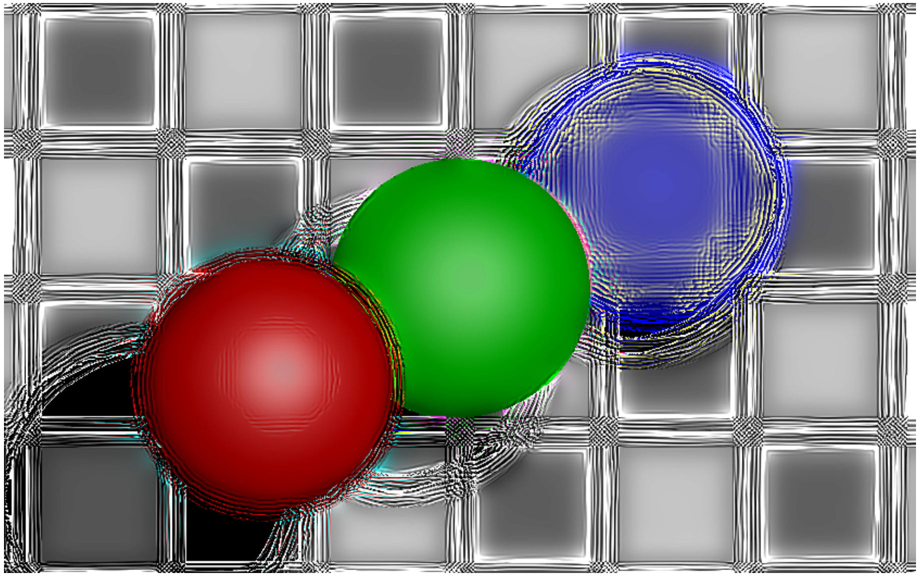

rear mask


front mask

Recent Work:
Content-Adaptive Parallax Barriers



rear mask



front mask

Douglas Lanman   Matthew Hirsch
Yunhee Kim   Ramesh Raskar

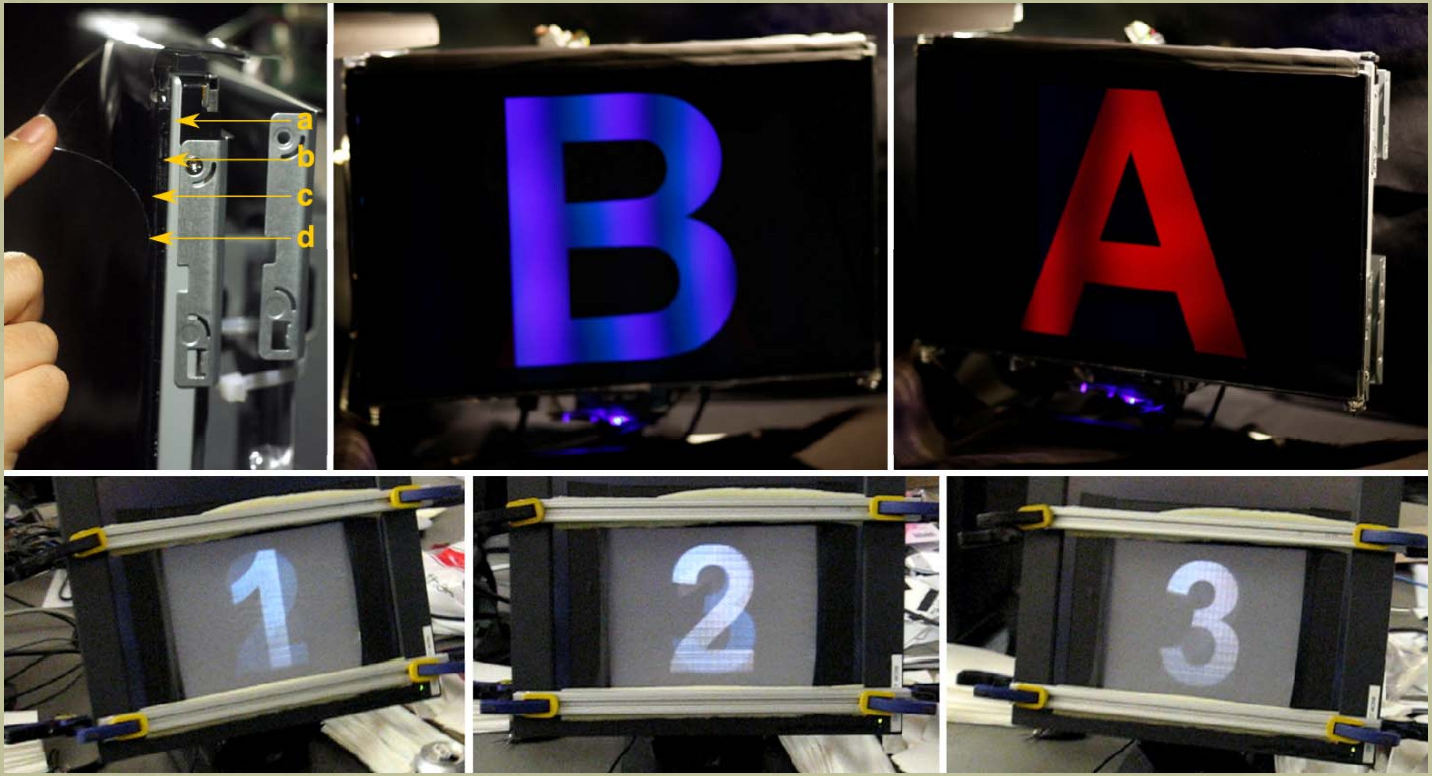
MIT Media Lab – Camera Culture Group

Imaging Hardware Session

Thursday, 16 December | 11:00 AM - 12:45 PM | Room E1-E4

Course Outline

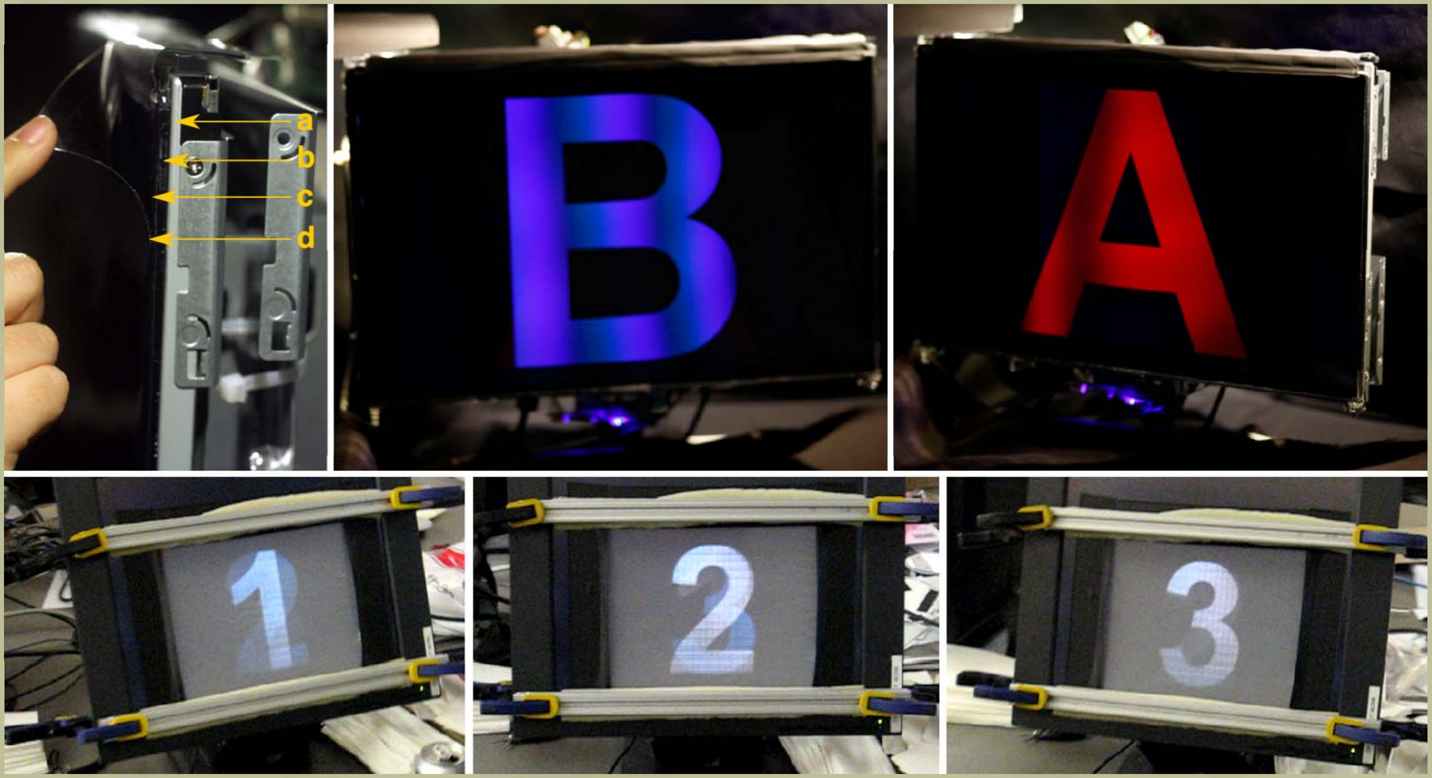
- Introduction: History and Physiology
- Representation and Display
- Glasses-bound Stereoscopic Displays
- Unencumbered Automultiscopic Displays
- Source Material: Rendering and Capture
- Emerging Technology
- ***Conclusion and Q & A***



Conclusion

Questions and Answers

{mhirsch, dlanman}@media.mit.edu
http://cameraculture.media.mit.edu/byo3d/



Thank you for attending.

Please come up front to look at the demos.

{mhirsch, dlanman}@media.mit.edu

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