Modern Display Technology

- Rendering Challenges -

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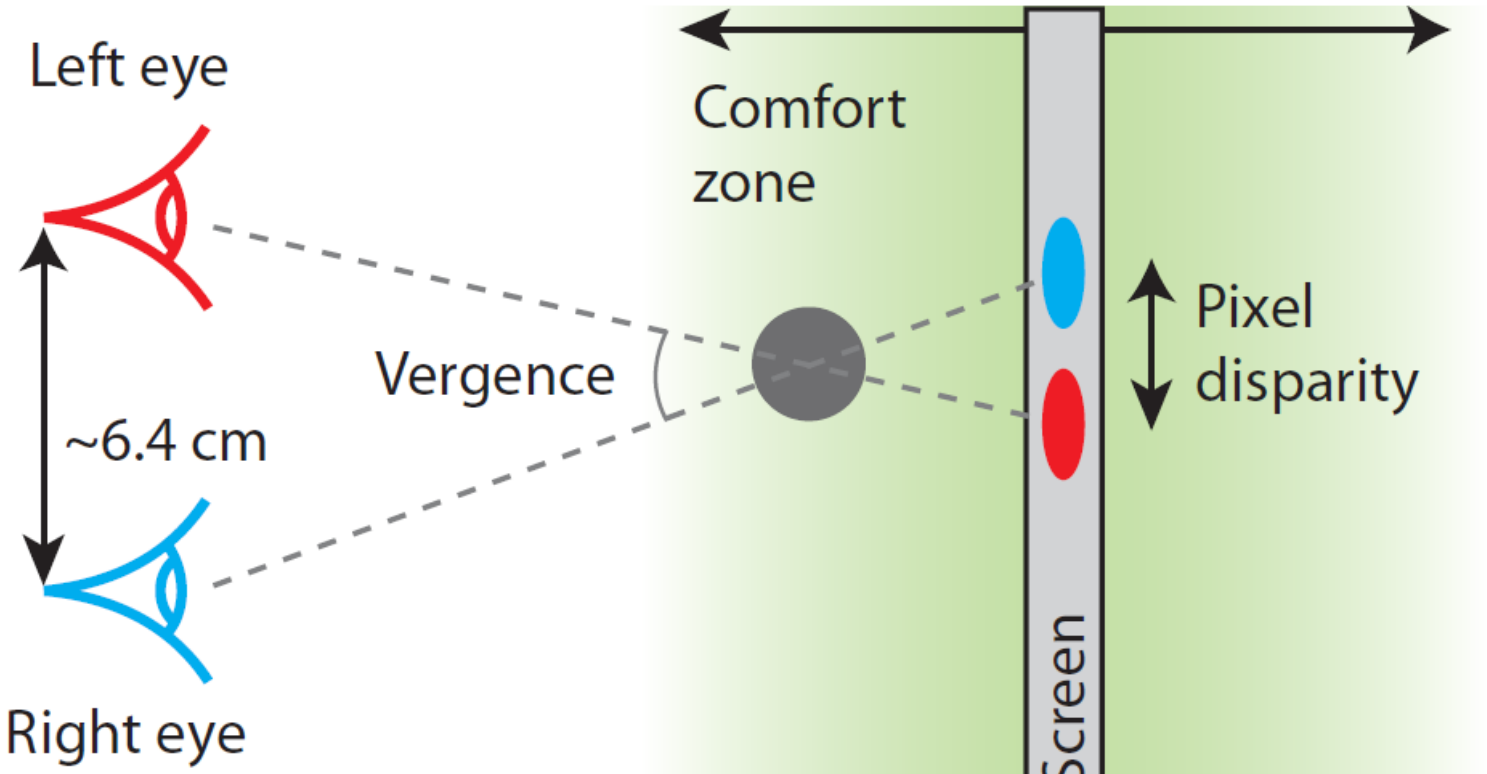
Outline

- Binocular 3D displays
  - Color Anaglyph
  - Polarization
  - Active Shutter Glasses
  - Head-Mounted Displays
- Autostereoscopic (Glass-free 3D) Displays
  - Parallax Barriers
  - Integral Imaging
  - Multi-layer displays
- Light field displays
- Multi-projector displays
- HDR displays

Binocular Stereovision

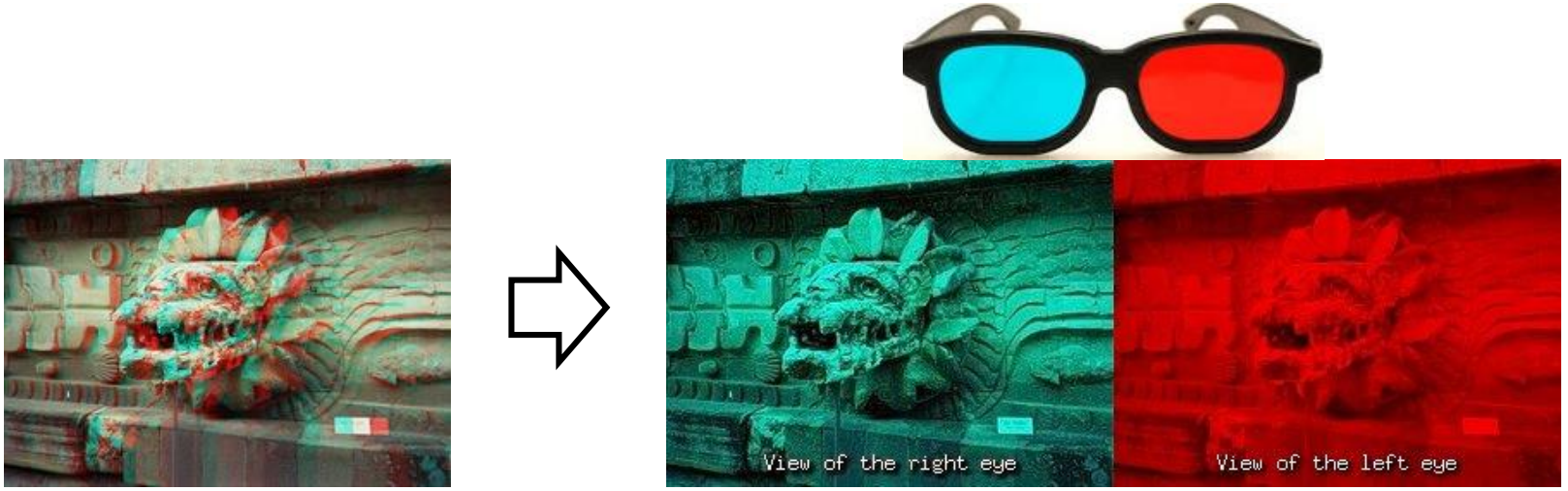


Binocular 3D Displays

- **Capable of providing sense of 3D by simulating binocular disparity**
  - Color Anaglyphs
  - Polarization
  - Shutter Glasses
  - Head-Mounted Displays
- **They mostly do not provide accommodation depth cue**

Color Anaglyphs

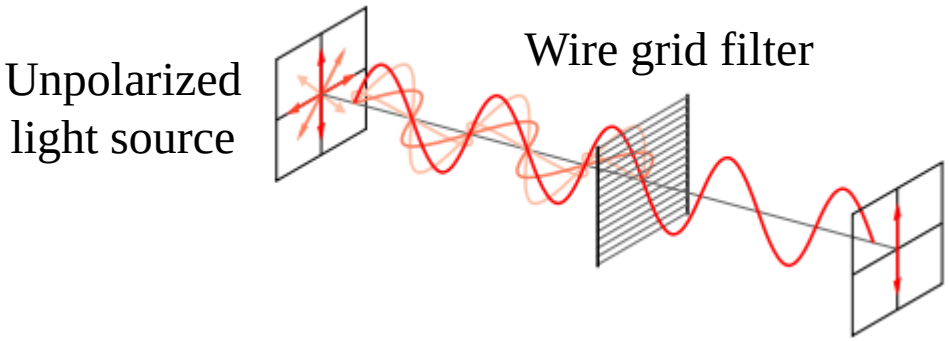
- **Left and right images are filtered using different colors (usually complementary):**
  - Red – Green, Red – Cyan, Green – Magenta
  - Amber – Blue (ColorCode 3D, patented [Sorensen et al. 2004])
- **Limited color perception (since each eye sees only a subset of whole colorspace)**

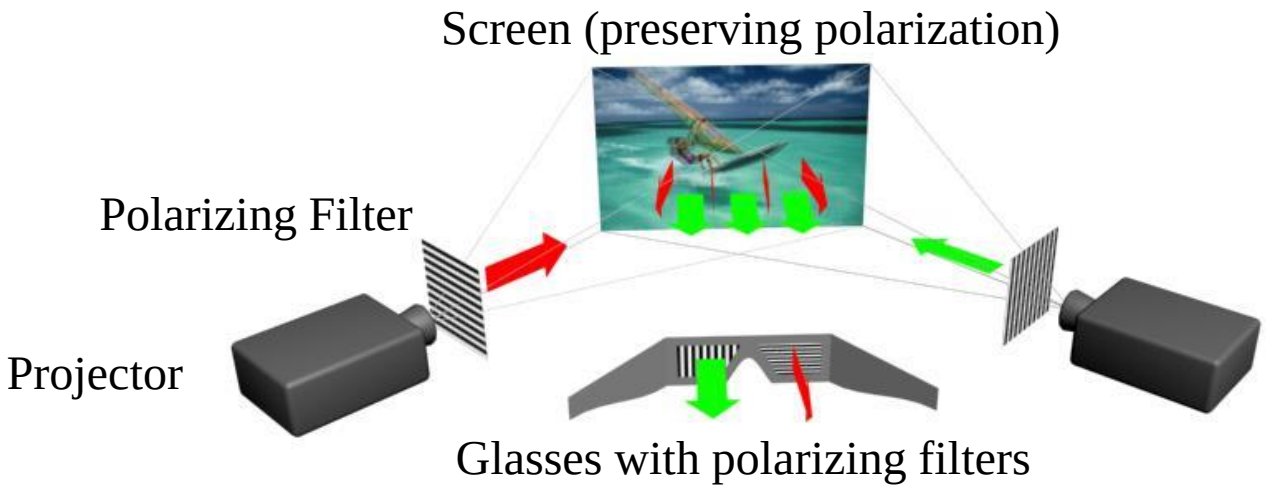


Images adapted from http://axon.physik.uni-bremen.de/research/stereo/color_anaglyph/

Polarization

- **Usually a wire grid filter converts the unpolarized light beam to a polarized one**

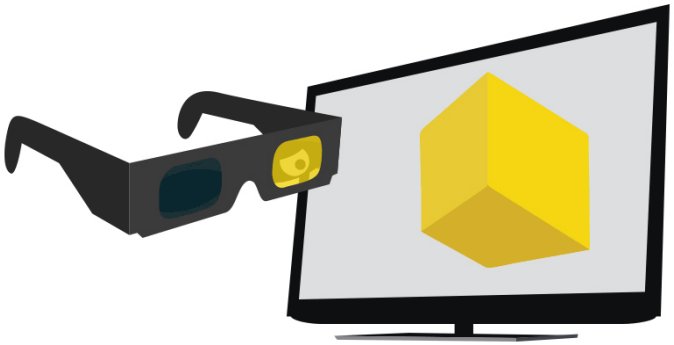


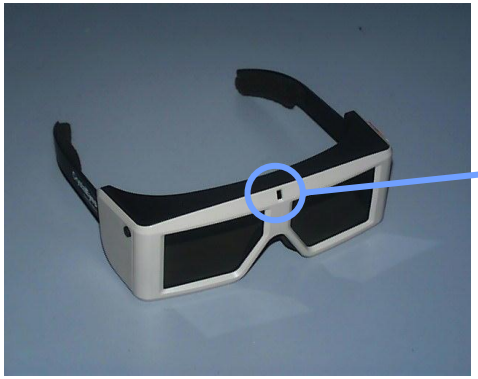


Images adapted from https://cpinettes.u-cergy.fr/S6-Electromag_files/fig1.pdf

Shutter Glasses

- **Exploits the “memory effect” of the Human Visual System [Coltheart 1980]**
- **Glasses have shutters which operate in synchronization with the display system**
- **Left and right eye images are shown in alternation**
- **Color neutral; however, temporal resolution is reduced**





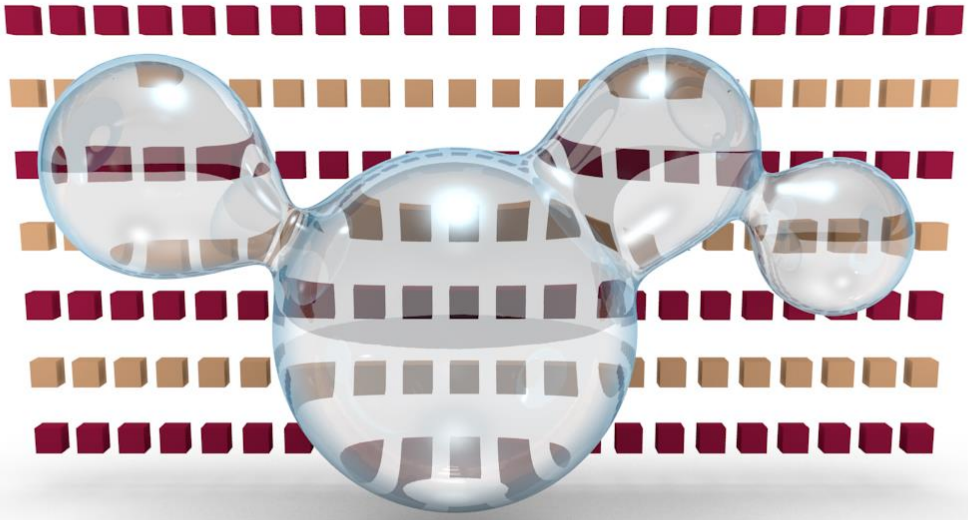
Images adapted from https://en.wikipedia.org/wiki/Active_shutter_3D_system

Head-Mounted Displays

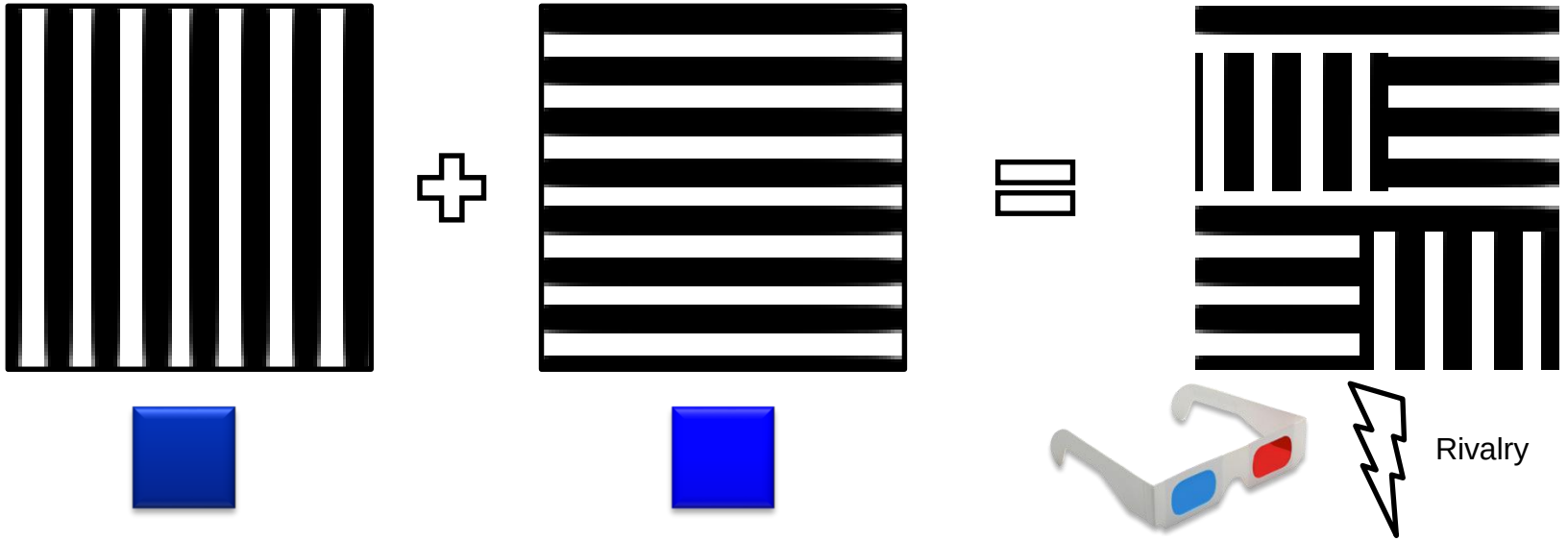
- **Separate displays for the left and right eye**
- **May provide current orientation of the head (and update the stimuli accordingly to provide a VR)**

Images adapted from http://www.oculus.com

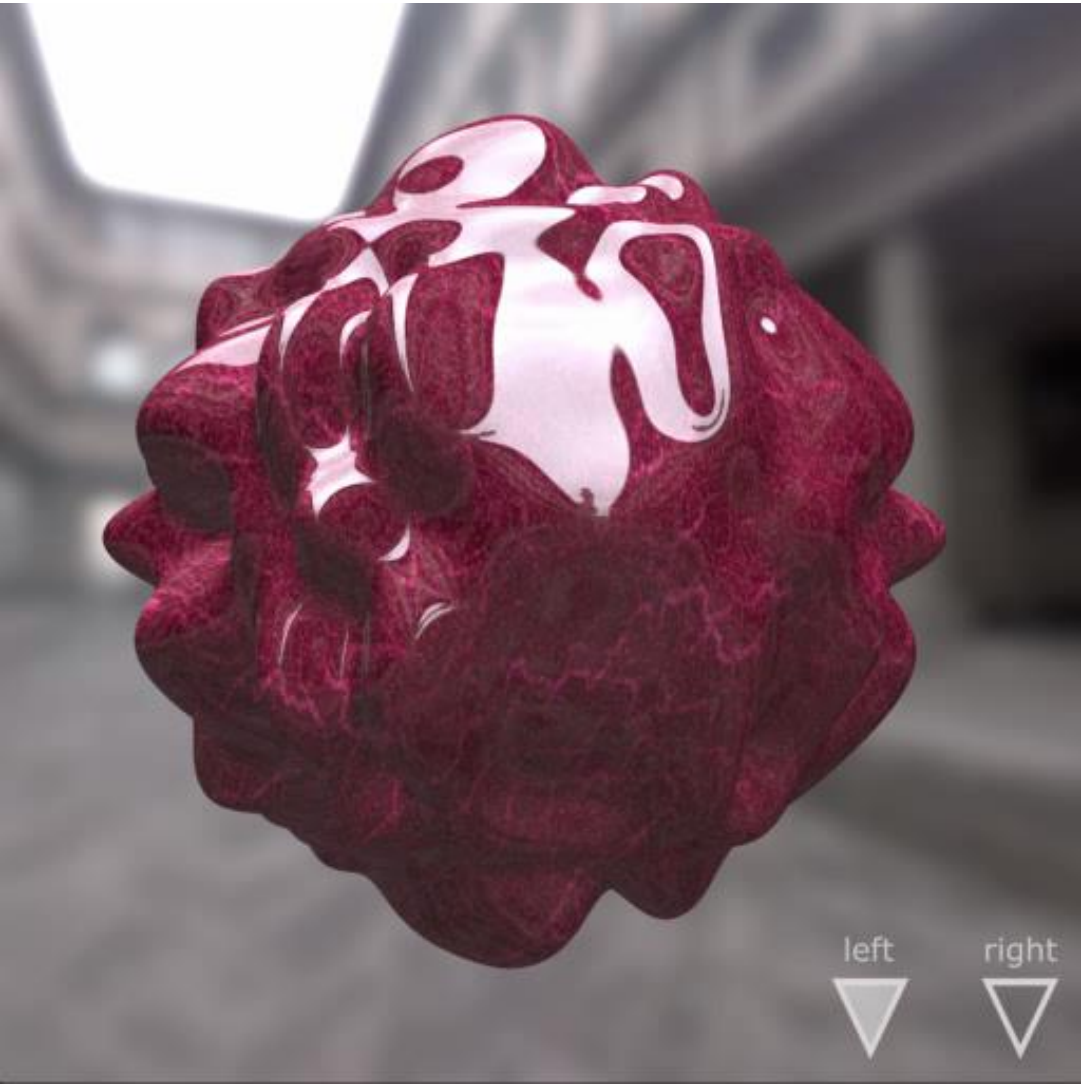
Reflections and Refractions in S3D

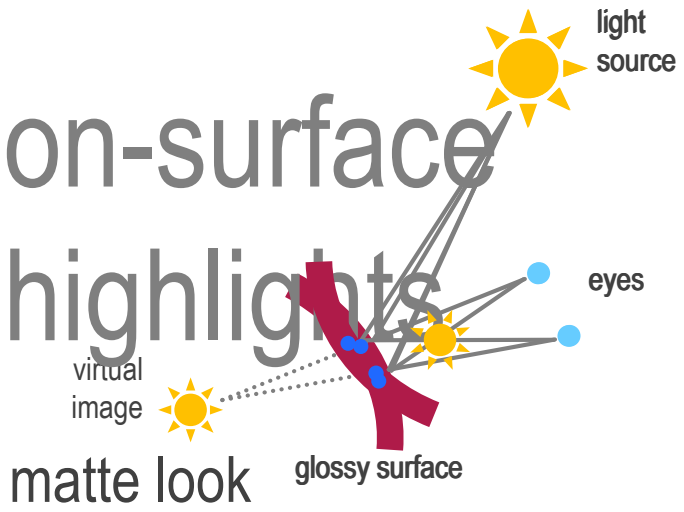


Reflections and Refractions in S3D



Reflections and Refractions in S3D





see: G. Wendt et al., 2008
Highlight disparity contributes to the authenticity and strength of perceived glossiness

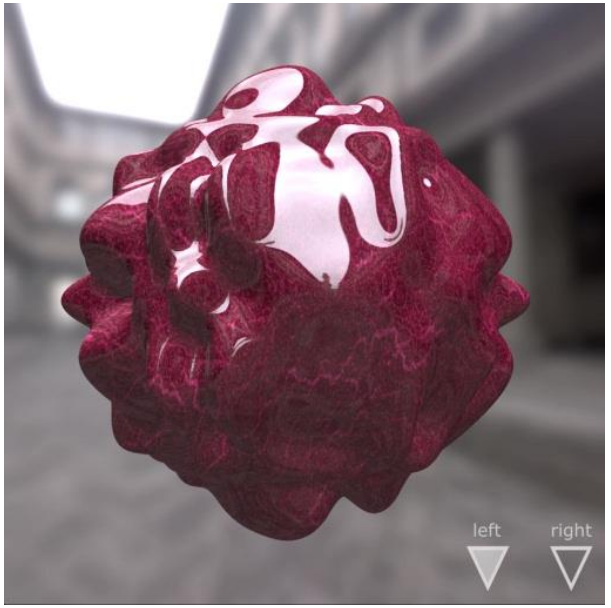
Highlights in Stereo 3D: Microdisparity

- Possible binocular rivalry
  - Even more annoying for HDR displays
  - Moving head does not help
- Highlight microdisparity solution improves viewing comfort while maintaining glossy look

Correct highlights

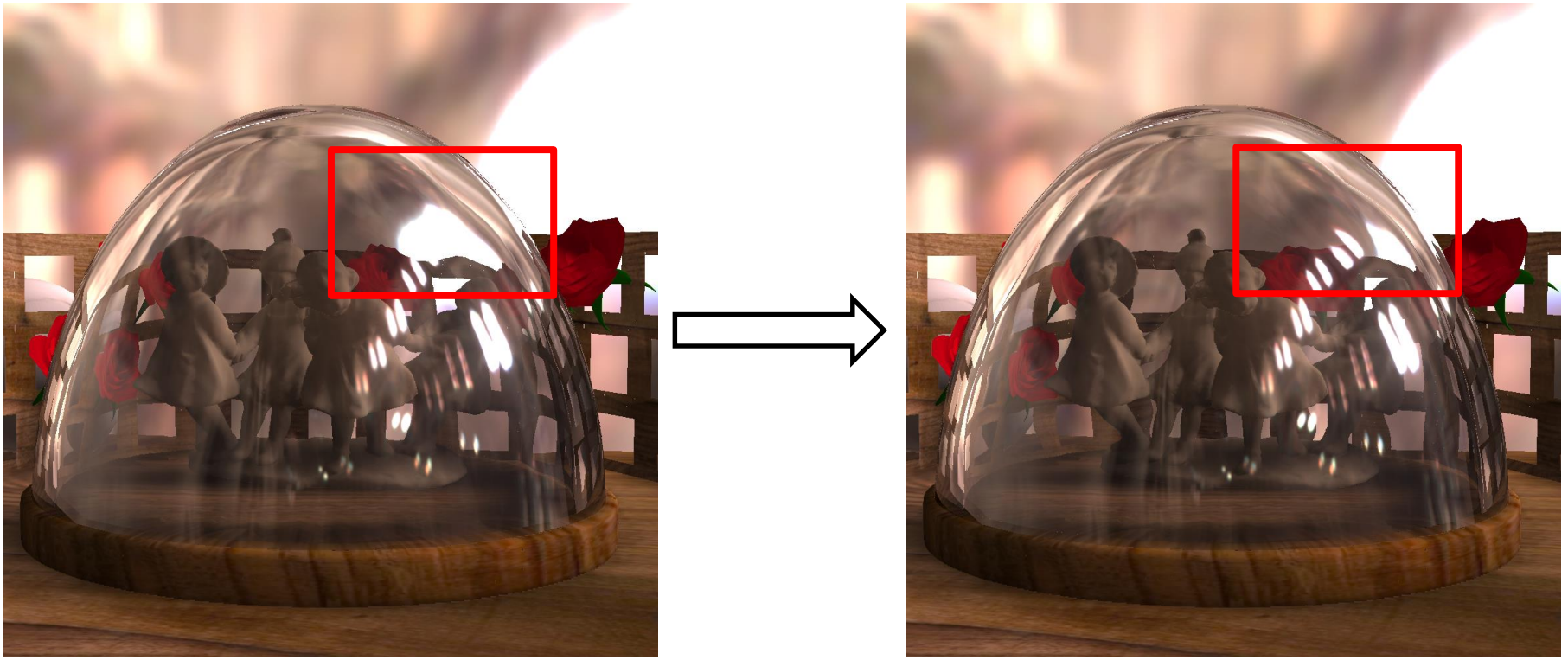
On-surface highlight

Our solution



[K. Templin et al., ACM SIGGRAPH 2012]

Refractions in Stereo 3D

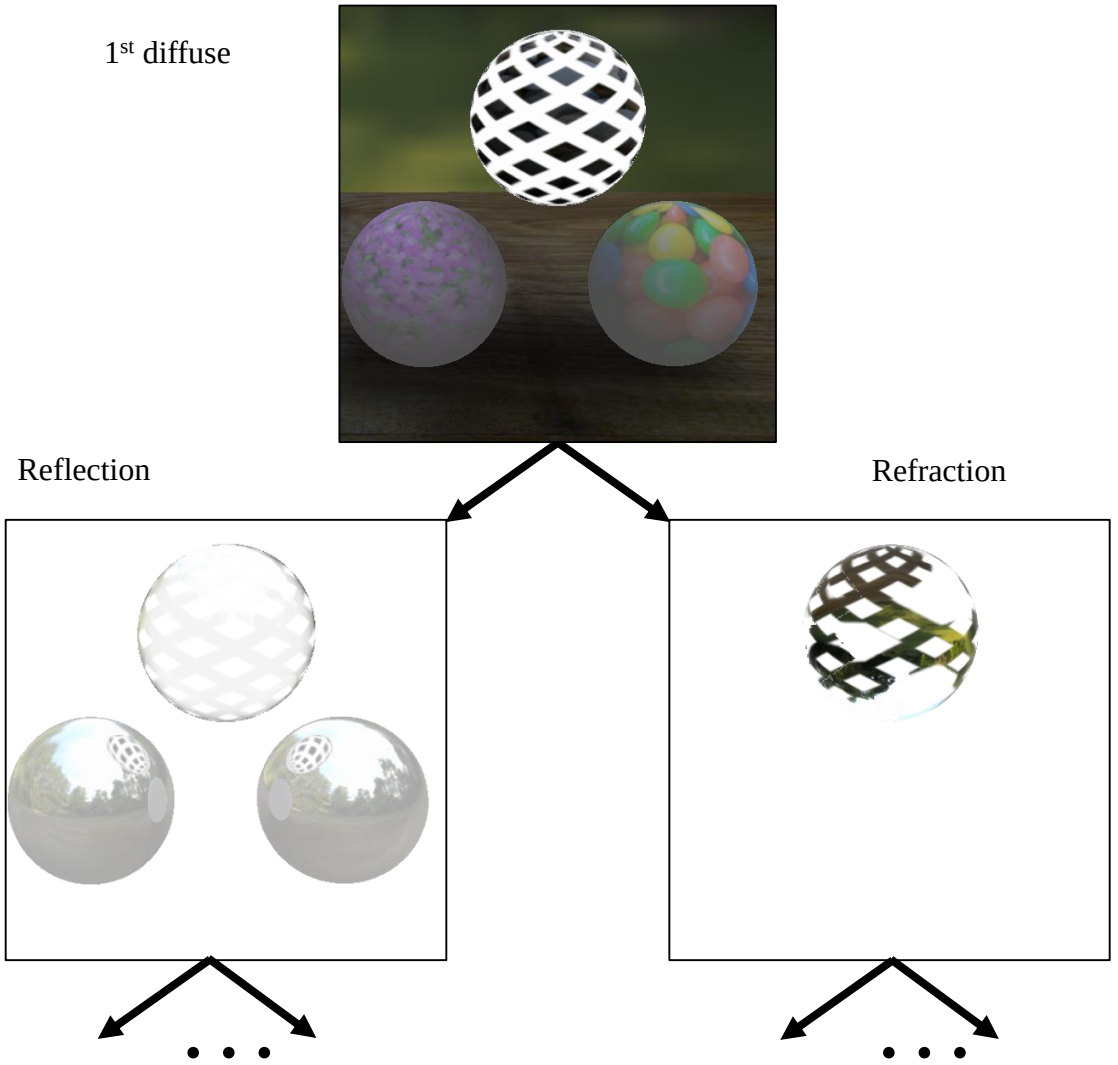


Physical

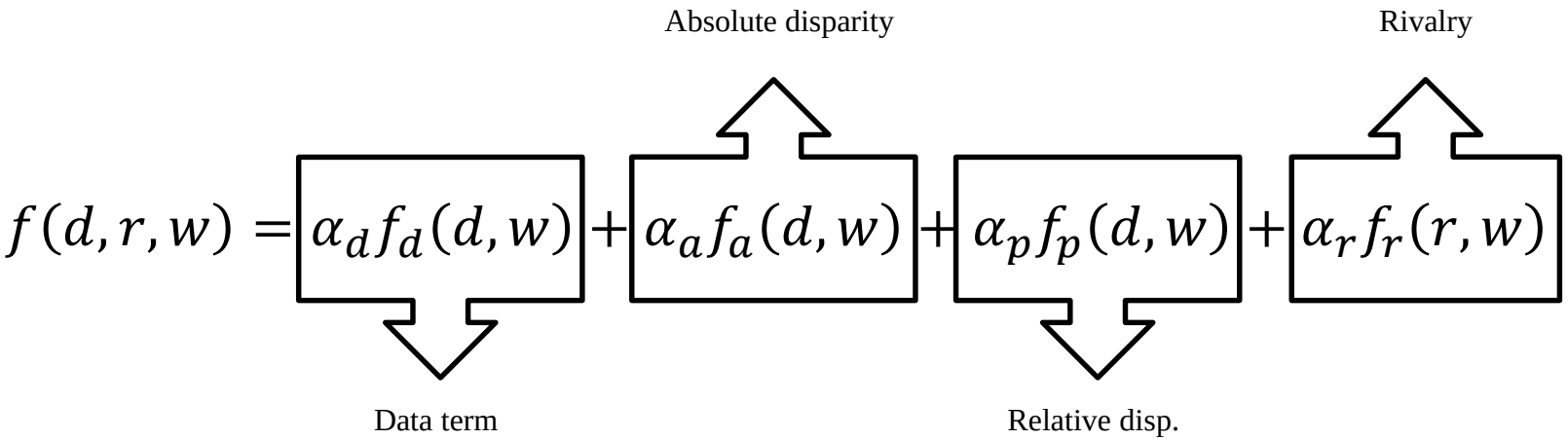
Ours

Dąbała et al. Manipulating refractive and reflective binocular disparity, Eurographics 2014, Strasbourg / France

Reflections and Refractions in S3D



Reflections and Refractions in S3D



Optimizing Eye Vergence – Film Cuts

Cut in a Regular Film

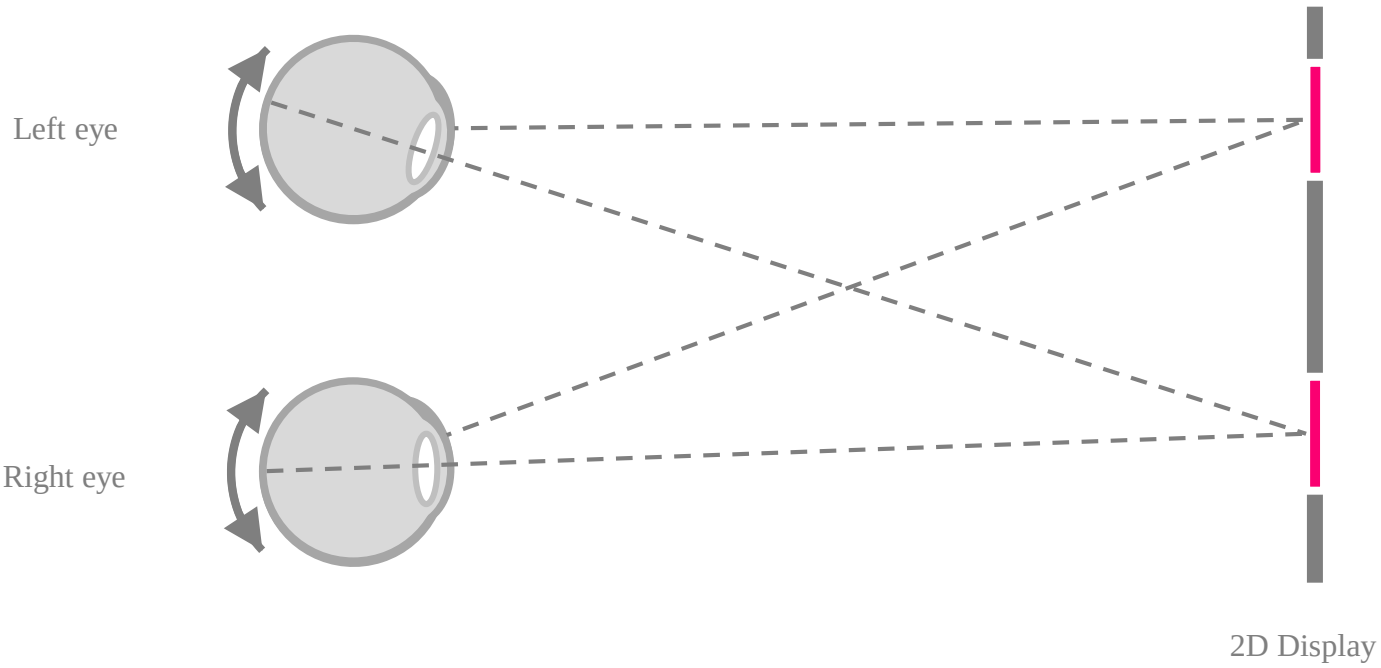
Shot 1

Shot 2

Cut

Source: *Big Buck Bunny* CC-BY Blender Foundation, Janus B. Kristensen

Saccades



Optimizing Eye Vergence – Film Cuts

Cut in a Stereoscopic 3D Film

Left eye Right eye

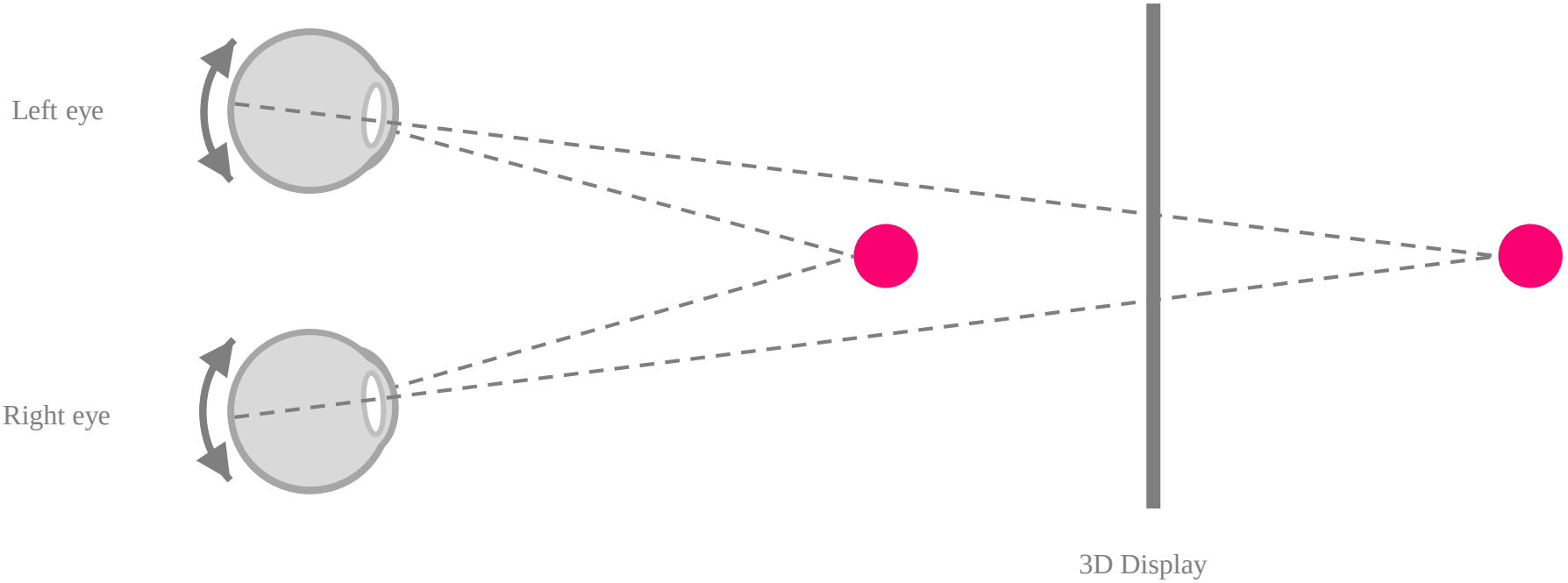
Shot 1

Cut

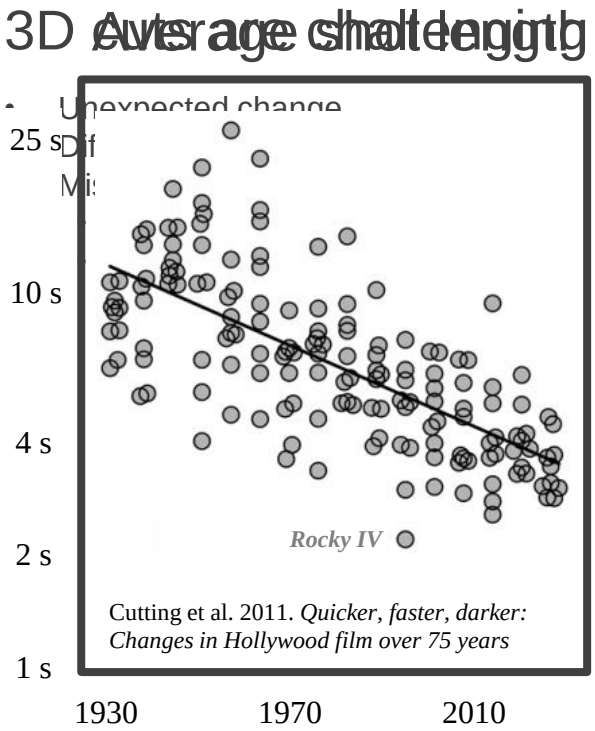
Shot 2

Source: *Big Buck Bunny* CC-BY Blender Foundation, Janus B. Kristensen

Vergence



Vergence vs. Film Editing



Cutting et al. 2011. *Quicker, faster, darker: Changes in Hollywood film over 75 years*

Autostereoscopic Displays

- **Stereo displays which are viewable without special glasses or head-wear equipment**
- **Simulate an approximate lightfield with a finite number of views**
  - Parallax Barriers
  - Integral Imaging
  - Multi-layer Displays

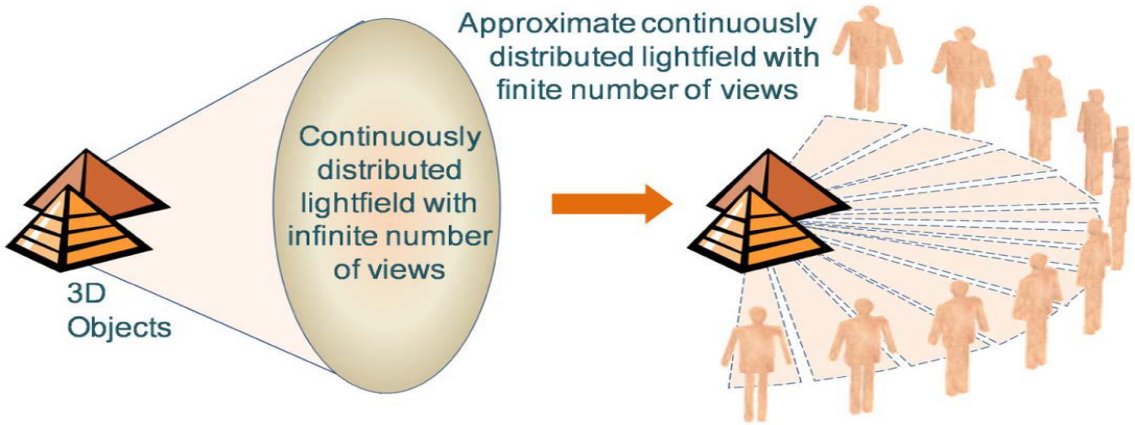
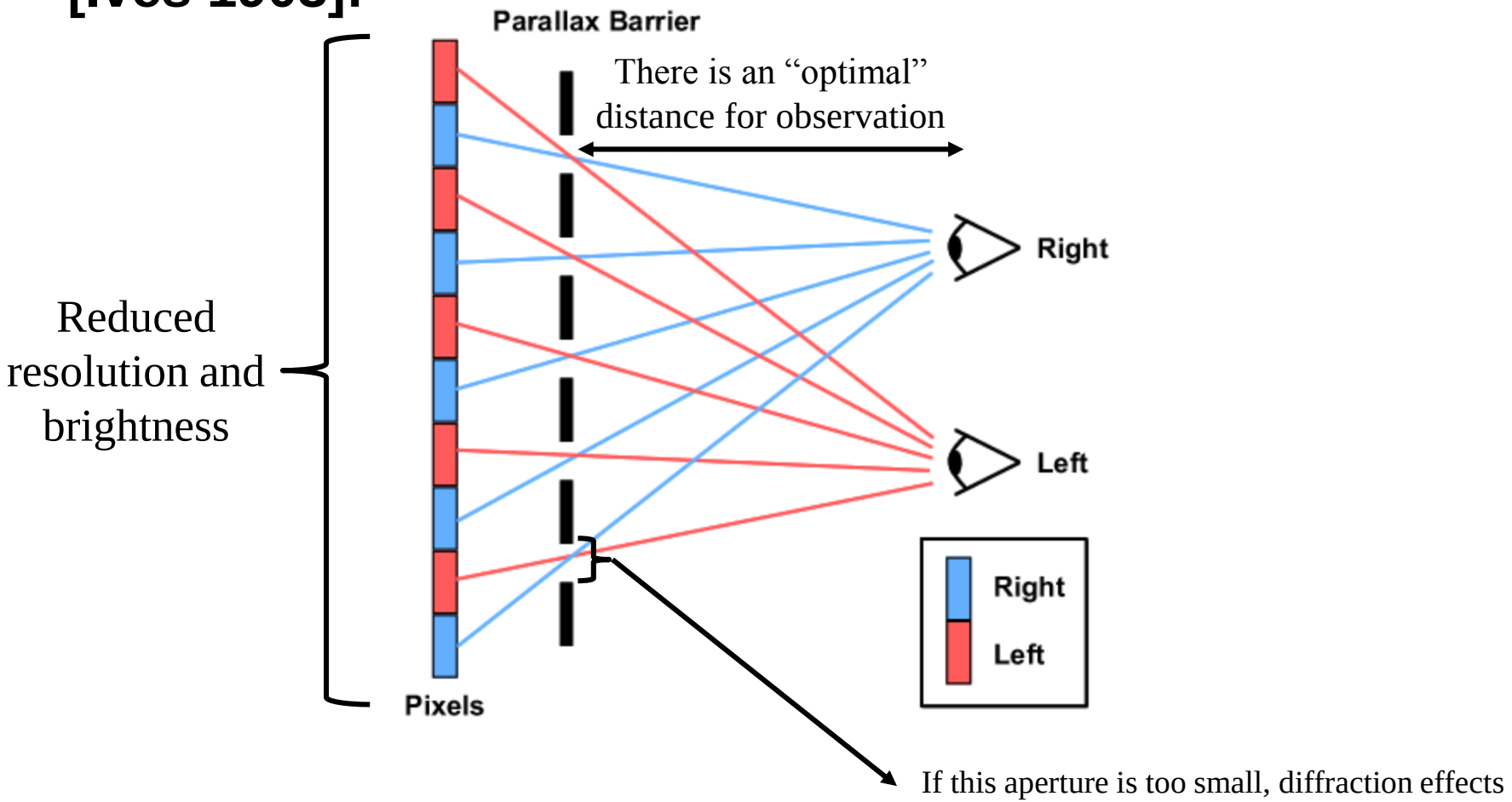


Image adapted from Geng, Jason. "Three-dimensional display technologies." Advances in optics and photonics 5.4 (2013): 456-535.

Parallax Barriers

- **Occlusion-based working principle and key features [Ives 1903]:**



Parallax Barriers

Video adapted from: http://www.youtube.com/watch?v=sxF9PGRiabw “Glasses-Free 3D Gaming for $5 (Parallax Barrier)”

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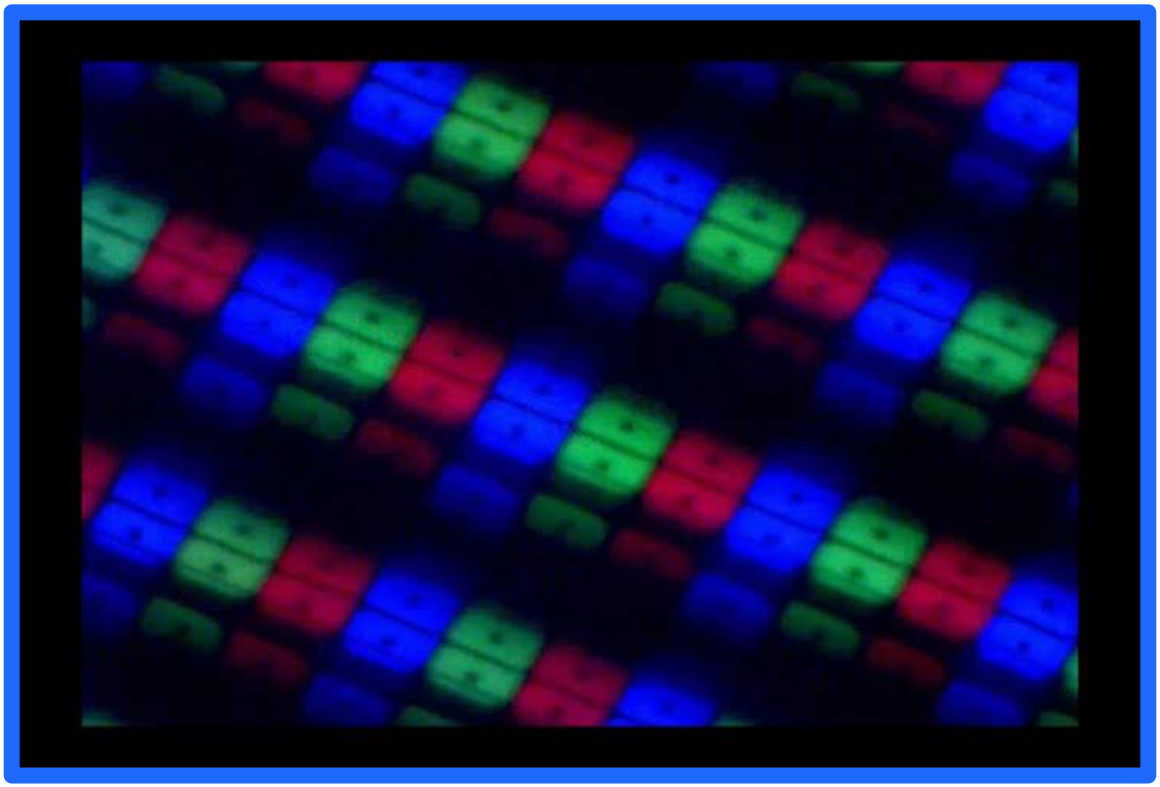
Parallax Barriers

- **It is possible to switch between 2D and 3D modes**
- **Parallax barrier of Nintendo 3DS turning on/off under microscope:**

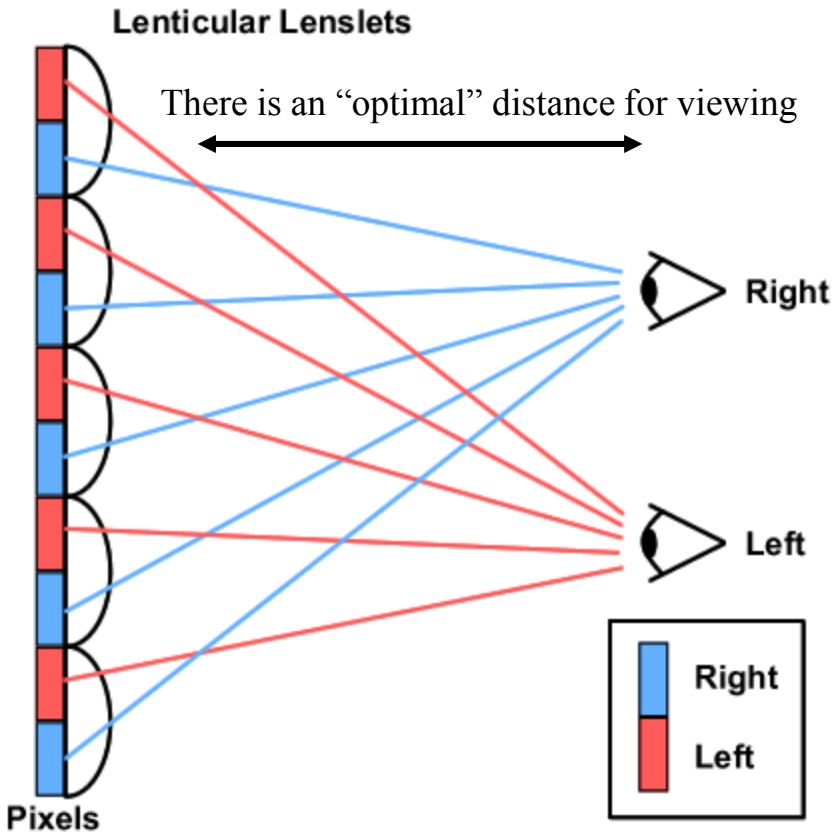


Video adapted from: https://www.youtube.com/watch?v=D-LzRT7Bvc0

Integral Imaging

- **Refraction-based working principle [Lippmann 1908]:**

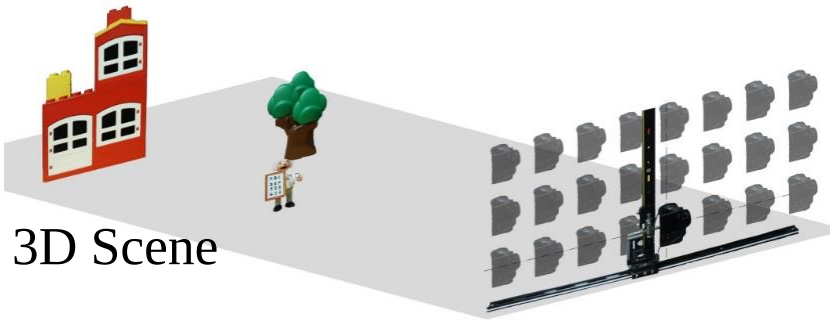
Reduction in resolution and brightness is still a problem.



It is possible to reproduce parallax, perspective shift and accommodation depth cues.

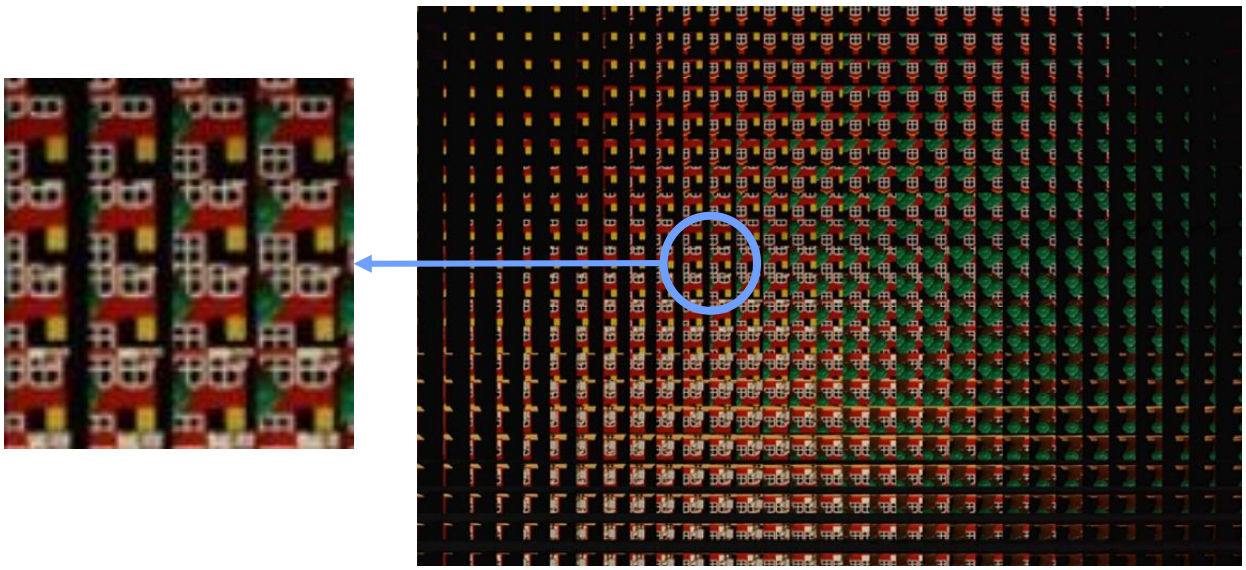
Images adapted from http://www.3d-forums.com/threads/autostereoscopic-displays.1/

Integral Imaging



3D Scene

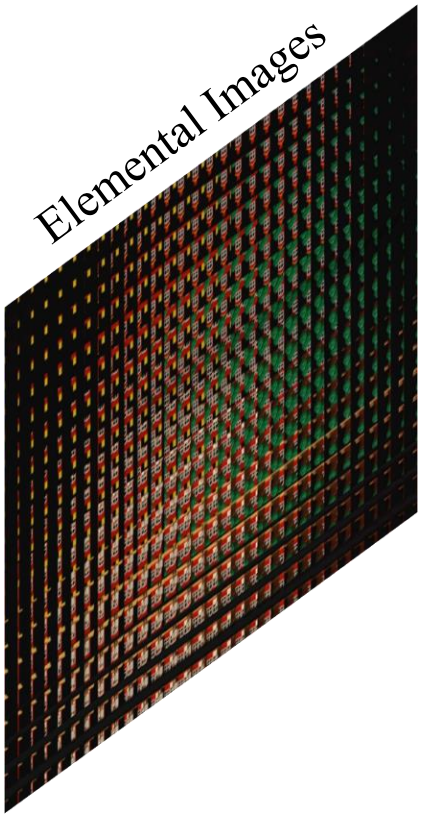
Array of lenses (multiple cameras each with a single lens [Wilburn 2005] or a single camera with multiple lenses in front of the sensor [Ng 2005])

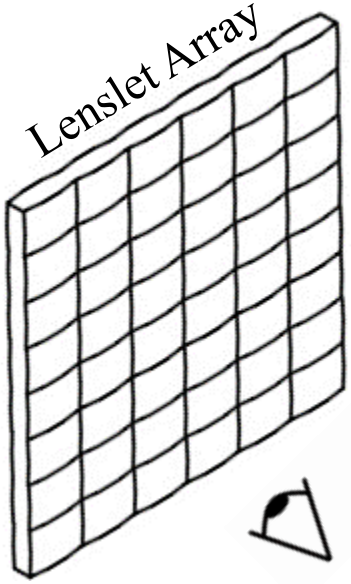


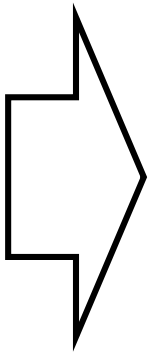
Elemental Images

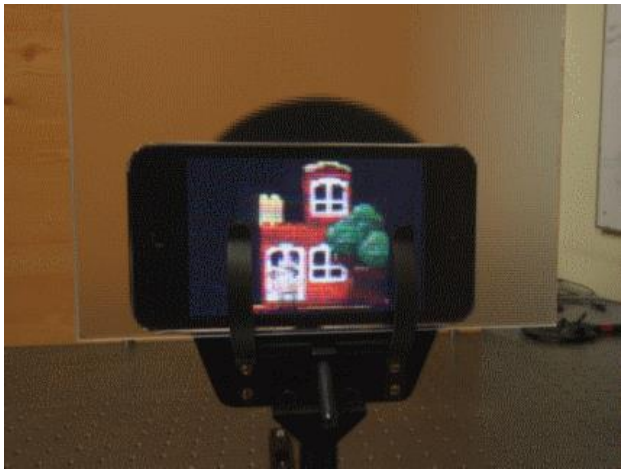
Images adapted from Martınez-Corral, Manuel, et al. "3D integral imaging monitors with fully programmable display parameters."

Integral Imaging









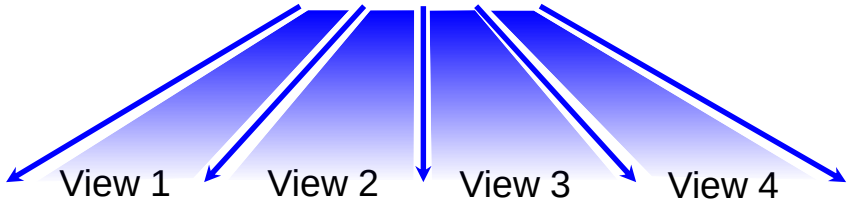
Integral Image as seen by the observer

Images adapted from Martınez-Corral, Manuel, et al. "3D integral imaging monitors with fully programmable display parameters."

Multi-view Autostereoscopic Display

- **Smooth transitions**

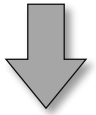
Multi-view autostereoscopic display



„Antialiasing for automultiscopic 3D displays” [Zwicker et al. 2006]

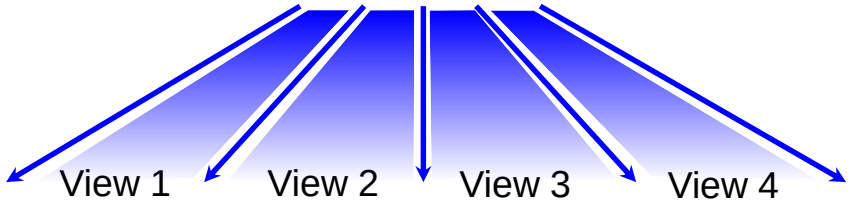
Multi-view Autostereoscopic Display

- **Smooth transitions**
- **Blur increases with depth**



Weaker depth percept

Multi-view autostereoscopic display



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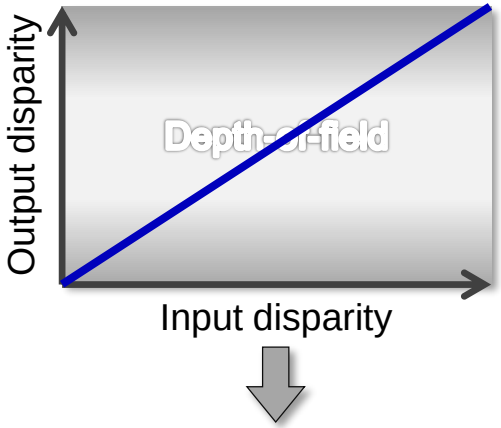
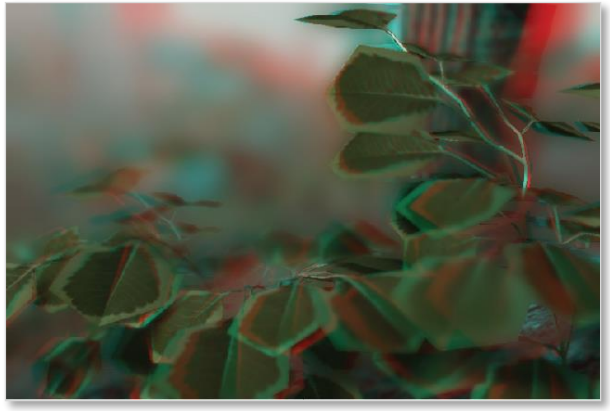
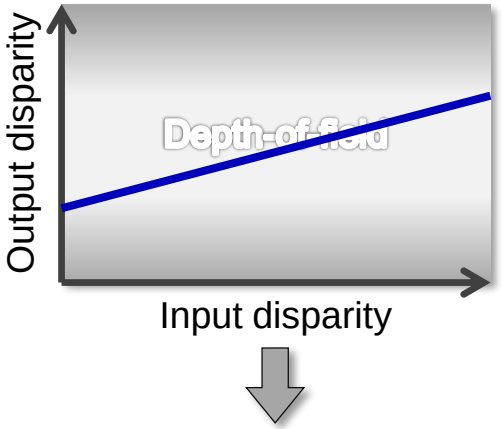
Multi-view Autostereoscopic Display





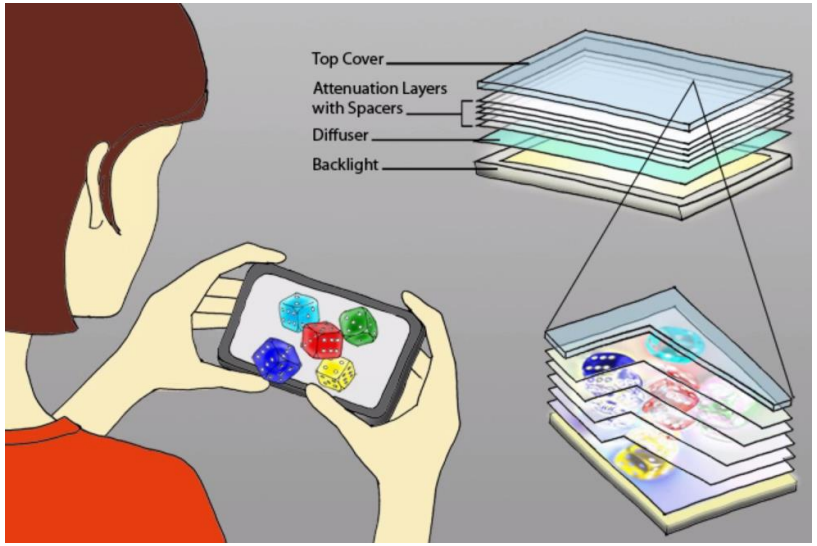
- Big disparity range
- Large part of the scene out of focus

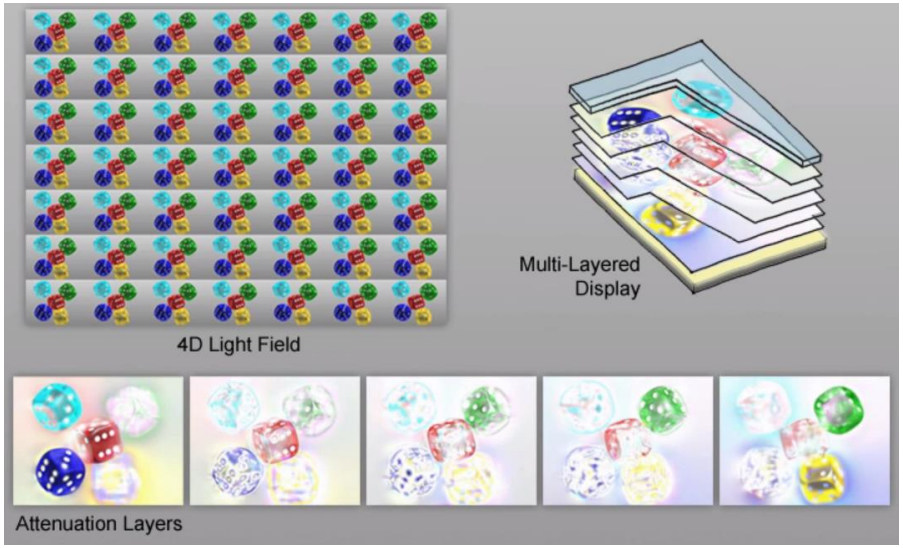


- Everything stays in focus
- Disparity range reduced

Multi-layer Displays

- **Improved resolution over parallax barriers and lenslet arrays**
- **Provides a solution to accommodation-vergence conflict**

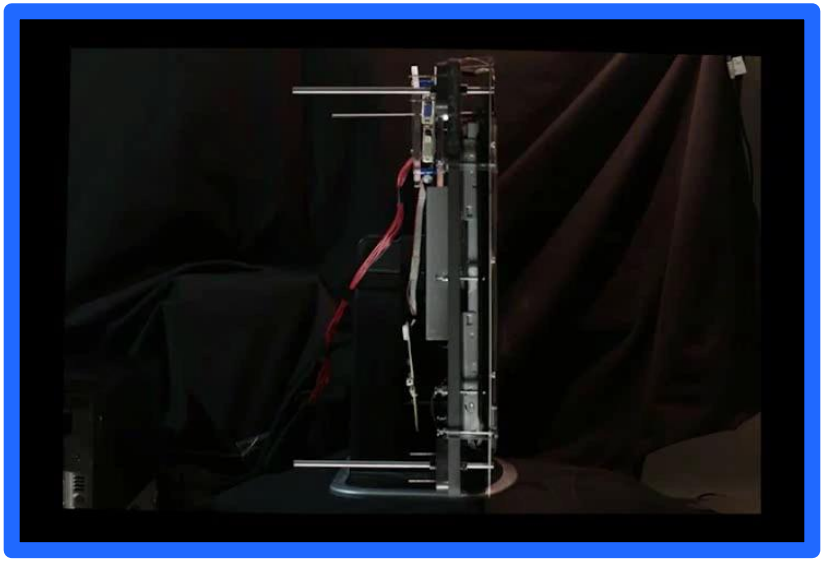




Images adapted from Wetzstein, Gordon, et al. "Layered 3D: tomographic image synthesis for attenuation-based light field and high dynamic range displays." ACM Transactions on Graphics (ToG). Vol. 30. No. 4. ACM, 2011.

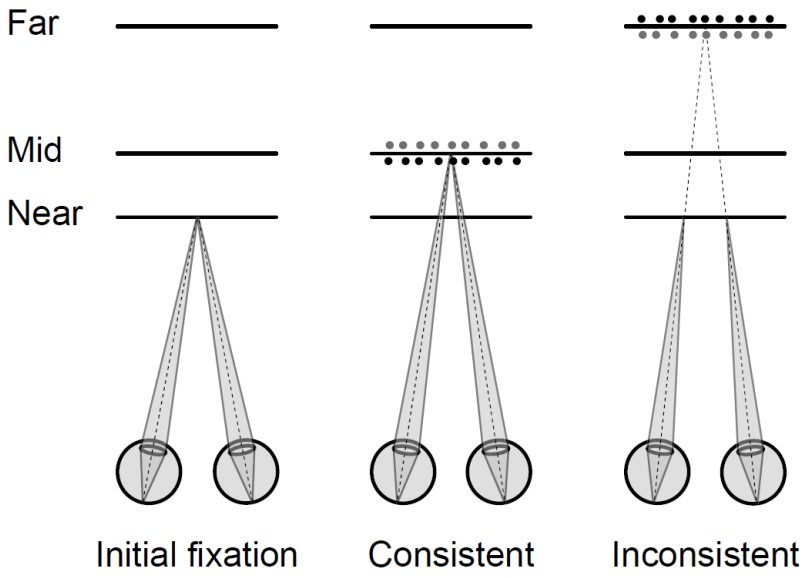
Tensor Displays

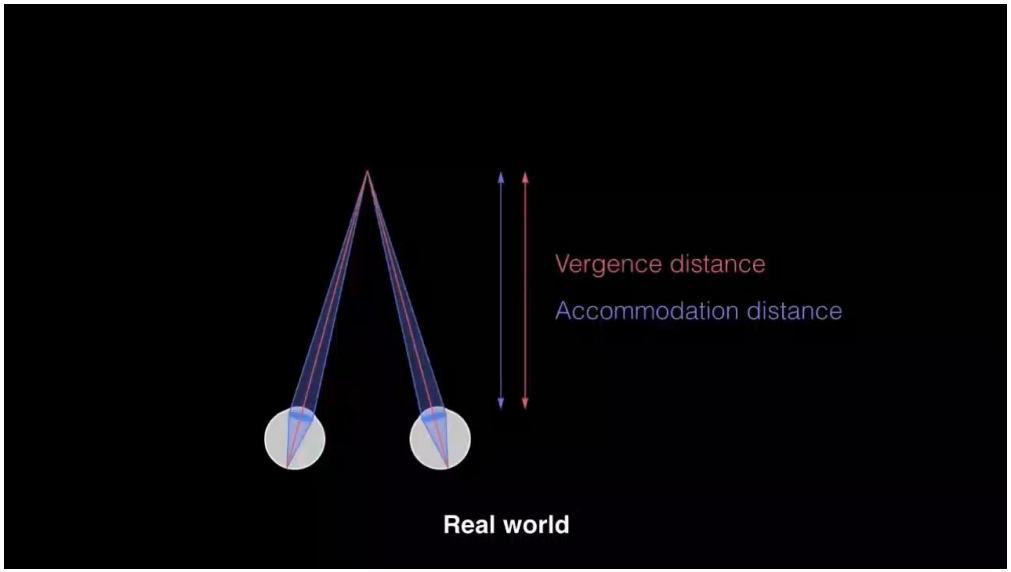
- **Lightfield emitted by a multi-layer display is represented by a tensor where rays span a 2D plane in 3D tensor space**
- **Target lightfield is decomposed into Rank-1 tensors using Nonnegative Tensor Factorization**
- **Rank-1 tensors are shown in quick succession with a high refresh rate, which are perceptually averaged over time by the Human Visual System**



Video adapted from Wetzstein, Gordon, et al. "Tensor displays: compressive light field synthesis using multilayer displays with directional backlighting." (2012).

Accomodation-Vergence Conflict

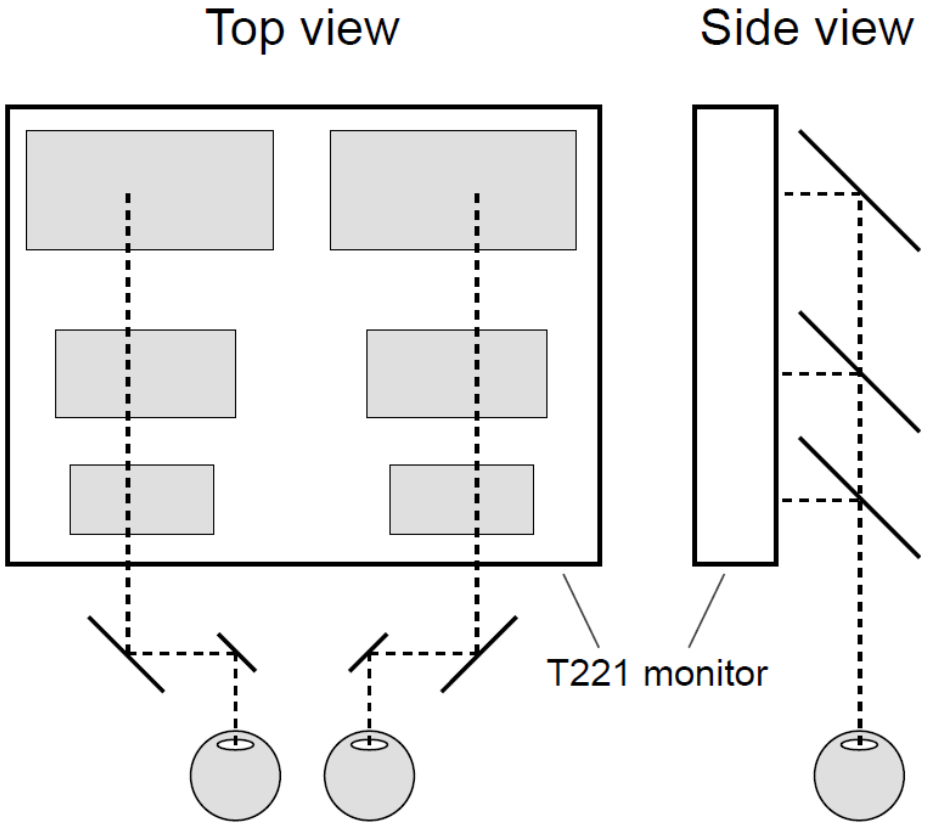




Visuals adapted from Akeley, Kurt, et al. "A stereo display prototype with multiple focal distances." ACM transactions on graphics (TOG). Vol. 23. No. 3. ACM, 2004. and Narain, Rahul, et al. "Optimal presentation of imagery with focus cues on multi-plane displays." ACM Transactions on Graphics (TOG) 34.4 (2015): 59.

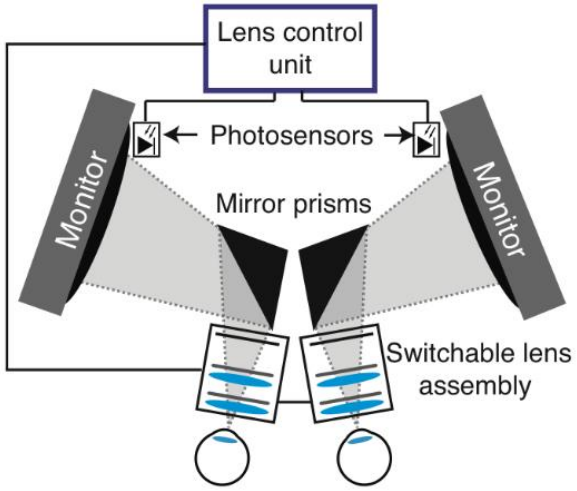
Multi-focal Plane Displays

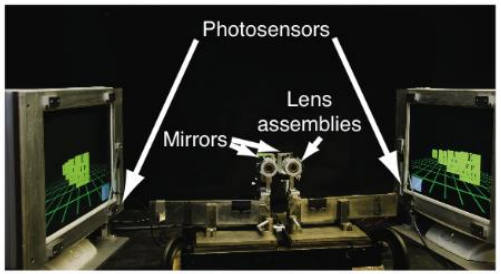
- **A display prototype with multiple focal distances using beam-splitters**



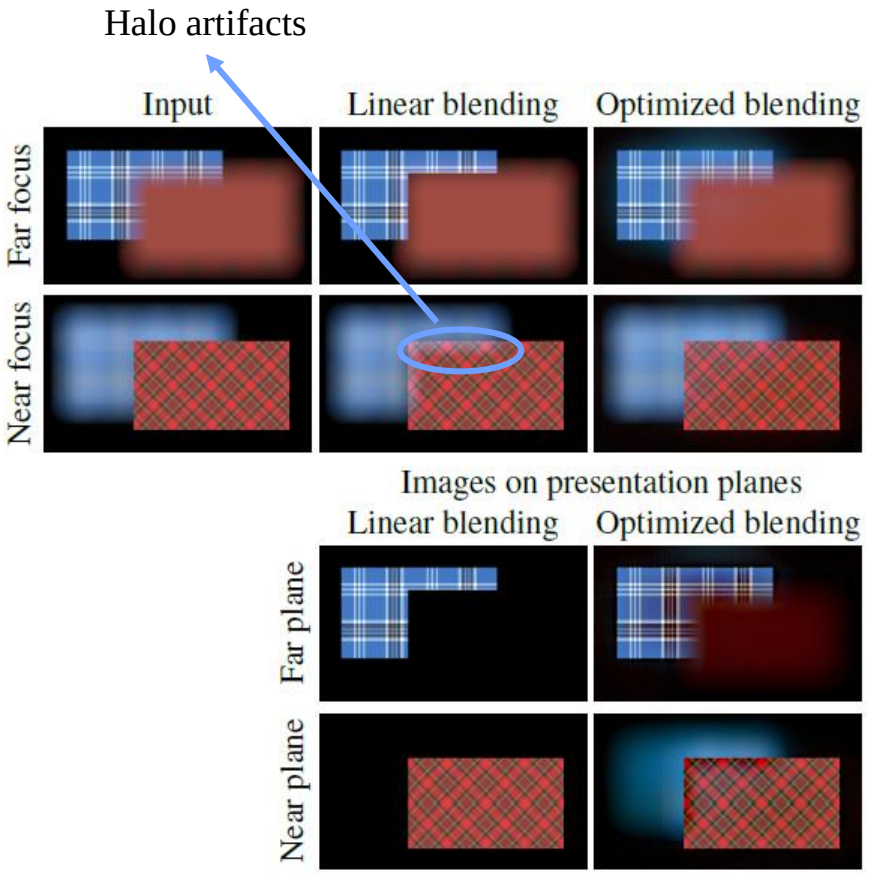
Images adapted from Akeley, Kurt, et al. "A stereo display prototype with multiple focal distances." ACM transactions on graphics (TOG). Vol. 23. No. 3. ACM, 2004.

Multi-focal Plane Displays





Prototype introduced by Love et al [2009]



Narain et al. [2015] optimize the focus cues for improved realism.

Images adapted from Narain, Rahul, et al. "Optimal presentation of imagery with focus cues on multi-plane displays." ACM Transactions on Graphics (TOG) 34.4 (2015): 59.

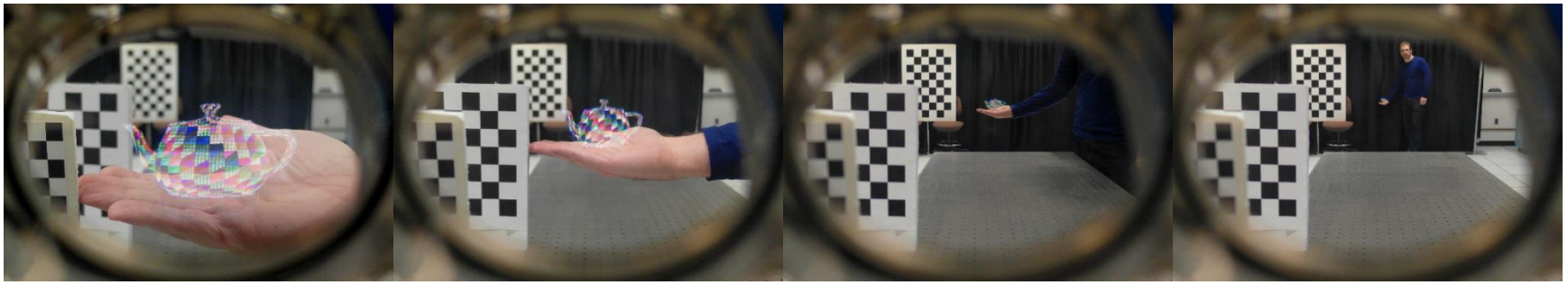
Deformable Beamsplitter

See-through

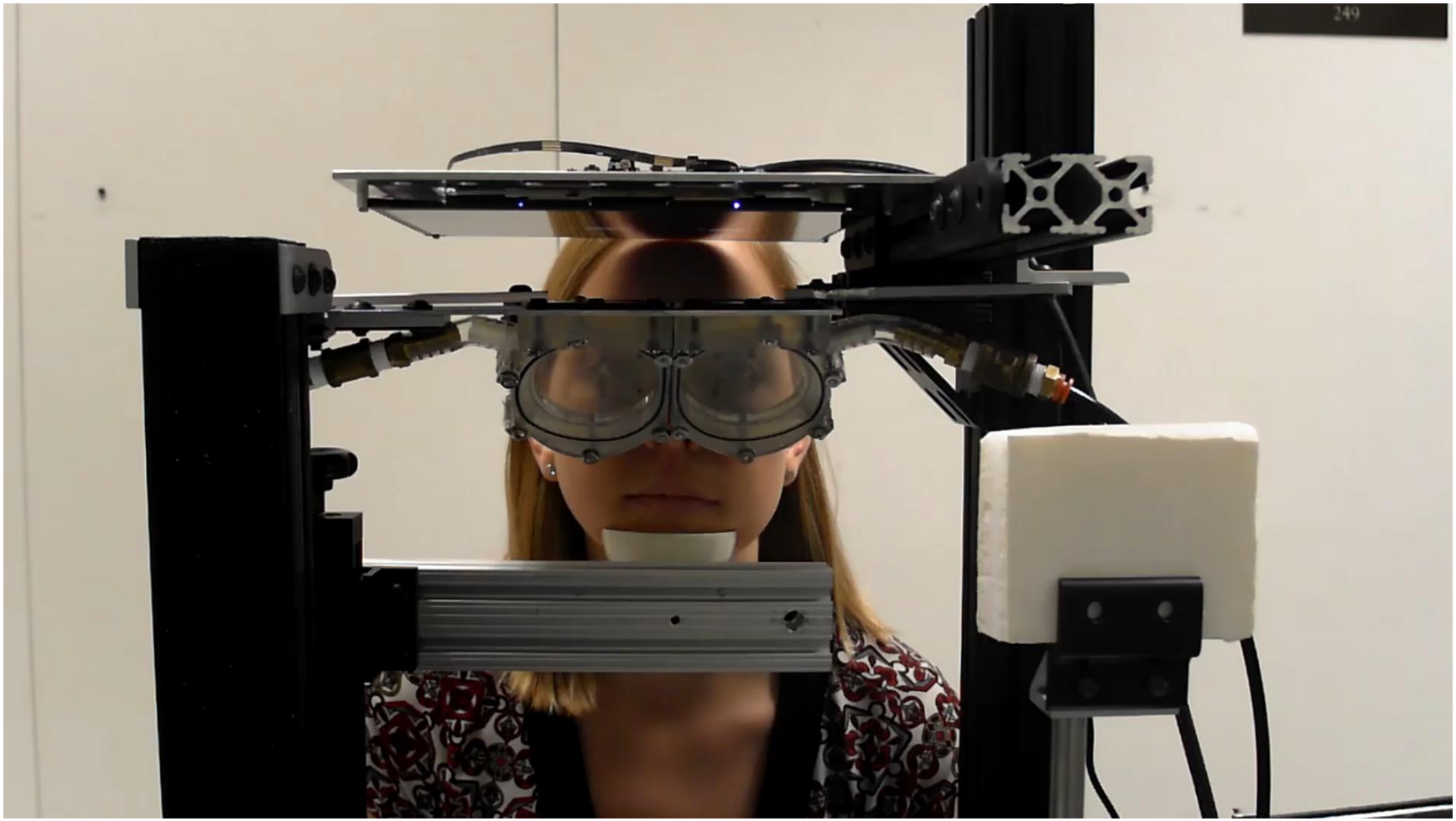
Dynamic focal depth: objects at any depth

Wide field of view

Optics are simple



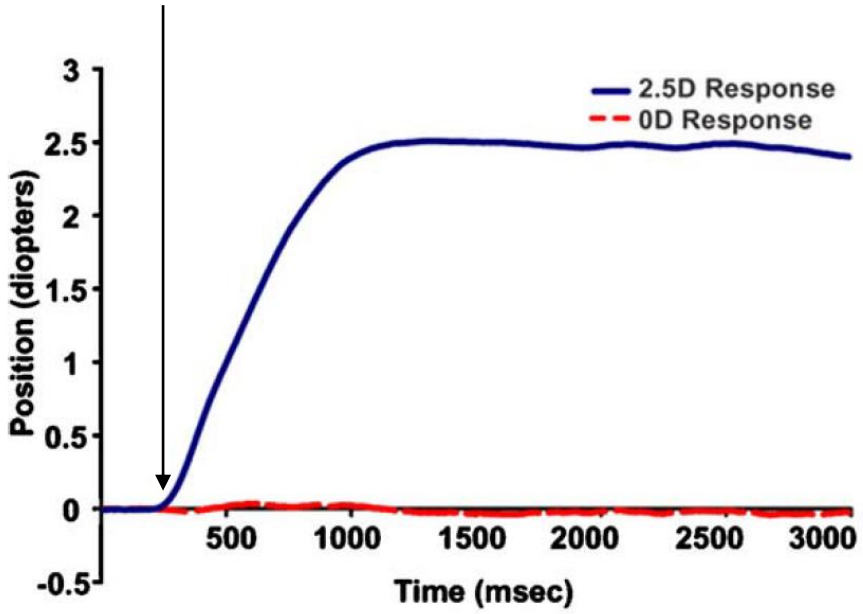
Deformable Beamsplitter



Membrane AR – Dunn et al.

Accommodation Response

- Step change of fixated object depth
  - Smooth and steady accommodation increase
    - up to 1 second to achieve the full accommodation state
    - ~300 ms latency



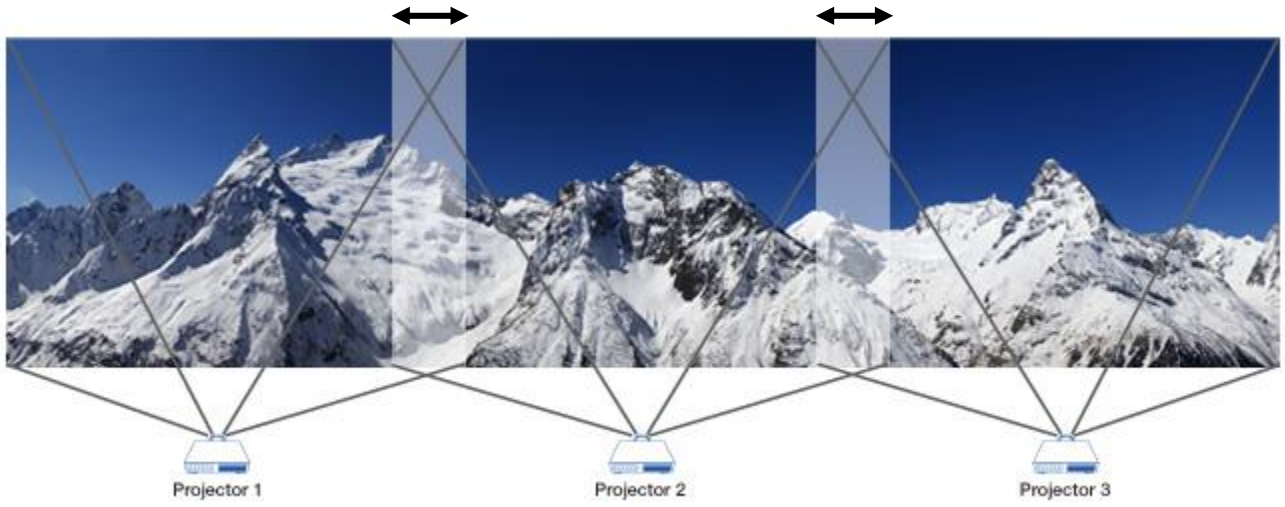
Bharadwaj and Schor, Vision Research 2004

Lightfield Displays

Displays Comparison

Multi-projector Displays

- **Mainly used to provide a wide panoramic display**
- **Edge blending, color/contrast/brightness matching between overlapping regions is an issue (the transition must be seamless)**
- **The display surface may be curved**



Images adapted from http://www.matrox.com

Multi-projector Displays

Video adapted from https://www.youtube.com/watch?v=dOY2lREuwjU

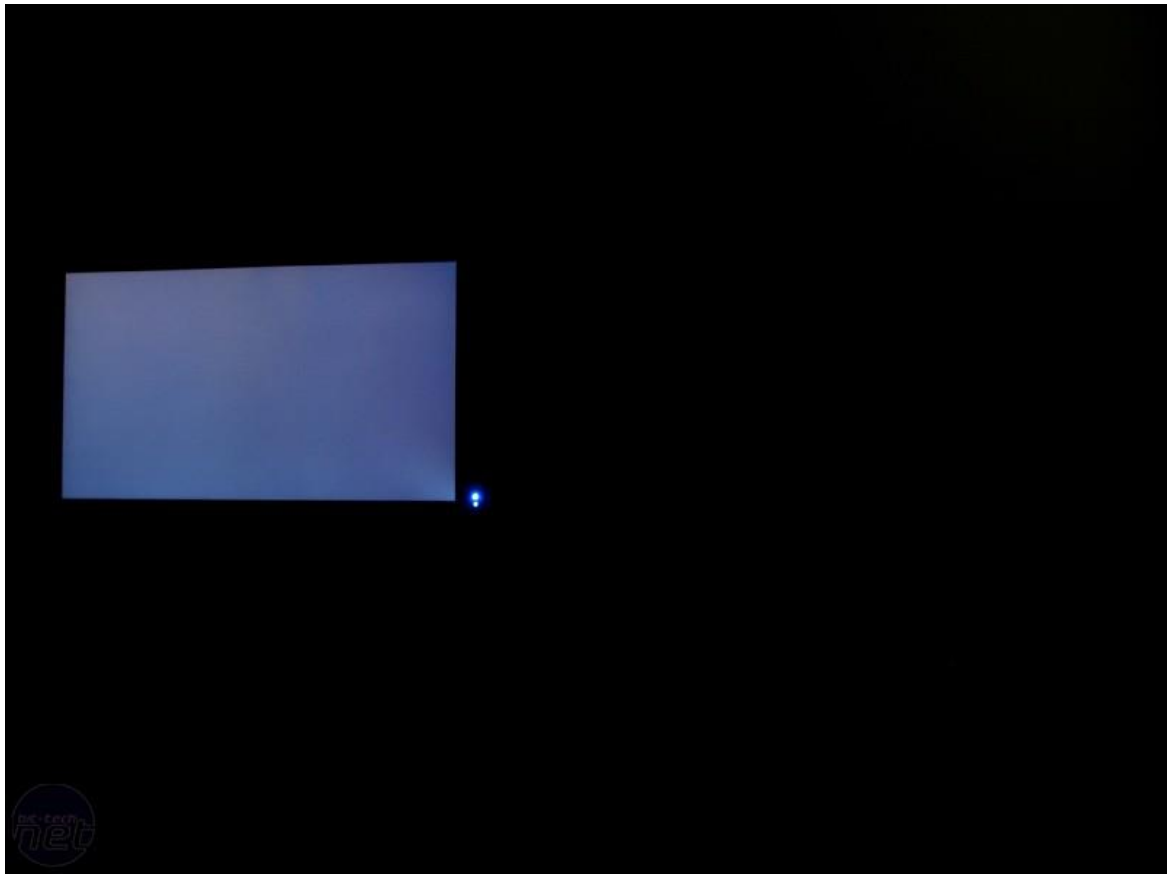
HDR Displays

- **Instead of using a single constant backlight source, an array of LEDs is used**
- **The LEDs may be individually adjusted for different brightness levels**

Images adapted from http://www.bit-tech.net/hardware/2005/10/04/brightside_hdr_edr/6

HDR Displays

- **Comparison of LDR display (left) with Brightside HDR display (right)**



Images adapted from http://www.bit-tech.net/hardware/2005/10/04/brightside_hdr_edr/8

HDR Displays

- **Comparison of LDR display (left) with Brightside HDR display (right)**

Images adapted from http://www.bit-tech.net/hardware/2005/10/04/brightside_hdr_edr/8

HDR Displays

- **Comparison of LDR display (left) with Brightside HDR display (right)**

Images adapted from http://www.bit-tech.net/hardware/2005/10/04/brightside_hdr_edr/8

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