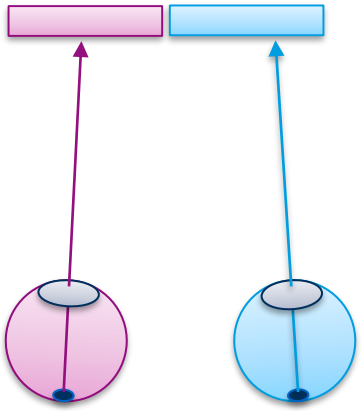
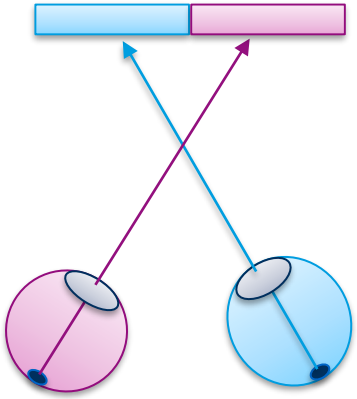
Scientific Visualization

Stereoscopy



Stereo Vision and Rendering



Parallel Eye Viewing

get help here

Cross Eye Viewing

Content – Part 1

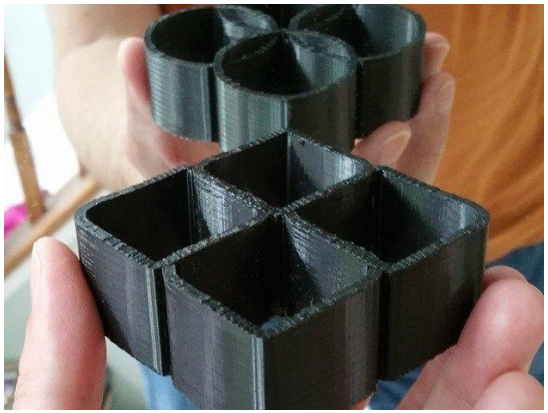
- Depth Perception & Cues
  - Pictorial cues
  - Dynamic cues
  - Ocular cues
  - Stereopsis
- Display Technology
  - Video Formats
  - Display Setups

Stereo

DEPTH PERCEPTION & CUES

Depth Perception – Illusion

https://www.youtube.com/watch?time_continue=16&v=tBNHPk-Lnkk



https://www.thingiverse.com/thing:1655999

Depth Cues

The human visual system (HVS) relies on a variety of depth cues, which can be categorized [Palmer 1999] as

- pictorial
  - occlusions, perspective foreshortening, relative and familiar object size, texture and shading gradients, shadows, aerial perspective
- dynamic
  - motion parallax, depth from motion, kinetic depth effect
- ocular
  - accommodation and vergence
- stereoscopic
  - binocular disparity

Stereo

DEPTH PERCEPTION
PICTORIAL

Depth Perception – pictorial

Perspective

- The property of parallel lines converging in the distance, at infinity, allows us to reconstruct the relative distance of two parts of an object, or of landscape features. An example would be standing on a straight road, looking down the road, and noticing the road narrows as it goes off in the distance.

Depth Perception – pictorial

Occultation / Occlusion

- Occultation (also referred to as **interposition**) happens when near surfaces overlap far surfaces. If one object partially blocks the view of another object, humans perceive it as closer. However, this information only allows the observer to create a "ranking" of relative nearness.

occlusion provides depth ranking of sailing boats

flee swarm without depth perception due to missing occlusion

Depth Perception – pictorial

Relative Size

- If two objects are known to be the same size (e.g., two trees) but their absolute size is unknown, relative size cues can provide information about the relative depth of the two objects. If one subtends a larger visual angle on the retina than the other, the object which subtends the larger visual angle appears closer.

Depth Perception – pictorial

Familiar size

- Since the visual angle of an object projected onto the retina decreases with distance, this information can be combined with previous knowledge of the object's size to determine the absolute depth of the object. For example, people are generally familiar with the size of an average automobile. This prior knowledge can be combined with information about the angle it subtends on the retina to determine the absolute depth of an automobile in a scene.

Depth Perception – pictorial

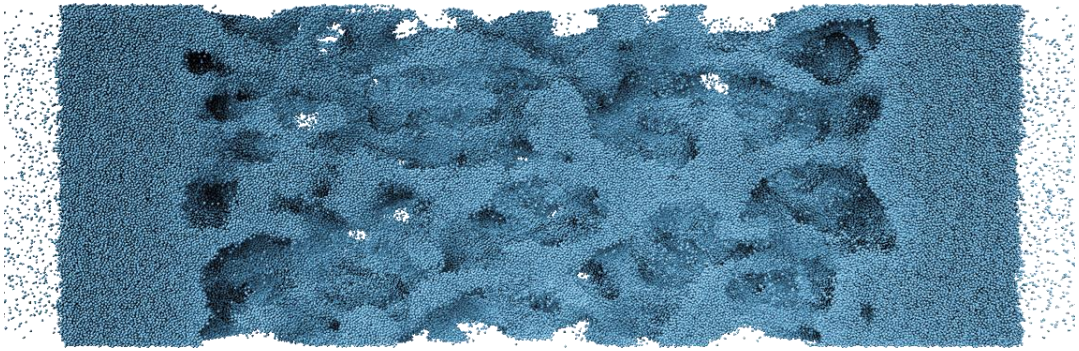
Absolute Size

- Even if the actual size of the object is unknown and there is only one object visible, a smaller object seems further away than a large object that is presented at the same location

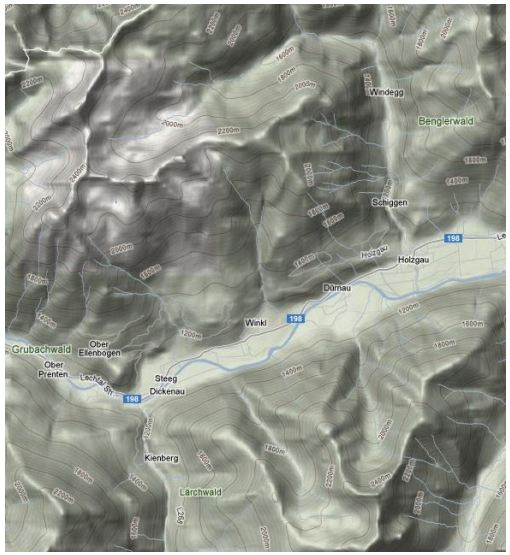
Depth Perception – pictorial

Lighting and Shading

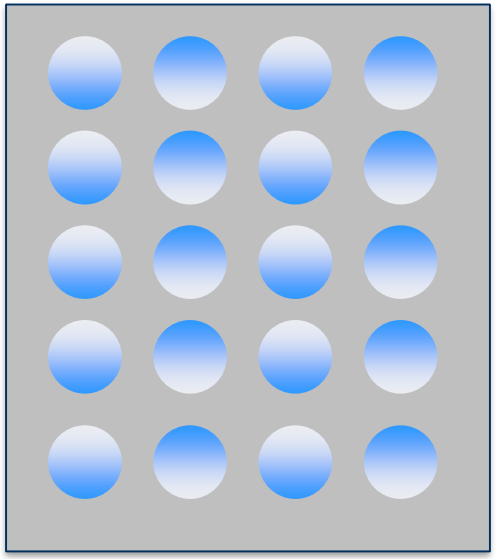
- The way that light falls on an object and reflects off its surfaces, and the shadows that are cast by objects provide an effective cue for the brain to determine the shape of objects and their position in space.



In SciVis ambient occlusion is often used to visualize local 3D structures independent of specific light source



In carthography elevation is often visualized through shading (© Google Maps)



HVS used to light from above ➔ rotating the top figure 180° turns bumps into holes

Depth Perception – pictorial

Areal Perspective

- Due to light scattering by the atmosphere, objects that are a great distance away have lower luminance contrast and lower color saturation. Due to this, images seem hazy the farther they are away from a person's point of view. The foreground has high contrast; the background has low contrast. Objects differing only in their contrast with a background appear to be at different depths. The color of distant objects are also shifted toward the blue end of the spectrum.

Depth Perception – pictorial

Defocus Blur

- Selective image blurring is very commonly used in photographic and video for establishing the impression of depth. This can act as a monocular cue even when all other cues are removed. It may contribute to the depth perception in natural retinal images, because the depth of focus of the human eye is limited. In addition, there are several and blurring. Some depth estimation algorithms based on defocus jumping spiders are known to use image defocus to judge depth.

Stereo

DEPTH PERCEPTION
DYNAMIC

Depth Perception – dynamic

Motion parallax

- When an observer moves, the apparent relative motion of several stationary objects against a background gives hints about their relative distance. If information about the direction and velocity of movement is known, motion parallax can provide absolute depth information. Squirrels move orthogonal to objects of interest to exploit motion parallax as their binocular vision is very limited due to little common field-of-view in their eyes.

https://www.youtube.com/watch?v=3-MqzjceE9o

Depth Perception – dynamic

Depth from motion

- When an object moves toward the observer, the retinal projection of an object expands over a period of time, which leads to the perception of movement in a line toward the observer. The dynamic stimulus change enables the observer not only to see the object as moving, but to perceive the distance of the moving object. Thus, in this context, the changing size serves as a distance cue. A related phenomenon is the visual system's capacity to calculate time-to-contact (TTC) of an approaching object from the rate of optical expansion.

https://www.youtube.com/watch?v=-C_jPcUkVrM

Depth Perception – dynamic

Kinetic Depth Effect

- If a stationary rigid figure (for example, a wire cube) is placed in front of a point source of light so that its shadow falls on a translucent screen, an observer on the other side of the screen will see a two-dimensional pattern of lines. But if the cube rotates, the visual system will extract the necessary information for perception of the third dimension from the movements of the lines, and a cube is seen. This is an example of the *kinetic depth effect*. The effect also occurs when the rotating object is solid (rather than an outline figure), provided that the projected shadow consists of lines which have definite corners or end points, and that these lines change in both length and orientation during the rotation.

https://www.youtube.com/watch?v=7GWeyXj-448

Stereo

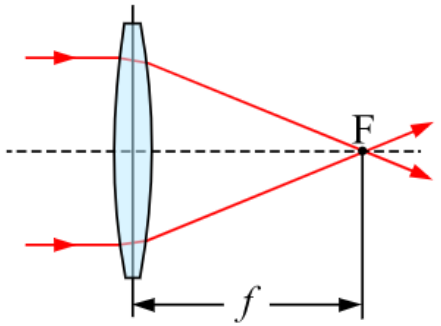
DEPTH PERCEPTION

OCULAR

Optics Basics – Accomodation

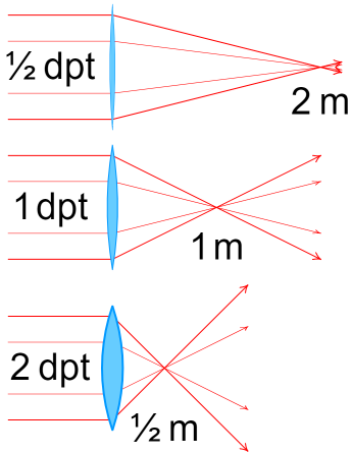
Focal Length

- a positive focal length f is the distance over which initially parallel rays are brought to a focus F.



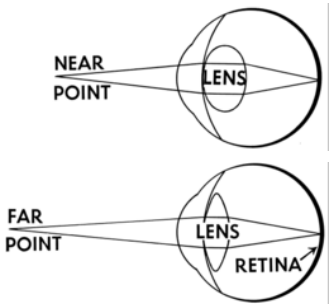
Optical power

- degree to which a lens converges light and equal to reciprocal of focal length.
- physical SI unit is Dioptre or dpt



Amplitude of Accomodation

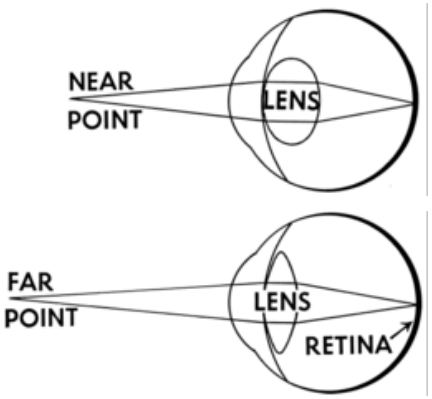
- The amplitude of accommodation is difference between maximum and minimum optical power that eye can accommodate and measured in dpt.



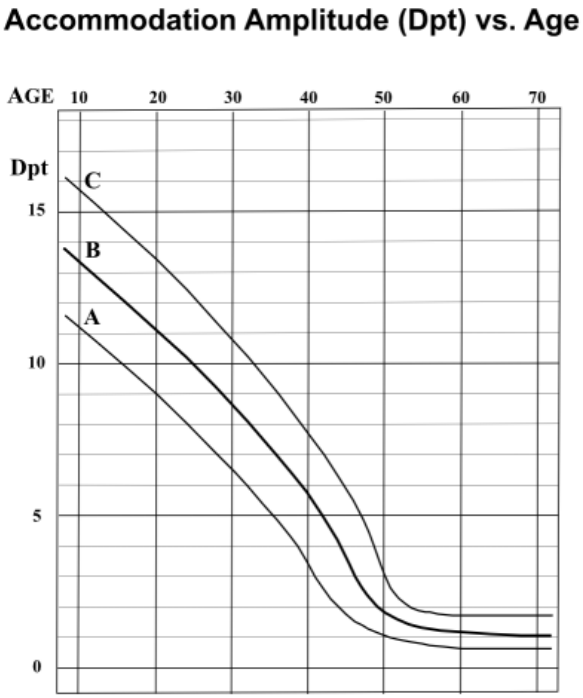
Depth Perception – ocular

Accomodation

- This is an oculomotor cue for depth perception. When we try to focus on far away objects, the ciliary muscles stretch the eye lens, making it thinner, and hence changing the focal length. The kinesthetic sensations of the contracting and relaxing ciliary muscles (intraocular muscles) is sent to the visual cortex where it is used for interpreting distance/depth.
- Accommodation is only effective for distances less than 2 meters.



maximum (top) and minimum accommodation (bottom)

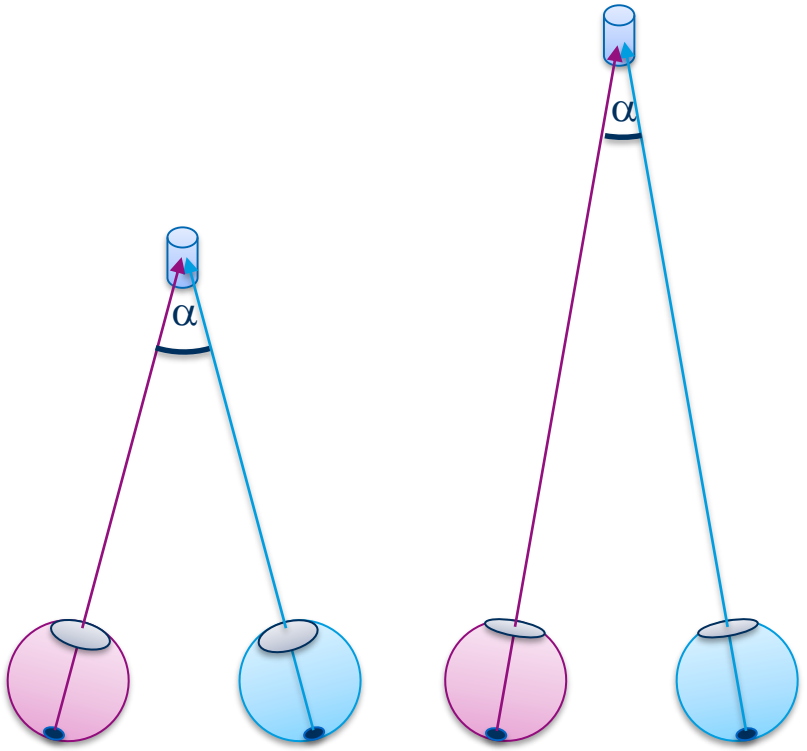


Duane's classical curves showing the amplitude or width of accommodation as changing with age. Mean (B) and approximate lower (A) and upper (C) standard deviations are shown

Depth Perception – binocular

Vergence

- This is a binocular oculomotor cue for distance/depth perception. Because of stereopsis the two eyeballs focus on the same object. In doing so they converge. The convergence will stretch the extraocular muscles. As happens with the monocular accommodation cue, kinesthetic sensations from these extraocular muscles also help in depth/distance perception. The angle of convergence is smaller when the eye is fixating on far away objects.
- Vergence is effective for distances less than 10 meters.



close objects lead to larger convergence α

distant objects have small convergence α

stereós = greek: „spatial" or „bodily“

Stereo

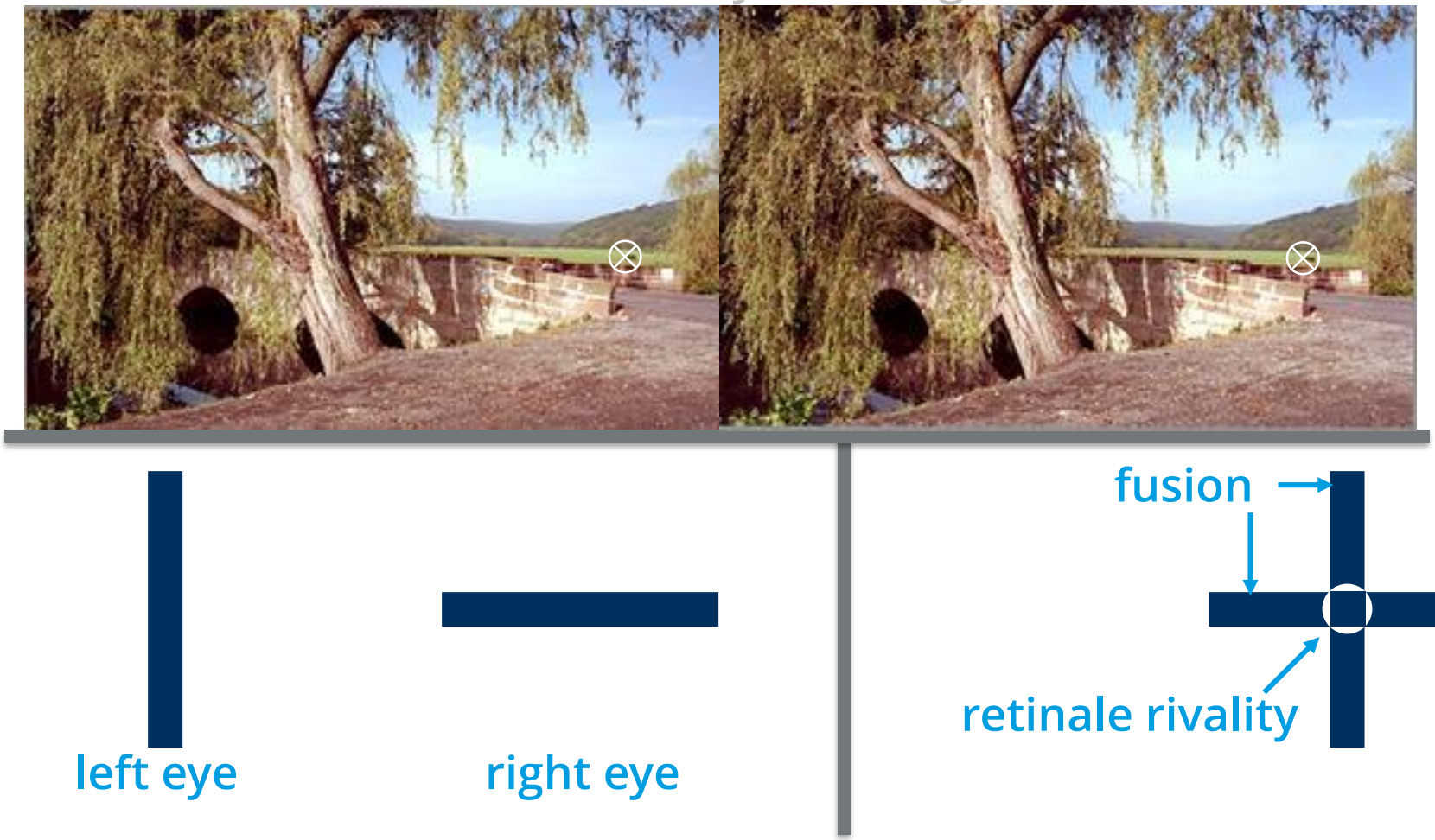
DEPTH PERCEPTION

STEREOPSIS

Stereoscopic Depth Perception

Binocular Fusion

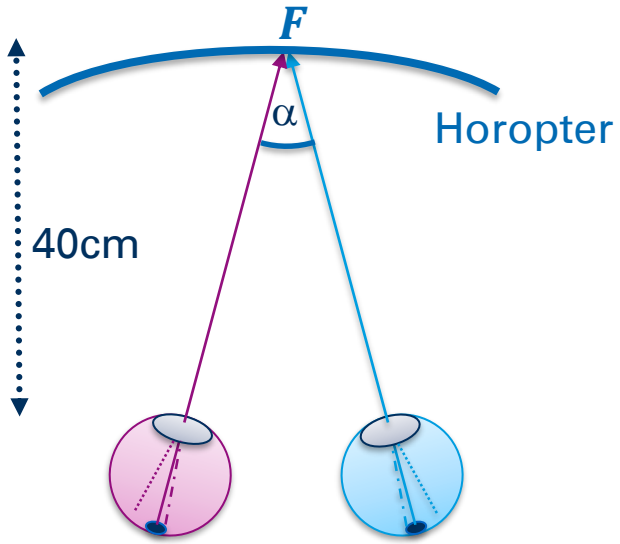
use cross eye viewing

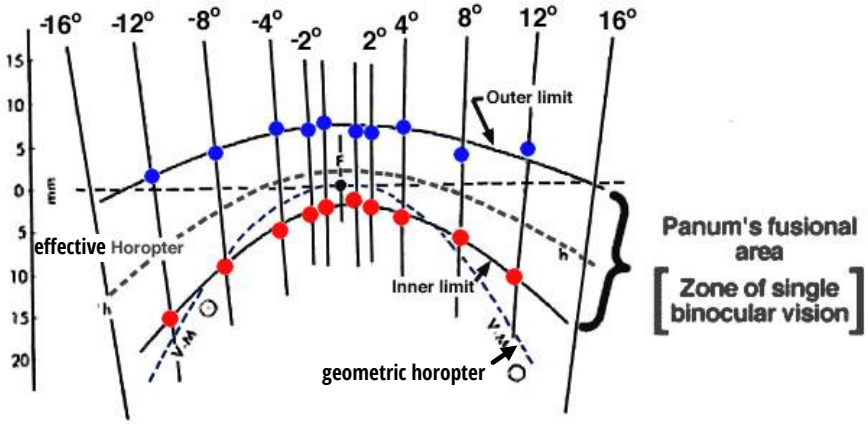


Stereoscopic Depth Perception

Binocular Fusion

- Retinal images can be fused only in the region around the horopter, called Panum's fusional area, and otherwise double vision (diplopia) is experienced.
- The fusion depends on many factors such as differences between individuals, stimulus properties (better fusion for small, strongly textured, well-illuminated, static patterns), and exposure duration.



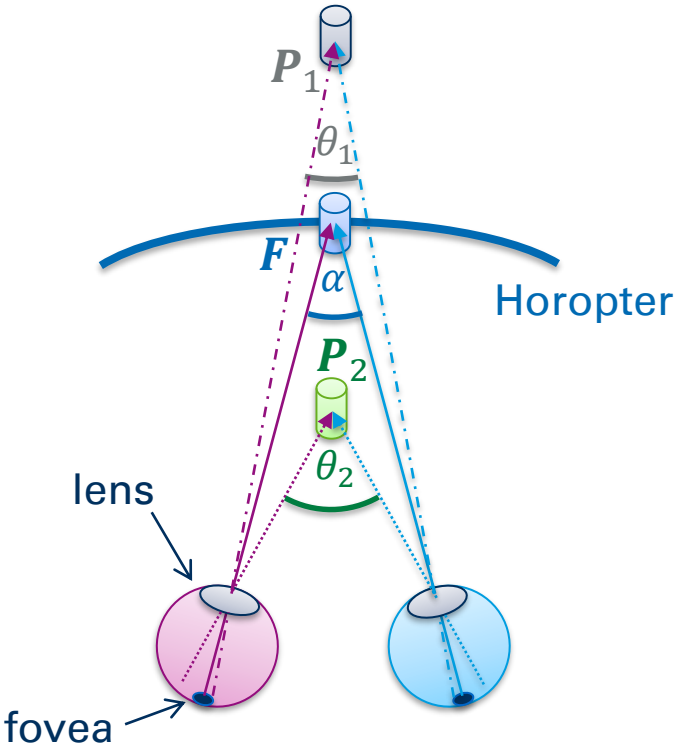


Panum's fusional area at 40cm distance:
points on **effective horopter** are perceived at focus distance
points on **geometric horopter** have same retinale position

Stereoscopic Depth Perception

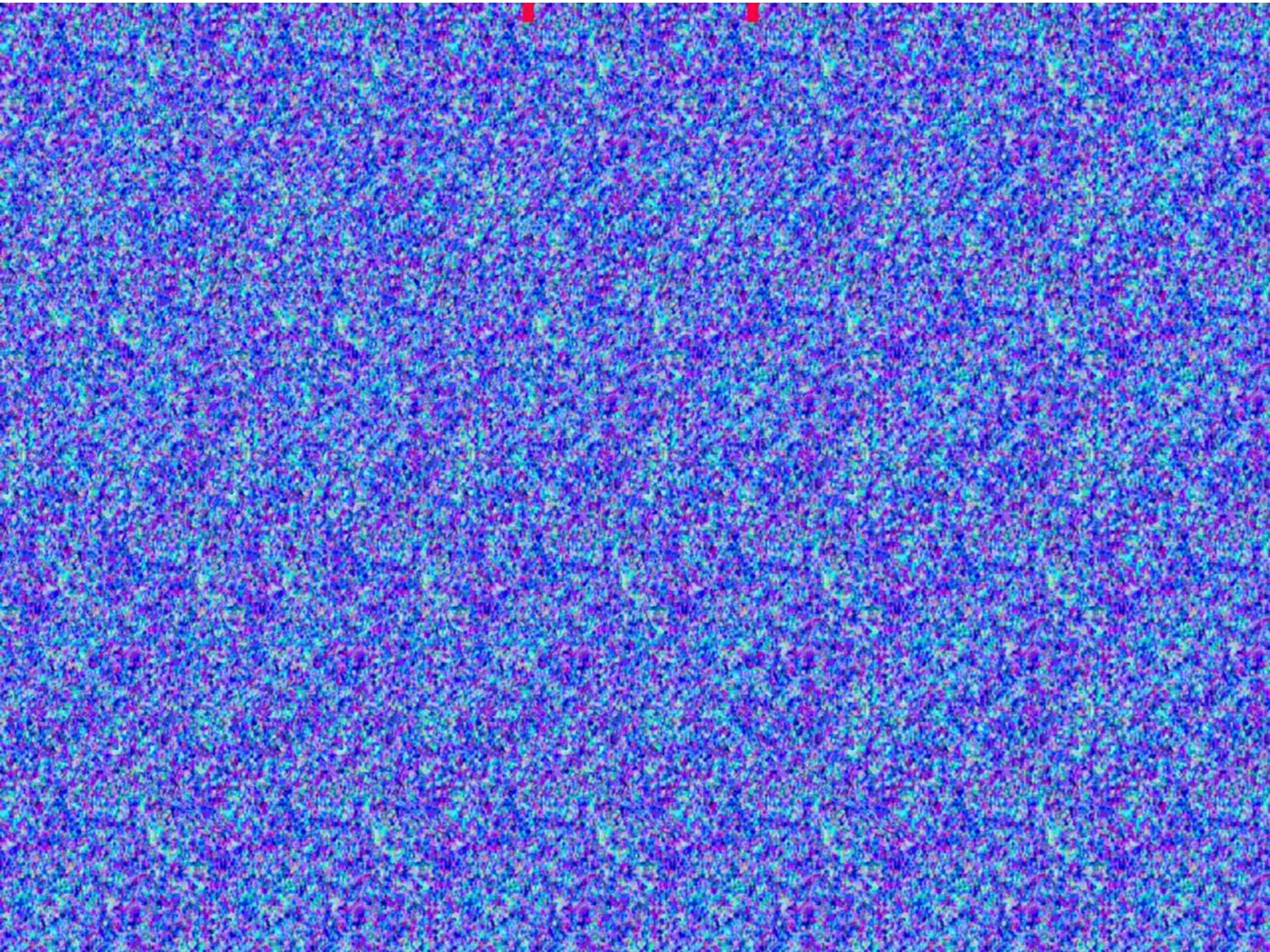
Binocular Disparity

- low-level preattetentive cue and one of the most important stereo cues
- Through vergence eyes fixate at point $\boldsymbol{F}$ of interest, which is projected to zero disparity on fovea in both eyes.
- Then the disparity at $\boldsymbol{P}_1/\boldsymbol{P}_2$ is measured relative to $\boldsymbol{F}$ as the difference of vergence angles $\alpha - \theta_1 > 0$ or $\alpha - \theta_2 < 0$.
- Note that this is different from the computer vision meaning of disparity that describes the lateral distance (e.g., in pixels) of a single object inside two images



Stereoscopic Depth Perception

- The HVS exhibits different sensitivity to all different depth cues (pictorial, dynamic, ocular and stereoscopic)
- Dominant cues may prevail or a compromise 3D scene interpretation (in terms of cues likelihood) is perceived
- There is no complete model to estimate perceived depth for a given [stereo] image|video
- For binocular disparity alone, a perceptual modal has been derived from measurements in
  - [Didyk'11] Piotr Didyk, Tobias Ritschel, Elmar Eisemann, Karol Myszkowski, Hans-Peter Seidel: A perceptual model for disparity. ACM Trans. Graph. 30(4): 96:1-96:10 (2011)



Stereoscopic Depth Perception

- [Didyk'11] study Disparity Sensitivity independent of other depth cues with random dot stereograms
- disparity detection threshold depends on the spatial frequency of a corrugated (wavy) in-depth pattern with a peak sensitivity around 0.3–0.5cpd (cycles-per-degree)
- The disparity sensitivity function (DSF) is U-shaped.
- Disparity discrimination threshold follows Weber's law like behavior and increases with amplitude
- Thresholds increase when moved away from zero-disparity plane

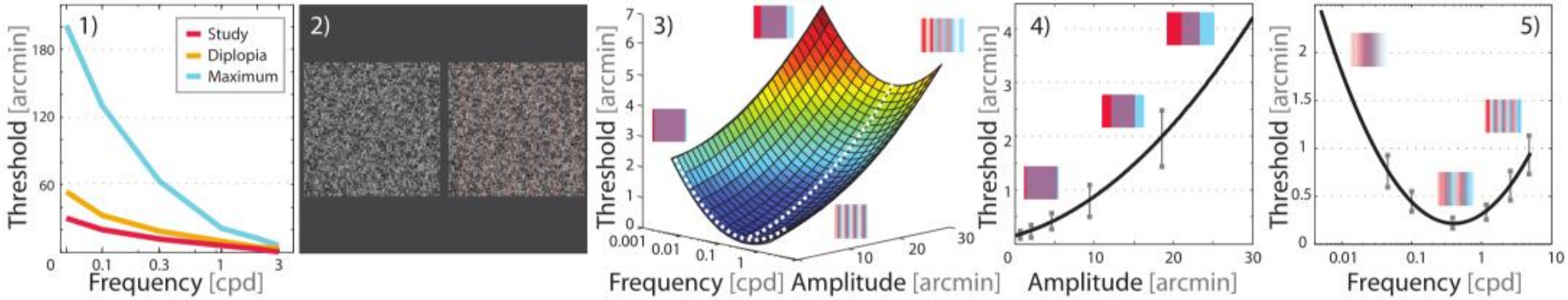


Figure 3: *Left to right: (1) Disparity magnitude ranges: (red) maximum disparity used in our experiments, (yellow) diplopia and (blue) maximum disparity limits. (2) The experimental setup where subjects select the sinusoidal gratings which exhibits more depth. (3) Our fit to the disparity discrimination threshold function $\Delta d(\mathbf{s})$. (4) The cross section of our fit at the most sensitive disparity frequency 0.3 cpd (the error bars denote the standard error of the mean (SEM) at measurement locations). (5) Analogous cross section along frequency axis showing the detection thresholds. Both cross sections are marked with white dashed lines in (3).*

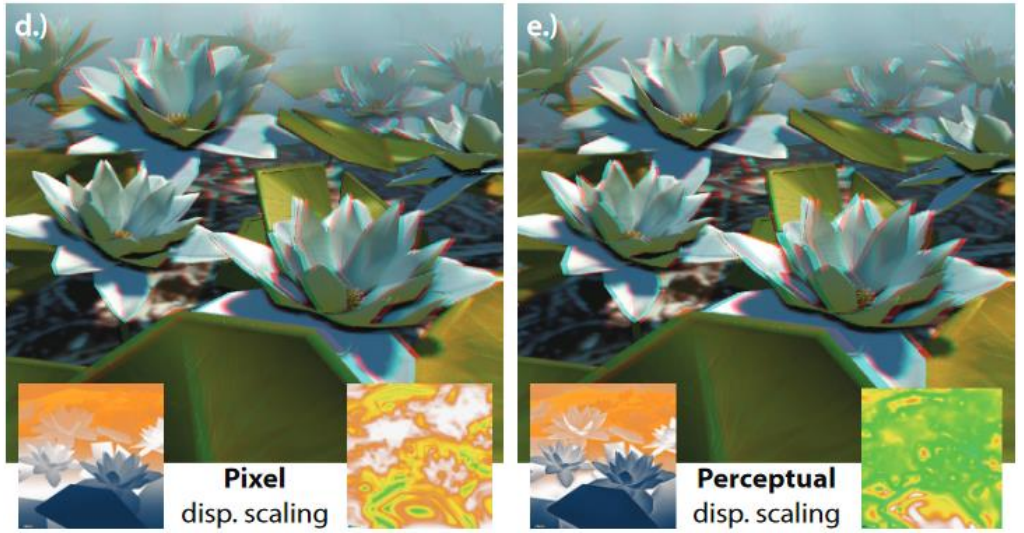
Stereoscopic Depth Perception

Findings on Disparity Contrast in [Didyk'11]

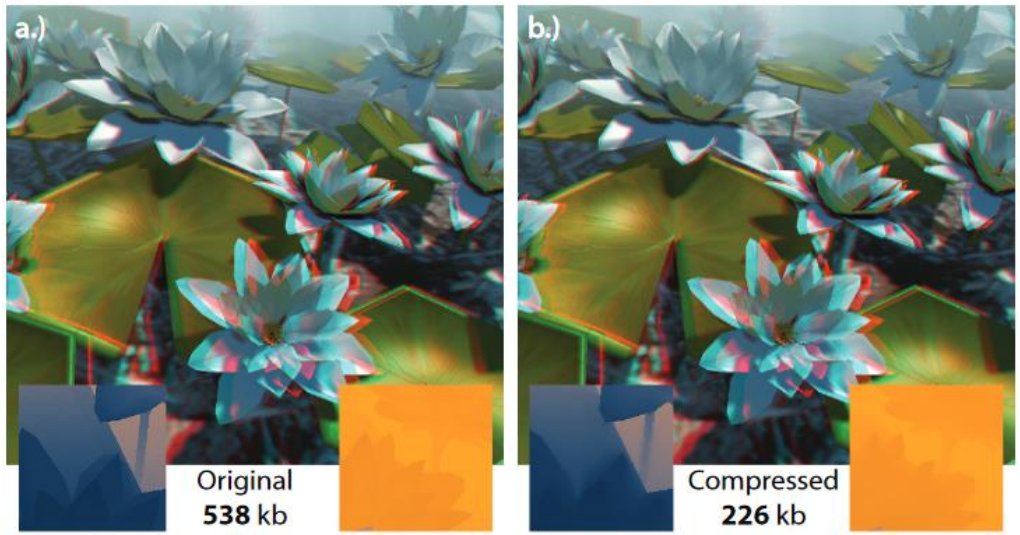
- Apparent depth is dominated by the distribution of disparity contrasts rather than absolute disparities
- depth is perceived most effectively at surface discontinuities and curvatures, where 2nd order disparity differences are ≠ 0.

Applications

- stereo-image-difference metric,
- disparity re-targeting,
- compression
- backward-compatible stereo and
- hybrid stereo images.



re-scaling of disparity left with pixel disparities and right in perceptual space



compression ignoring disparity of 1 JND

Backward-Compatible Stereo

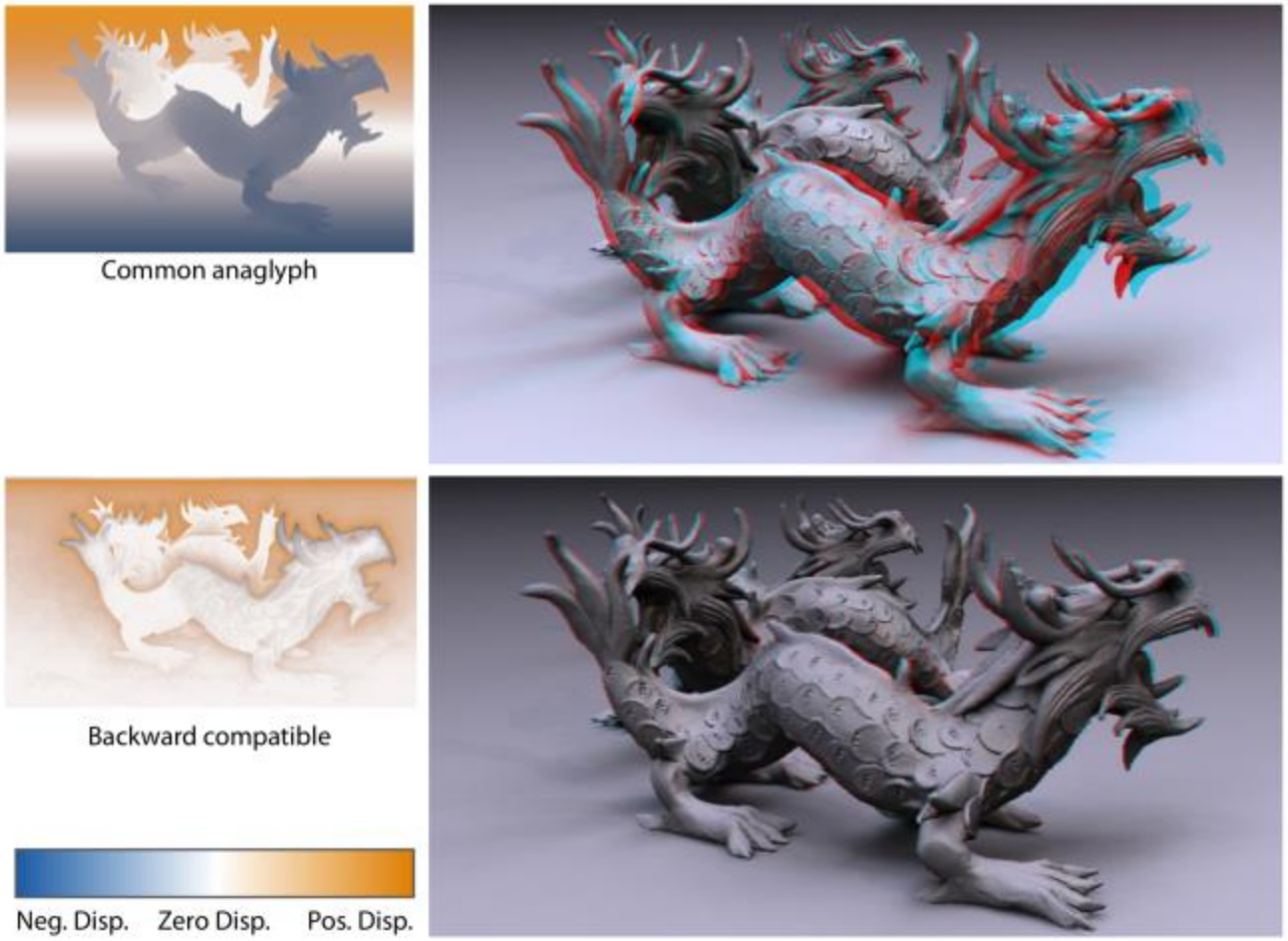


Figure 11: *Backward compatible stereo provides just-enough disparity cues to perceive stereo, but minimizes visible artifacts when seen without special equipment.*

Stereoscopic Depth Perception

Shadow Stereopsis

- Antonio Medina Puerta demonstrated that retinal images with no parallax disparity but with different shadows are fused stereoscopically, imparting depth perception to the imaged scene. He named the phenomenon "shadow stereopsis". Shadows are therefore an important, stereoscopic cue for depth perception

- *Medina Puerta A (1989). "The power of shadows: shadow stereopsis". J. Opt. Soc. Am. A.* ***6*** *(2): 309–311. doi:10.1364/JOSAA.6.000309.*

Stereoscopic Depth Perception

Shadow Stereopsis

use parallel eye viewing

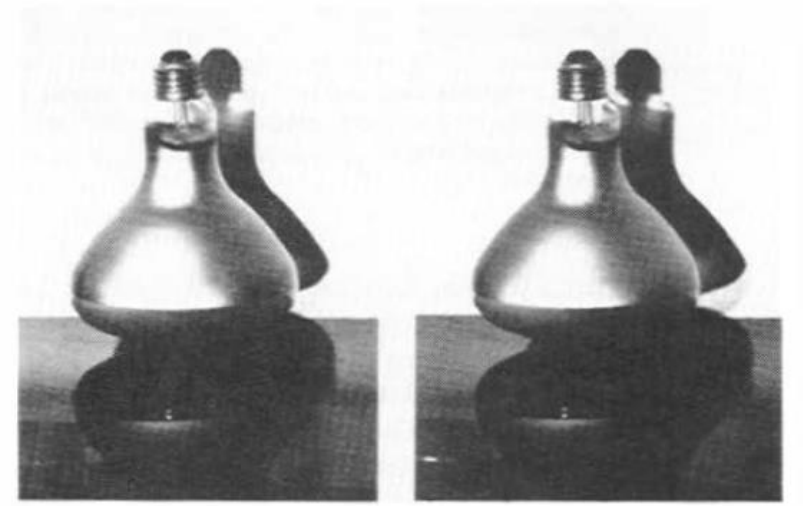


Fig. 2. Experiencing stereoscopic depth of an object without parallax disparity. Shadow stereopsis is isolated when viewing an object photographed as depicted in Fig. 1b (light sources at the left-hand side). The electric bulb is viewed binocularly in vivid depth, arising solely from the different shadows.

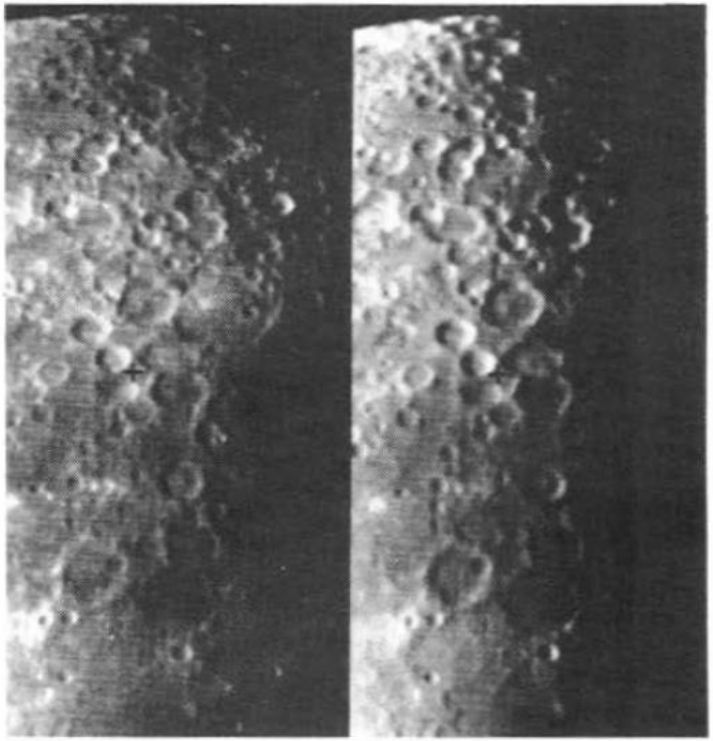


Fig. 3. Depth information encoded in the shadows alone of Moon craters photographed approximately 25 h apart (right-hand image: September/11/1986, 9:50 p.m.; left-hand image: September/12/1986, 10:30 p.m.; telescope pointed to southwest; Boston, Massachusetts). The Sun in two different locations served as the light source. To experience the stereoscopic depth effect, gaze at the two images until they fuse. Observe the right-hand panel with the right eye and the left-hand panel with the left eye. The two crosses may be used to facilitate fusion.

Medina Puerta A (1989). "The power of shadows: shadow stereopsis". J. Opt. Soc. Am. A. ***6*** *(2): 309–311. doi:10.1364/JOSAA.6.000309.*

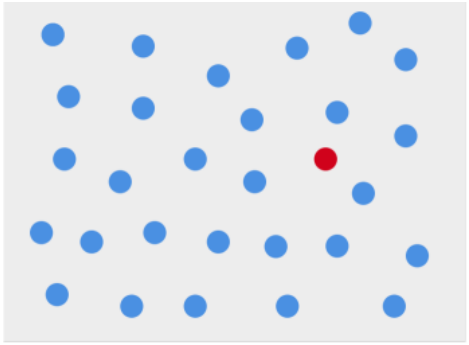
Why does this not look real???

Why does this not look real???

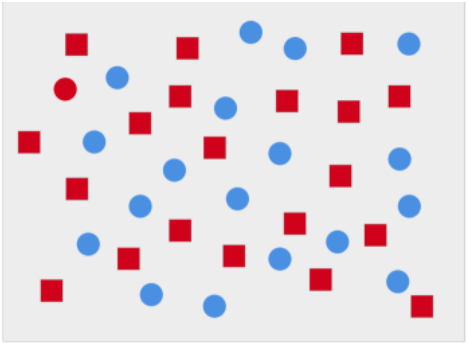
Deadeye – stereoscopic popout

- Krekhov et al examined the pop-out effect induced by presenting to be emphasized image parts to only one eye
- They found that their deadeye technique is the only preattentive cue that can be combined with all other cues.
- They exemplarily applied the deadeye effect to line plots, 3D scenes and complex molecules
- The deadeye effect had been used during world war II for fast change detection on area photography

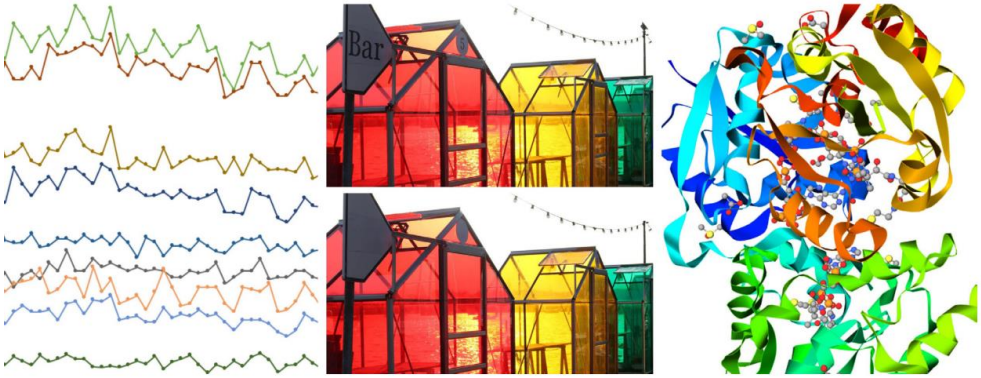
demo



In pre-attentive color perception outlier can be found in constant time



Linear time search in case of conjunction of colour and shape (find red circle)



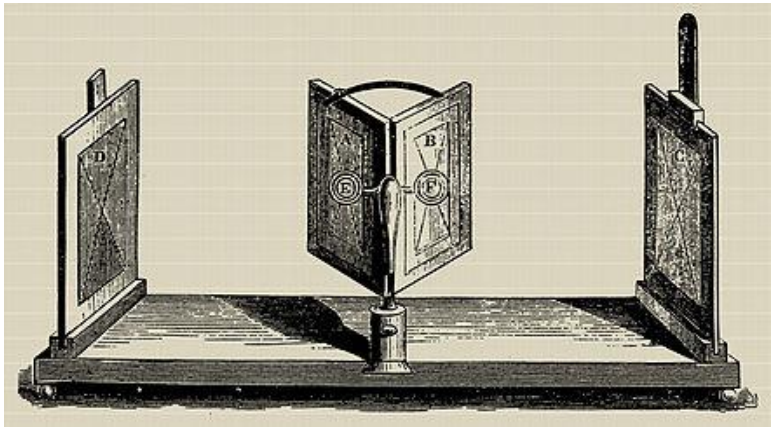
Andrey Krekhov, Jens H. Krüger: *Deadeye: A Novel Preattentive Visualization Technique Based on Dichoptic Presentation*. IEEE Trans. Vis. Comput. Graph. 25(1): 936-945 (2019)

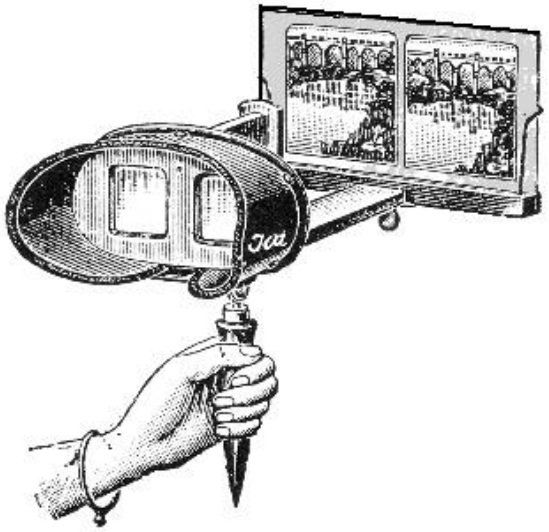
Stereo

DISPLAY TECHNOLOGY

Display Technology – History

- acient greek knew about single and double view binocular vision, but only in
- 1838 Sir Charles Wheatstone built first mirror stereoscope
- 1852: Anaglyph was introduced
- 1860: 1 Million stereoscopes sold
- 1950ies:





The history of stereoscopy: https://link-springer-com.wwwdb.dbod.de/content/pdf/10.1007/BF00155009.pdf

Display Technology

- 3D Video Formats
- Multiplexing Techniques
- Display Setups

Stereo

DISPLAY TECHNOLOGY
VIDEO FORMATS

Display Technology – Video Formats

HDMI 1.4a

Frame packing: **FHD3D**

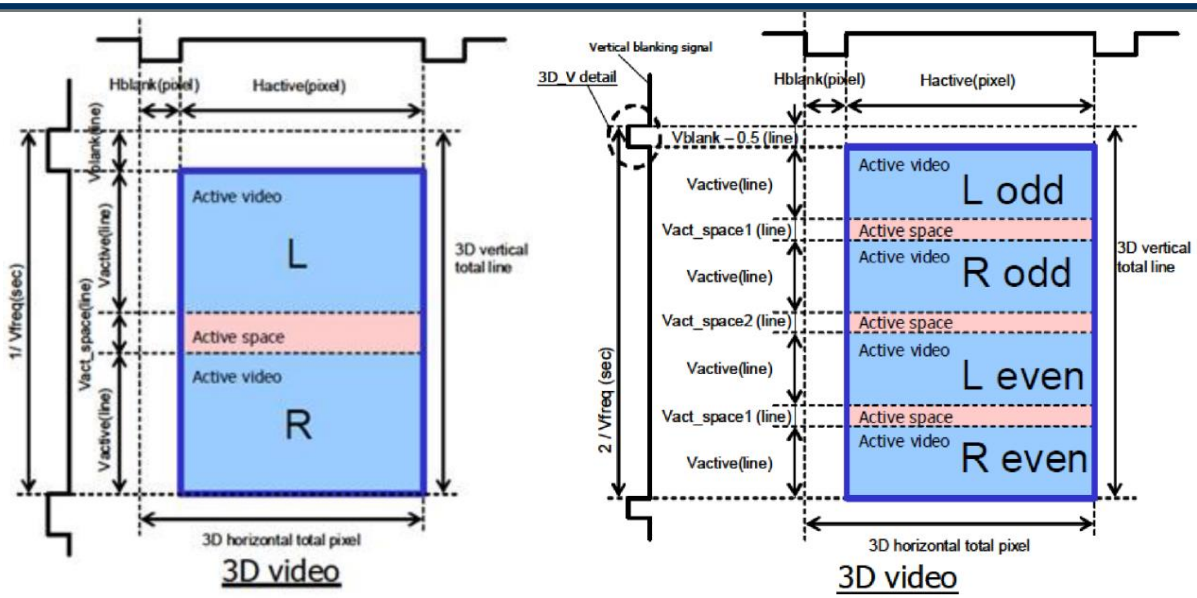
- twice full HD packed into 1920x2205 pixels with 45 pixels empty space in between

Compatibility Formats:

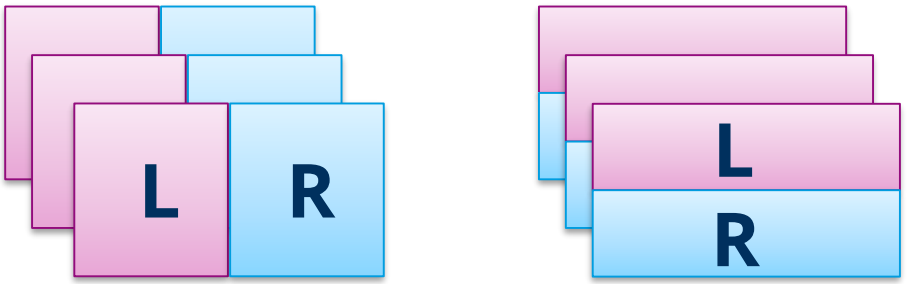
- Two halve resolution images packed into one HD frame:
- Side-by-Side
- Top-and-Bottom

HDMI 2.1

- support for full 4k Stereo at 60Hz



Progressive (left) and interleaved (right) frame packing formats



Side-by-Side (left) and top-and-bottom (right) compatibility HDMI formats

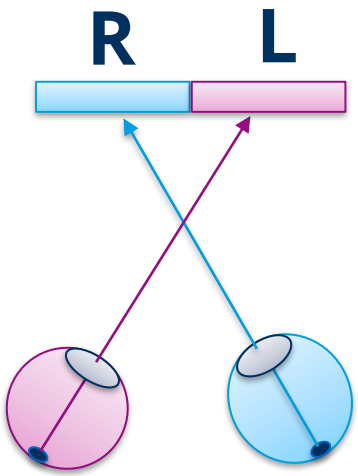
Stereo

DISPLAY TECHNOLOGY
MULIPLEXING TECHNIQUES

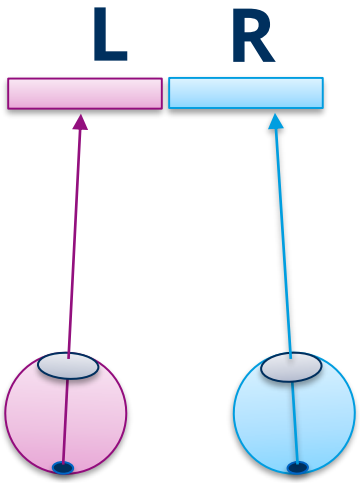
Display Technology – Multiplexing

Spatial

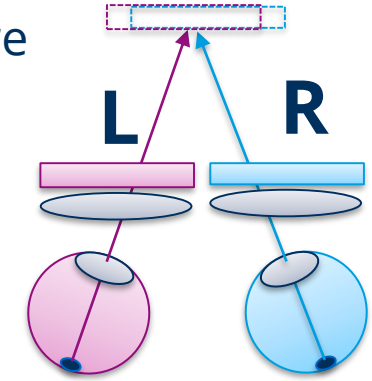
- Autostereograms (cross|parallel)
  - no special display hardware necessary
  - significantly wrong vergence and accommodation cues
- stereoscope & Head Mounted Display (HMD)
  - additional lense optics allows to project images into fixed depth where accommodation and vergence cues are correct for ~2m distant objects
- Auto-stereoscopic
  - Lenticular sheets (Lentikularfolien) are used to project two or more images to different spatial regions



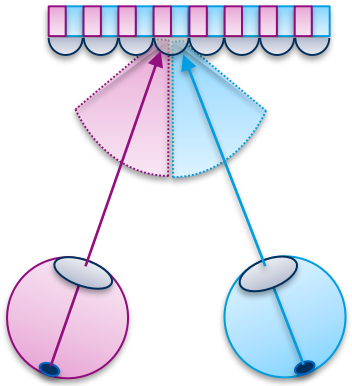
Cross-Viewing



Parallel-Viewing



HMD



Lenticular sheets

Display Technology – Multiplexing

Temporal

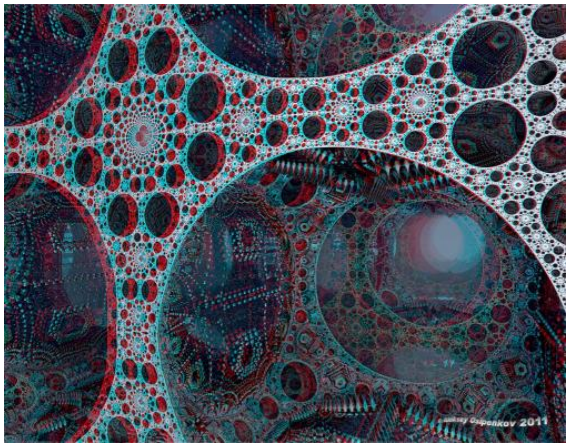
- active stereo multiplexes over time with >120Hz display and shutter classes synchronized via infrared emitter

active stereo display with infrared emitter

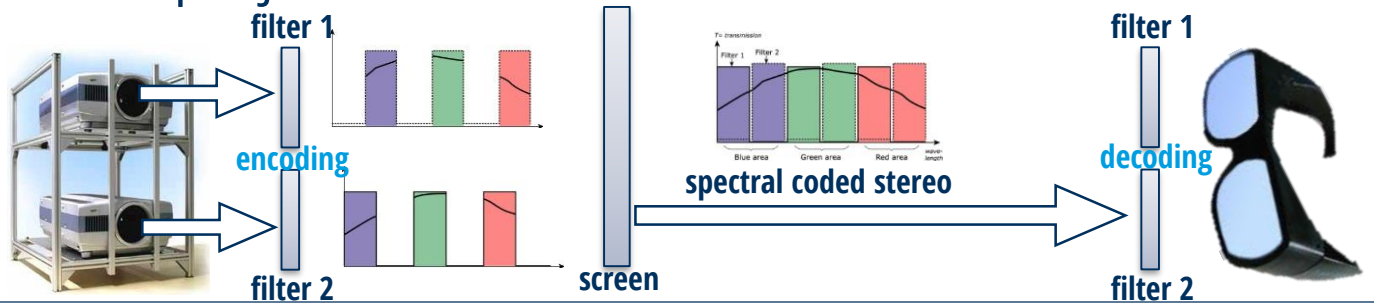
active classes toggle eye in synch with display

Spectral

- Anaglyph splits images according to color channels and does not need any specific display
- Infitec uses two spectral filters with disjoint RGB bands in glasses and before 2 projector



default anaglyph: left: red, right: cyan



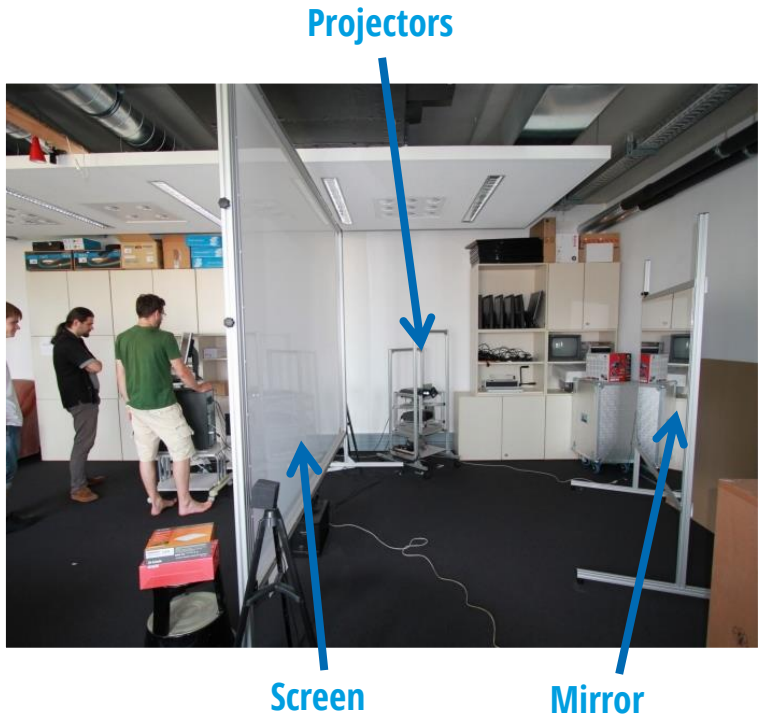
Display Technology – Multiplexing

Polarization

- passive stereo uses 2 polarization filters (linear or circular) with 2 projectors as in infitec setup
- glasses are lightweight and cheap

Additional **requirements** wrt infitec:

- projection screen needs to preserve polarization
- glasses need to be horizontal and mostly orthogonal to screen



Powerwall in Holodeck of CGV

Stereo

DISPLAY TECHNOLOGY
DISPLAY SETUPS

Display Technology – Display Setups

Technology

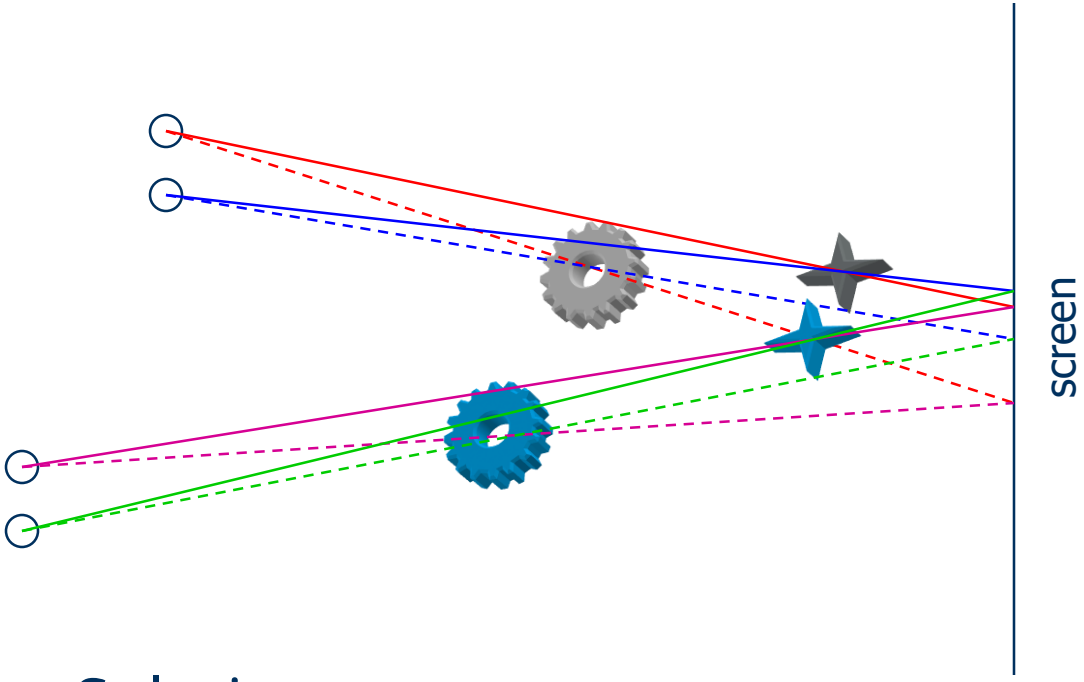
- Monitor
- Head-Mounted Displays (HMDs)
- Head-Coupled Displays (HCDs)
- Immersive projection displays (IPDs)
  - "Powerwall"
  - Workbench
  - Cave
- Retinal displays

Further Terms

- Parallax
  - Horizontal difference of left and right image on screen
- Immersion
  - to „dive“ into virtual world
- Stereo Frame Violation
  - Conflict between display geometry and virtual world leading to collapse of fusion
- Tracking
  - Real-time measurement of poses (location & orientation) of HMD, and controllers

Display Technology – Display Setups

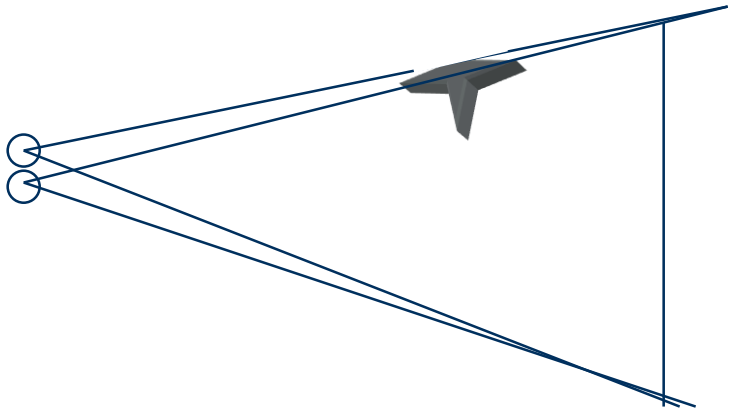
- Why stereo is a one-man show: (second user perceives objects rendered for first user distorted and out of place)

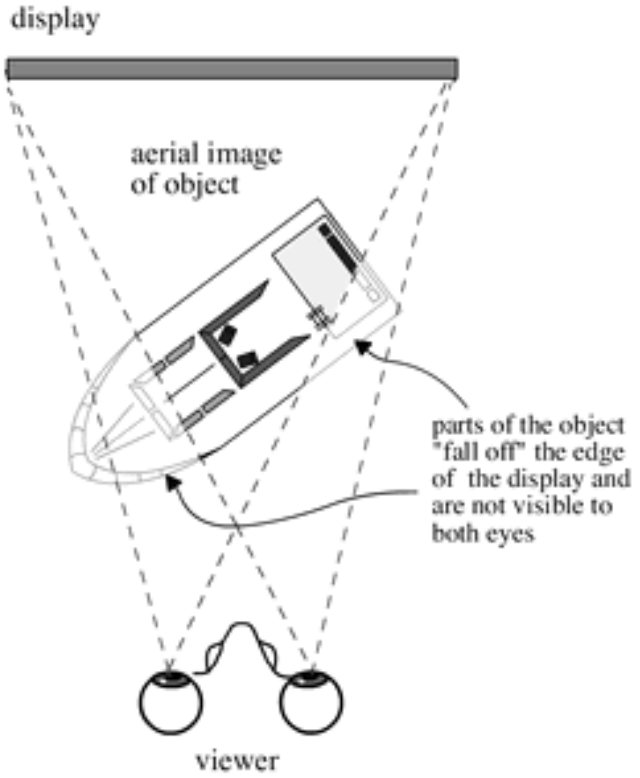


- Multi-User Solutions:
  - For n users, 2 x n images need to be rendered and multiplexed
  - Holographic/Volumetric Displays

Stereo Frame Violation

- 2 contradictory effects occur together:
  - Clipping
  - Conflicting depth cues:
    object is clipped, even though it is in front of window edge

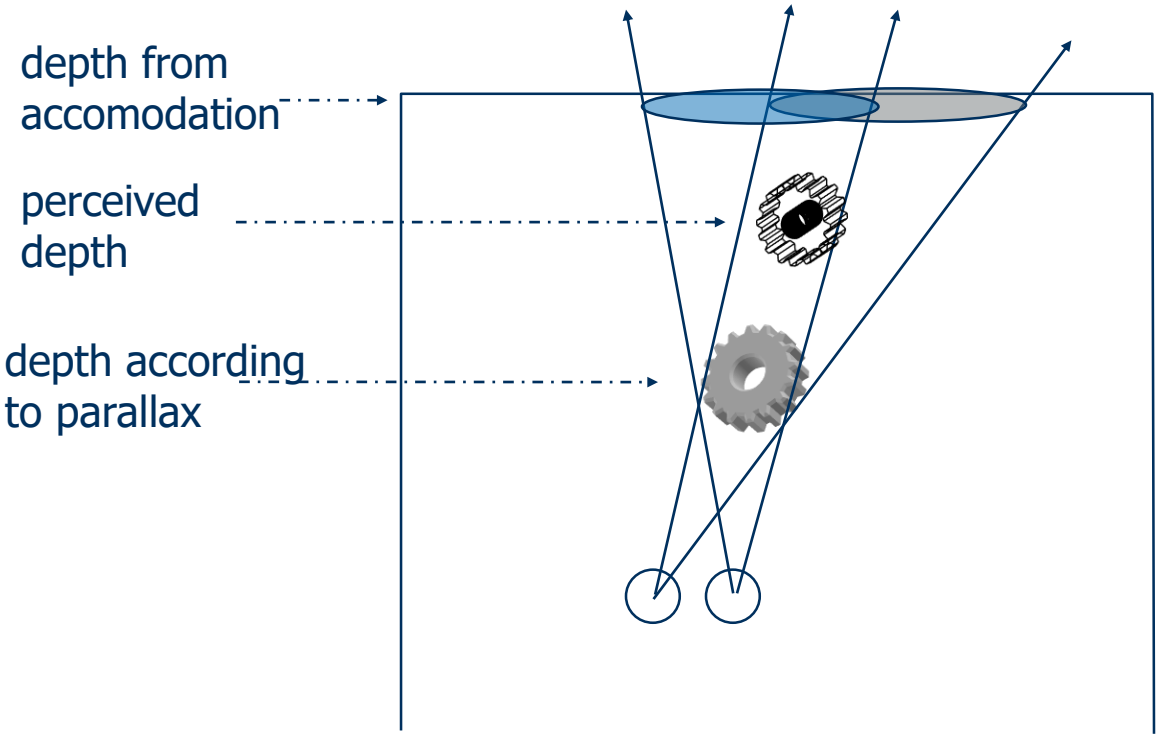




Display Technology – Display Setups

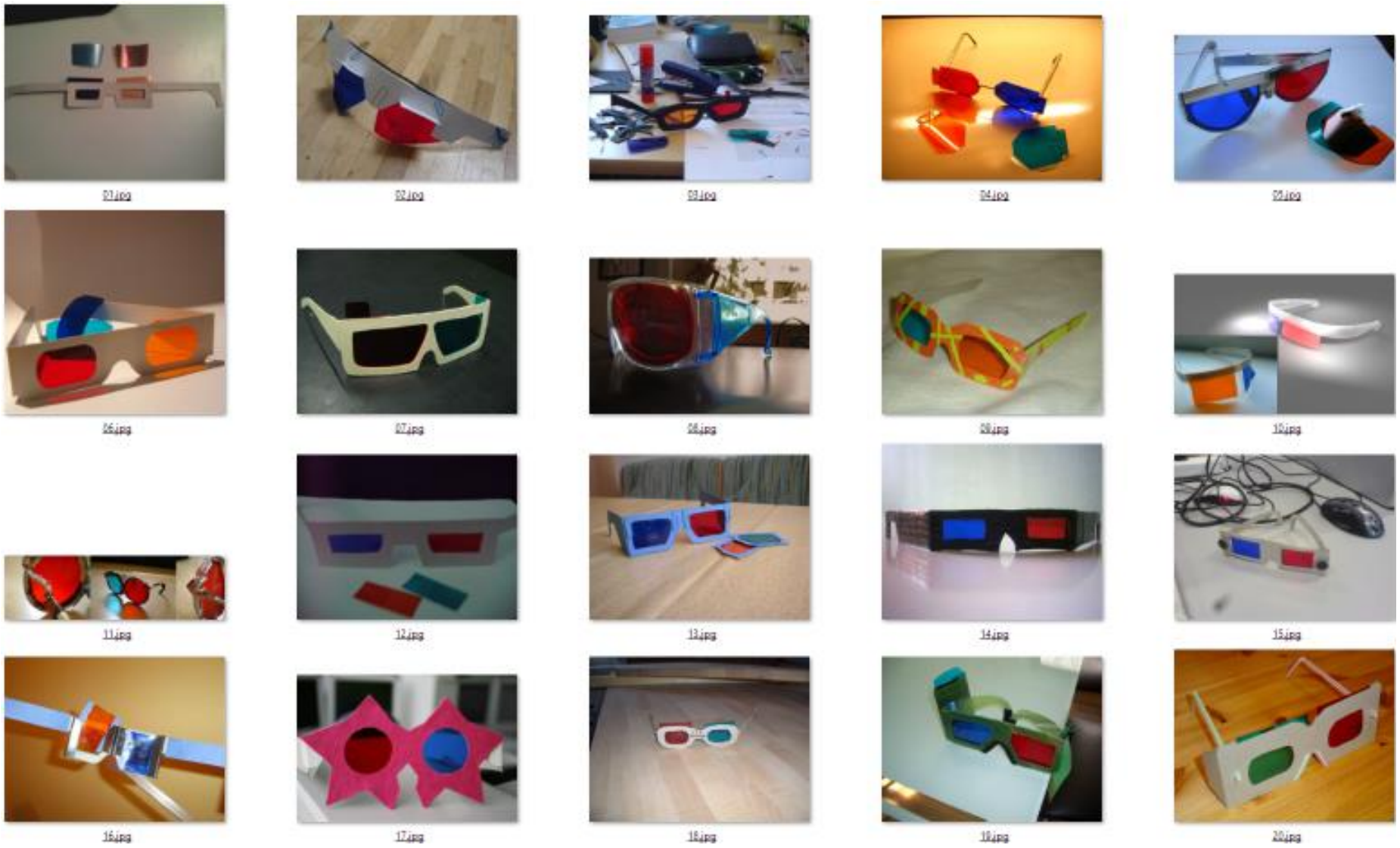
Accomodation Vergence Conflict makes Stereo exhausting!

- Effect: near objects appear too far away in the cave.



- Solution: holographic or volumetric display!

Display Technology – Anaglyph



Display Technology – Display Setups

Head Mounted Displays

- **Hololens 2:** 2x2048x1080@75Hz **70°** seethrough
- **VIVE Pro:** 2x1440×1600@90Hz **110°**
- **Meta Quest Pro :** 2x1800×1920@90Hz **106°**
- **Varjo XR-3:** 2x1920x1920 foveal(**27°**) +
  2x2880x2720 (peripheral) @90Hz **115°**

Pocket stereoscope with original test image. Used by military to examine stereoscopic pairs of aerial photographs.

HoloLens 2 HMD

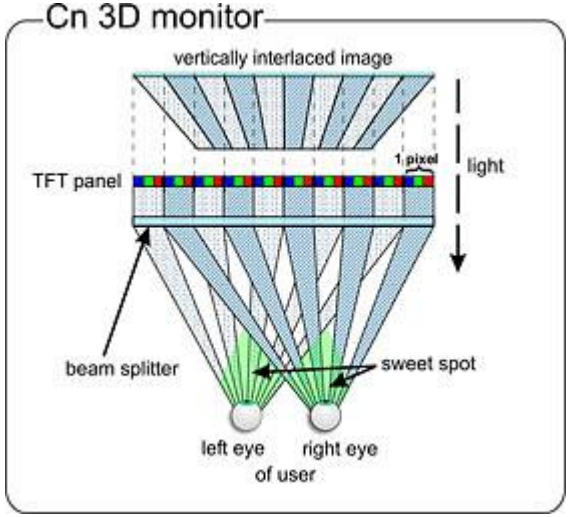
Meta Quest Pro

VIVE Pro HMD

Varjo XR-3

Display Technology – Display Setups

- Autostereoscopic
  - Use of lenticular sheets for directional projection of different images
  - LCD: 2 views
  - Paper print: 12 views
  - LookingGlass: 45-100 views
- discussion
  - spatial resolution reduced by number of views
  - 2 views demands for eye tracking (single user)
  - LookingGlass: multi-user
  - Suffers from accommodation vergence conflict

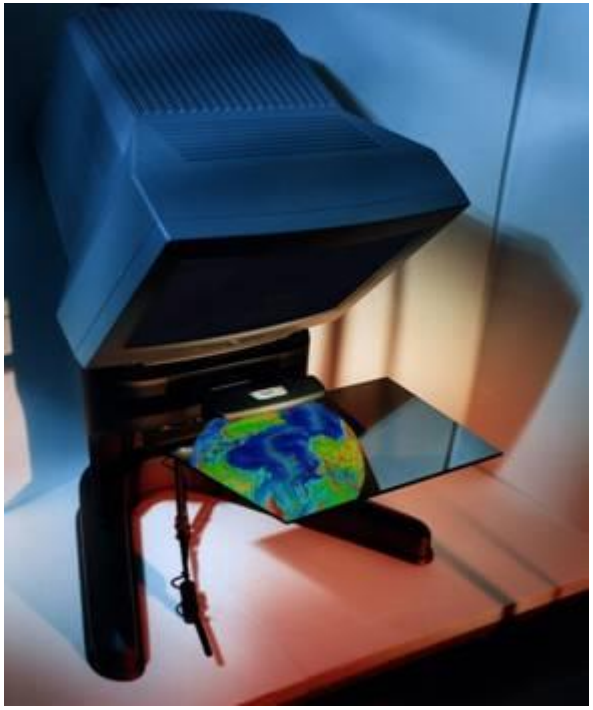


SeeReal C-i 3D

different sizes of LookingGlass holographic displays

Display Technology – Display Setups

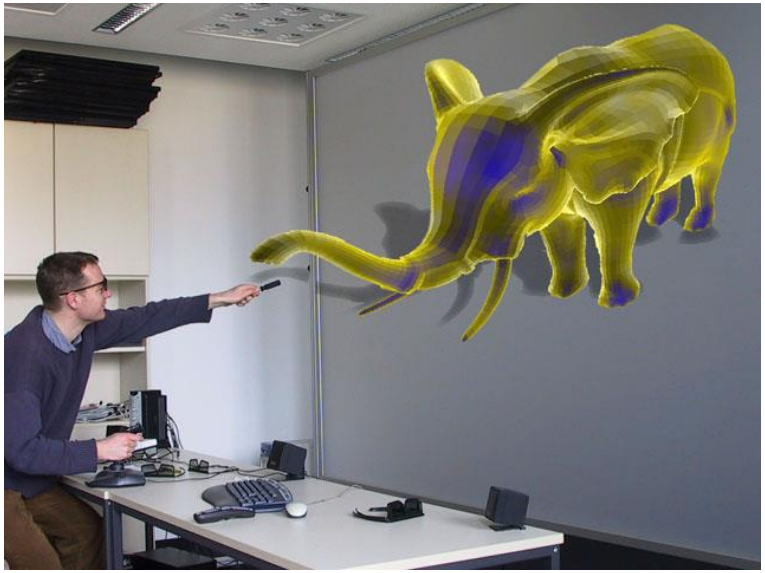
- Reachin



Immersive Projection Displays (IPDs)

- Idea similar to 3D cinema but with 1-6 screens
- Powerwall: 1 wall (3x6 meters e.g.)
- Workbench: 1 horizontal display area
- Holobench: 2 surfaces, 1 vertical, 1 horizontal
- Cave: 3 - 6 walls
- "Desktop Cave": 2 horizontal walls

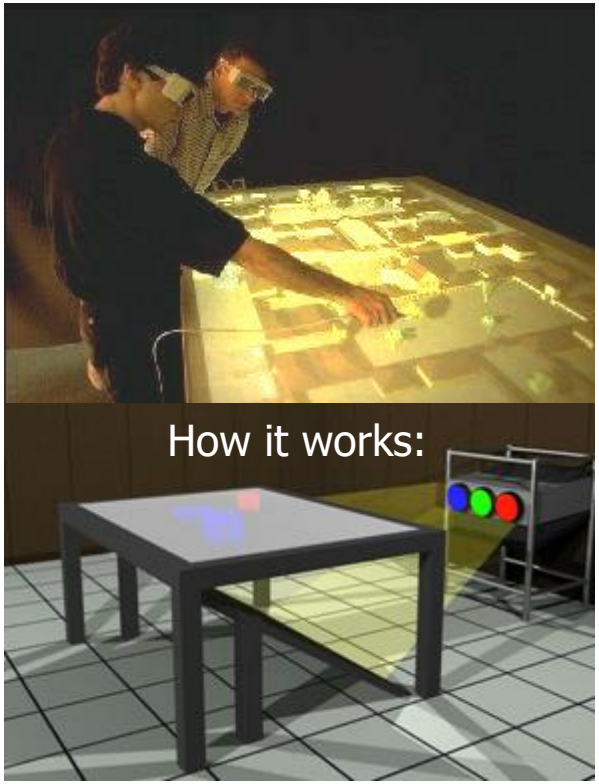
Powerwall



back projection,
passive stereo
in holodeck of CGV
~~2x1400x1050~~
2x3820x2160

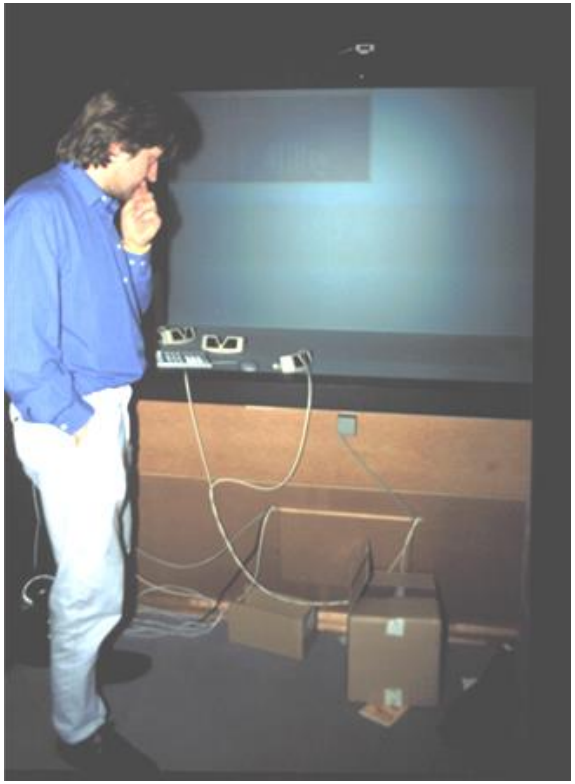
Powerwall with front projection,
multiple projectors per image
→edge-blending & hot spots can arise

Display Technology – Display Setups



Workbench

tiltable projection



Holobench (projection on table and orthogonal wall)

Display Technology – Display Setups

Curved display technology gives better field of view

curved display wall with three projectors

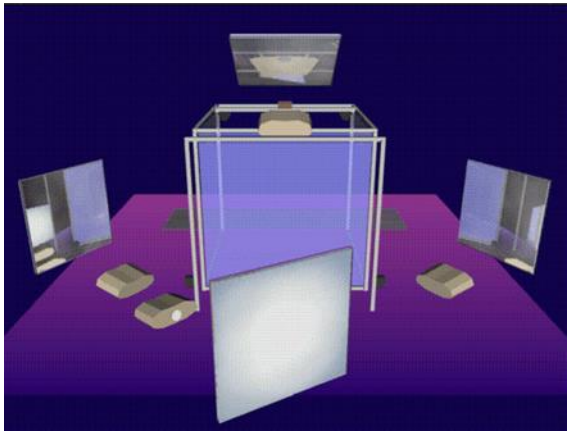
old triple monitor curved display

modern curved monitor with resolution 5120x1440

Display Technology – Display Setups

CAVE

3-Wall Cave



Mirror setup in 4-wall cave

5-wall Cave, Darmstadt

6-wall Cave, Alborg, DK

Display Technology – Display Setups

Multi-User Setups

- HMDs: scales to large number of users; most important challenge: how to render body and face of other users
- Active Stereo: ultra high speed projectors exist with 360 fps to support up to 3 users
- Combined techniques: active + passive + anaglyph allows support for 4 users

INSIGHT 4K HFR 360

Holographic Displays

~~VIRTUALON~~ VIRTUAL WONDERS

- 1, 2, 3 or 4 sided holographics spaces based on multiple displays hidden in booth providing up to 360° experience

Dreamoc Diamond 4 sided 4K holograms

Looking Glass

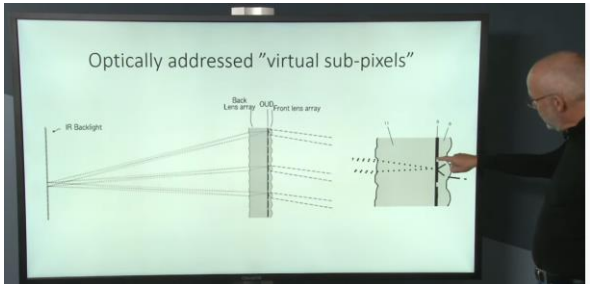
- Lenticular sheets distribute 45-100 views onto 58° viewing cone. Input resolution: 2k,4k,8k No eye tracking needed.

8k Looking Glass

Project Echo

REALFICTION™

- Direct pixel into tracked eyes by extending thin film technology



virtual sub-pixel idea: watch

Systeme – Hardware – IPDs

Advantages:

- High resolution (up to 12800x8000)
- Large field-of-view without HMD
- No isolation from the real world
- Cave:
  - Head rotation only causes small changes in projected image such that latency problems are reduced
- (several users very costly)

Disadvantages:

- space requirements
- Price for investment, warranty and energy consumption
- Precise adjustment necessary
- Possible stereoscopic violation
- (correct view only for one viewer)

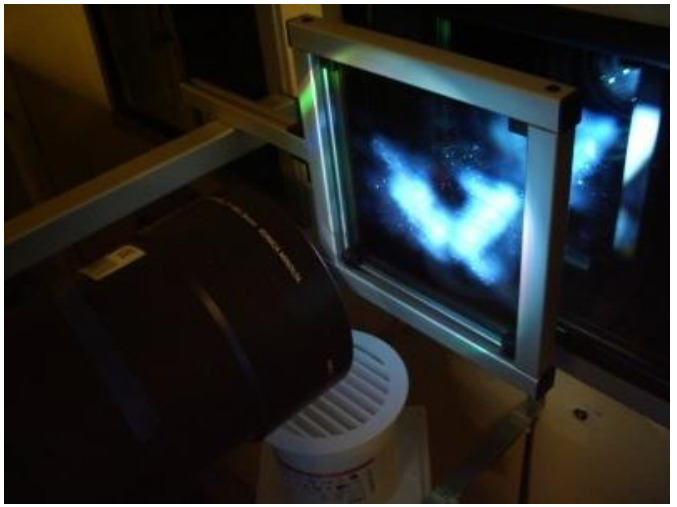
Systeme – Hardware – Vergleich

Art	Advantages	Disadvantages
Fishtank	Low cost, well accepted, good resolution,	no immersion, stereoscopic violation, small action zone, small field-of-view
Head-mounted	Good immersion, large field-of-view, no stereoscopic violation, large action zone	Resolution lower, less comfortable, distortion when close to content, face of user is hidden
Projection-based	High resolution, large field-of-view, good availability, face of user is visible	expensive, high power and maintainance costs, (stereoscopic violation)

Dresdner Rundkino

Image Calibration

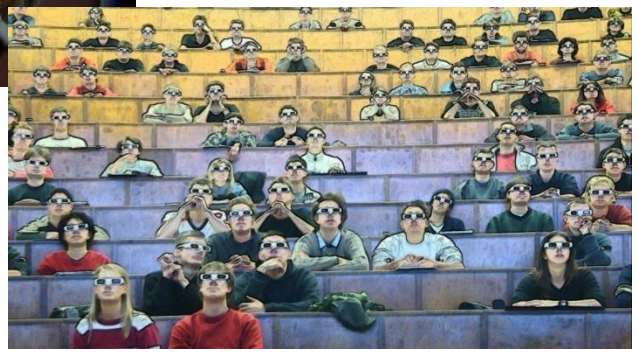
2x6000W Projector



Polarisation Filters

Lichtenheldt-Lecture Hall in ZEU

Rekonstruierter und denkmalgeschützter Lichtenheldt-Hörsaal im Zeunerbau



- 3D presentation for up to 400 people.
- Use in courses, at conferences and large seminars.

Interactive agricultural machine Simulator in HEI

Fast change of cabine

Virtuell cocpit