Display Blocks

EE367/CS448I: Computational Imaging and Display
stanford.edu/class/ee367
Winter 2016, Lecture 15

Gordon Wetzstein
Stanford University
Pepper’s Ghost

John Henry Pepper, 1862
Pepper’s Ghost
Pepper’s Ghost

hidden room
not directly visible!

visible room

beam splitter
(green)

viewing window
(red)
Pepper’s Ghost - Lighting

Same as all near-eye augmented reality displays!
Google Glass

A clever prism projects a layer over reality light.

electroembedded.blogspot.com/2014/03/google-glass.html
Google Glass
Digital Displays - Overview

- spatial light modulators
- liquid crystal displays
- projection displays
- gamut mapping
- stereo displays
- light field displays
- of course: digital pepper’s ghost & AR!

displayblocks.org
Spatial Light Modulators (SLMs)

- some type of spatially-varying light modulation (amplitude or phase)

Liquid Crystal Display (LCD)  Liquid Crystal Display on Silicon (LCoS)  Digital Micromirror Device (DMD)

Light Emitting Diodes (LEDs) and OLEDs  E Ink

- mirasol
- pixtronix
- Ostendo
- quantum dots …
Light Emitting Diodes (LED)

- Epoxy lens/case
- Wire bond
- Reflective cavity
- Semiconductor die
- Anvil Post
- Leadframe
- Flat spot

Anode
Cathode
Light Emitting Diodes (LED)
LED Displays
White LEDs

- either multiple dies (i.e. R+G+B dies)
- or blue die + phosphor

![Image of white LED](wikipedia)

**Blue LED**

**Blue LED + phosphor (Ce:YAG)**
Organic Light Emitting Diodes (OLEDs)

- electroluminescent material is organic
- can be printed, e.g., on flexible substrates
Transparent OLEDs
OLED – Active vs Passive Matrix
Active vs Passive Matrix Addressing Scheme

**active matrix**

- more complex electronics (1 capacitor & 1 transistor per pixel)
- pixel can “store” information, e.g. while scanning over the rest of the screen
- similar to phosphor lifetime in CRT

**passive matrix**

- simpler electronics
- “dead” time between pixel updates – can lead to flicker (slow response)
- imprecise voltage control
<table>
<thead>
<tr>
<th>Toshiba Satellite 440CDT</th>
<th>Apple PowerBook 1400cs</th>
</tr>
</thead>
<tbody>
<tr>
<td>133-MHz Pentium MMX</td>
<td>166-MHz PowerPC 603e</td>
</tr>
<tr>
<td>12&quot; active-matrix LCD</td>
<td>11&quot; passive-matrix LCD</td>
</tr>
<tr>
<td>(800x600 TFT)</td>
<td>(800x600 DSTN)</td>
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</table>
Liquid Crystal Displays

- most common displays for monitors and TVs
LCDs - Twisted Nematic (TN)

Twisted Nematic Cell

Incident Light

Transmitted Light

Electric Field

Blocked Light

Back Light

Polarizer

Molecular Orientation Layers

Transparent Electrodes

Glass

Liquid Crystal

Polarizer
LCDs - Twisted Nematic (TN)

relaxed (twisted), crystalline state
LCDs - Twisted Nematic (TN)

voltage applied: un-twisting – liquid state
LCDs – In-plane Switching (IPS)

- electrodes on same side
- in-plane LC alignment
- pro: more consistent across viewing angles, don’t change color when touched
- con: more power, slower, more expensive than TN
LCD Subpixels

TN subpixels

IPS

S-IPS

IPS
LCD Subpixels - Pentile Pixels

- exotic subpixel layouts with different advantages and disadvantages
LCD Backlight
LCD Backlight – CCFL vs LED

• used to be: cold-cathode fluorescent lamps
• now mostly LEDs: last longer, brighter, thinner, lower power, but a bit more expensive
... at the end, you have a “light box”
Directional Backlight - Leia

Fattal et al., 2013
Quantum Dots (QD)

- semiconductor nanocrystal
- extremely narrow, tunable emission spectrum (visible+IR)
- band gap (which determines emitted wavelength) is inversely proportional to dot size

- quantum dot displays used in LCD backlight (we’ll get back to that a but later) by QD Vision
Quantum Dots
Quantum Dot Backlight – QD Vision

Liquid Crystal on Silicon (LCoS)

- basically a reflective LCD
- standard component in projectors and head mounted displays
- used e.g. in google glass
- without 2nd polarizer: phase modulation!
Electronic Ink (E Ink)

- reflective display – no active lighting!
- high contrast, low power
- bistable
- invented by Joe Jacobsen
Mirasol (Qualcomm)

- interferometric modulator display (IMOD)
- color from gap size (changed via MEMS)
- intensity from subpixels – low res?!
Digital Micromirror Device (DMD)

- developed by Texas Instruments
- MEMS device
- binary states (e.g. +/- 10 degrees)
- gray-level through pulse width modulation (PWM)
Digital Micromirror Device (DMD)

• when used in projector, usually called digital light processing device (DLP)
Digital Light Processing (DLP) Projectors

- color multiplexed in time (field sequential color)
- for example using color wheel in DPL projectors
Anatomy of a Projector (without the light)

- Diffuse Screen
- Projection Lens
- Viewer
- Modulator
LCD Projectors

- 3 separate optical paths (1 per color channel)
- splitting via dichroic mirrors
- separate modulation via transmissive LCDs
- combination via x-cube prism
- projection lens
Scanned Laser Pico Projectors

- biaxial MEMS scanner
- 43.2° by 24.3° at 60 Hz

Microvision, Freeman et al. 2009
Scanned Laser Pico Projectors

Microvision, Freeman et al. 2009
Holographic Laser Projectors

- developed by light blue optics
- coherent light – phase modulation in Fourier plane
Laser/LCD Projector

- phosphor + blue laser = white (same as white LED)
Scanning Fiber Projector

- Schowengerdt et al., University of Washington
- now at Magic Leap
Questions?
Stereoscopic and 3D / Light Field Displays

many slides from Douglas Lanman (thanks)
Some Depth Cues of the HVS

- **binocular disparity**
- **convergence**
- **motion parallax**
- **accommodation/blur**

Current glasses-based (stereoscopic) displays

Near-term: compressive light field displays

Longer-term: holographic displays
Taxonomy of Direct 3D Displays:

**Glasses-bound vs. Unencumbered Designs**

**Glasses-bound**

- Stereoscopic
  - Head-mounted (eyepiece-objective and microdisplay)
  - Multiplexed (stereo pair with same display surface)

**Unencumbered**

- Automultiscopic
  - Parallax-based (2D display with light-directing elements)
  - Volumetric (directly illuminate points within a volume)
  - Holographic (reconstructs wavefront using 2D element)

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

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

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

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

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

Taxonomy adapted from Hong Hua
Taxonomy of 3D Displays:

- **Immersive Head-mounted Displays (HMDs)**
  - **Head-mounted** (eyepiece-objective and microdisplay)
  - **Glasses-bound**
  - **Stereoscopic**
  - **Multiplexed** (stereo pair with same display surface)

- **Immersive** (blocks direct-viewing of real world)
Taxonomy of 3D Displays:

See-through Head-mounted Displays (HMDs)

- Glasses-bound
  - Stereoscopic
    - Multiplexed (stereo pair with same display surface)
  - Immersive (blocks direct-viewing of real world)

- See-through (superimposes synthetic images onto real world)
Taxonomy of 3D Displays:

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

- Glasses-bound
- Head-mounted (eyepiece-objective and microdisplay)
- Multiplexed (stereo pair with same display surface)

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

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

**Spatially-multiplexed**
- (Field-concurrent)
  - (Color filters, polarizers, etc.)
Taxonomy of 3D Displays:

Temporal Multiplexing (e.g., Shutter Glasses)

- Glasses-bound
- Immersive (blocks direct-viewing of real world)
- See-through (superimposes synthetic images onto real world)
- Spatially-multiplexed (field-concurrent) (color filters, polarizers, autostereograms, etc.)
- Temporally-multiplexed (field-sequential) (LCD shutter glasses)

- Head-mounted (eyepiece-objective and microdisplay)
- Multiplexed (stereo pair with same display surface)

Overlapping images displayed on the screen. The images switch so fast that without glasses the images seem to be blended.
Perceptual Issues of Stereo Displays

Visual Discomfort

A perceptual model for disparity, SIGGRAPH 2011 [Didyk et al.]
Perceptual Issues of Stereo Displays

Visual Discomfort

Viewing discomfort

Comfort zone

Scene manipulation

Viewing comfort

A perceptual model for disparity, SIGGRAPH 2011 [Didyk et al.]
Perceptual Issues of Stereo Displays

Disparity Remapping

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

Introduce more distortions where they will be less perceived

“Nonlinear Disparity Mapping for Stereoscopic 3D” by Lang et al. 2010
Perceptual Issues of Stereo Displays

Disparity Remapping

Visual Importance based on saliency

"Nonlinear Disparity Mapping for Stereoscopic 3D" by Lang et al. 2010
Taxonomy of Direct 3D Displays:

- **Parallax Barriers**
  - Unencumbered
  - Automultiscopic
  - Parallax-based (2D display with light-directing elements)
  - Volumetric (directly illuminate points within a volume)
  - Holographic (reconstructs wavefront using 2D element)

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

Parallax Barriers (uniform array of 1D slits or 2D pinhole arrays)
Parallax Barriers – Ives 1903

- low resolution & very dim
Taxonomy of Direct 3D Displays:

- **Integral Imaging**
  - Lenticular Lenslets

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

- **Unencumbered**
- **Automultiscopic**

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

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

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

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

Alioscopy 3DHD 42''
(1920x1200, 1x8 views)
Integral Imaging – Lippmann 1908

- low-res, but brighter than parallax barriers
Integral Imaging – Light Field
Integral Imaging – Interlaced Light Field

# Display Pixels Y

# Display Pixels X
Integral Imaging – Observed Central View
Directional Backlighting

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

Nelson and Brott, 2010
US Patent 7,847,869
Taxonomy of Direct 3D Displays:

- **Multi-planar Volumetric Displays**
- **Unencumbered Automultiscopic**
- **Volumetric** (directly illuminate points within a volume)
- **Holographic** (reconstructs wavefront using 2D element)

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

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

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

**Parallax Barriers** (uniform array of 1D slits or 2D pinhole arrays)
Taxonomy of Direct 3D Displays:

**Transparent-substrate Volumetric Displays**

- **Parallax-based**
  - (2D display with light-directing elements)
- **Volumetric**
  - (directly illuminate points within a volume)
- **Holographic**
  - (reconstructs wavefront using 2D element)
- **Parallax Barriers**
  - (uniform array of 1D slits or 2D pinhole arrays)
- **Integral Imaging**
  - (lenticular sheets or fly’s eye lenslet arrays)
- **Multi-planar**
  - (time-sequential projection onto swept surfaces)
- **Transparent Substrates**
  - (intersecting laser beams, fog layers, etc.)
Taxonomy of Direct 3D Displays:

Static Holograms

- **Parallax-based**
  - (2D display with light-directing elements)
- **Volumetric**
  - (directly illuminate points within a volume)
- **Holographic**
  - (reconstructs wavefront using 2D element)

**Unencumbered Automultiscopic**

- **Parallax Barriers**
  - (uniform array of 1D slits or 2D pinhole arrays)
- **Integral Imaging**
  - (lenticular sheets or fly’s eye lenslet arrays)
- **Multi-planar**
  - (time-sequential projection onto swept surfaces)
- **Transparent Substrates**
  - (intersecting laser beams, fog layers, etc.)
- **Static**
  - (holographic films)
Taxonomy of Direct 3D Displays:

**Dynamic Holograms (Holovideo)**

- **Parallax-based** (2D display with light-directing elements)
- **Volumetric** (directly illuminate points within a volume)
- **Holographic** (reconstructs wavefront using 2D element)

**Unencumbered Automultiscopic**

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

**Integral Imaging**
lenticular sheets or fly’s eye lenslet arrays

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

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

**Static**
holographic films

**Dynamic**
holovideo

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Tay et al.
[Nature, 2008]

MIT Media Lab Spatial Imaging Group
[Holovideo, 1989 – present]
Glasses-free 3D Theaters

Cyclostereoscope, France, 1940-50s

Seymon Palovich Ivanov, Russia, 1935

Inventors & Filmmakers, 1950s
Multi-projector Glasses-free 3D

USC ICT – SIGGRAPH 2013 ETech

Holografika
Anatomy of a Projector

Diffuse Screen

Projection Lens

Viewer

Modulator
Building a 3D Projector
Building a 3D Projector

Side View

Vertical-Only Diffuser
Pepper’s Ghost
Next: Computational Displays

- HDR displays
- projection displays
- volumetric and other 3D displays
- vision-correcting displays
References and Further Reading

- many more details on LCDs: http://www.personal.kent.edu/~mgu/LCD/index.htm
- good article for LCDs: http://en.wikipedia.org/wiki/LCD_television (better than the wikipedia LCD article)
- Freeman, Champion, Madhaven “Scanned Laser Pico-projectors”, Microvision, 2009
- Fattal, Peng, Tran, Vo, Fiorentino, Brug, Beausoleil, “A Multi-directional backlight for a wide-angle, glasses-free three-dimensional display”, Nature 2013
- Jones, McDowall, Yamada, Bolas, Debevec “Rendering for an Interactive 360° Light Field Display”, SIGGRPH 2007
- Favalora, Napoli, Hall, Dorval, Dorval, Giovinco, Richmond, Chun “100-million-voxel volumetric display”, SPIE 4712, 2002