Vision & Visuals

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Overview

- Human Visual Systems
- Visual Perceptions
- 3D Depth Cues
- 3D Stereographics Terminology
- Stereo Approximation
- 3D Displays & Auto-Stereoscopic Displays
- Design Issues for VR Visual Displays

Human Perception System

- Obtain information about environment through **vision**, **audition**, **haptic/touch**, **olfaction**, **gustation**, **vestibular/kinesthetic senses**.
- Human perception capability provides HCI design issues.

Vision

- Vision is one of the most important research areas in HCI/VR because designers should know
  - What can be seen by users
  - What a user can see better
  - What can attract user's attention
- Vision
  - Physical reception of stimulus
  - Processing and interpretation of stimulus
  - No clear boundary between the two

Human Visual System

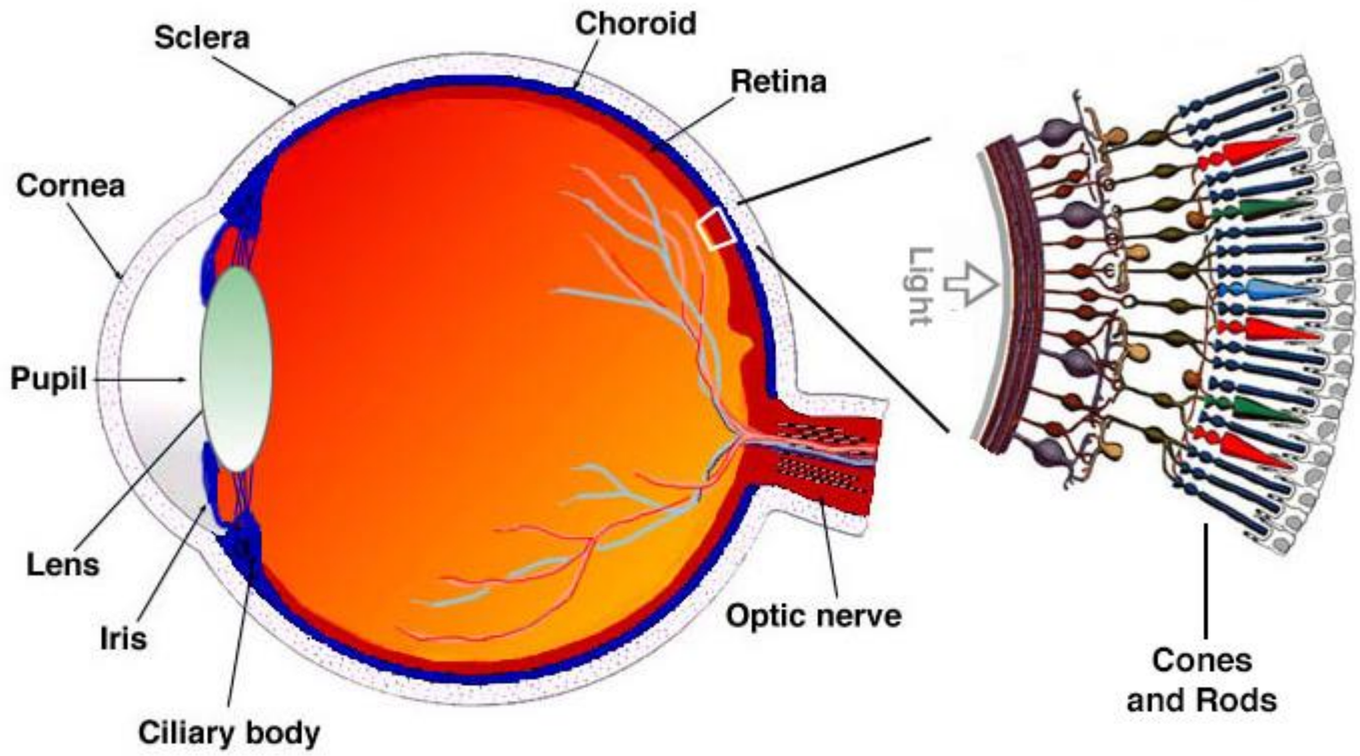
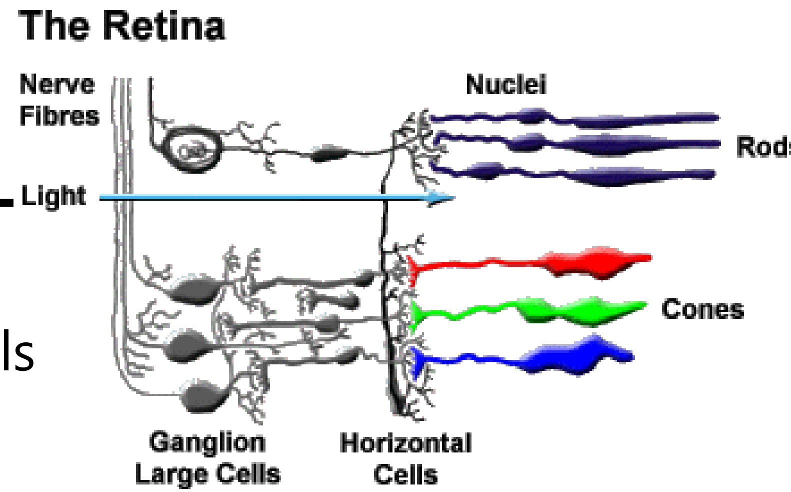


Image from http://www.blueconemonochromacy.org/how-the-eye-functions/

Human Eyes

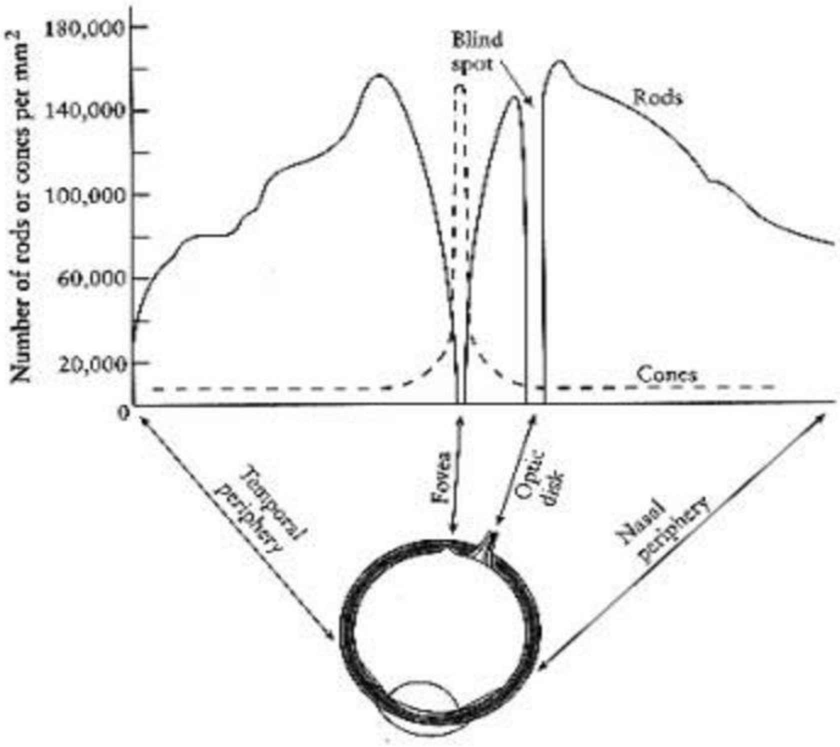
- Light is focused by the cornea and the lens onto the retina
- Light passing through the center of the cornea and the lens hits the **fovea** (or macula)
- Iris permits the eye to adapt to varying light levels, controlling the amount of light entering the eye.
- Retina is optically receptive layer like a film in a camera
- Retina translate light into nerve signals.
- Retina has photoreceptors (rods & cones) and inter-neurons.

Photoreceptors



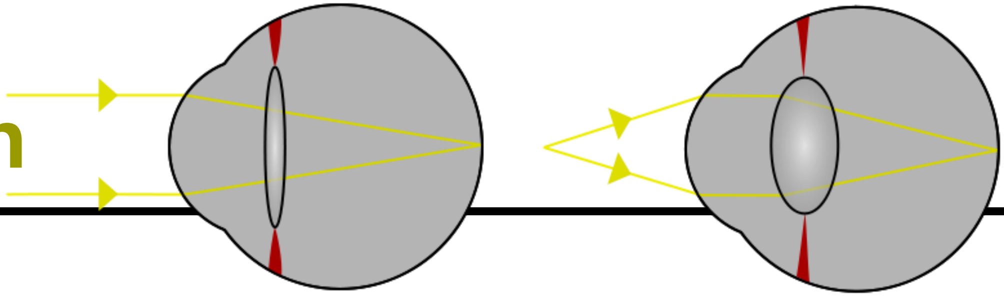
- Rods
  - Operate at lower illumination levels
  - Luminance-only
  - The most sensitive to light
  - At night where the cones cannot detect the light, the rods provide us with a **black and white** view of the world
  - The rods are also more sensitive to the blue end of the spectrum
- Cones
  - **Operate at higher illumination levels**
  - Provide better spatial resolution and contrast sensitivity
  - Provide **color vision** (currently believed there are 3 types of cones in human eye, one attuned to red, one to green and one to blue) [Young-Helmholtz Theory]
  - Provide visual acuity

Rods & Cones Distribution



- Rods & Cones Distribution
- Fovea
  - only cone receptors with very high density
  - no rods
  - no S-cones (blue cones)
  - responsible for high visual acuity
- Blind Spot
  - no receptors
  - Axons of all ganglion cells pass through the blind spot on the way to the brain

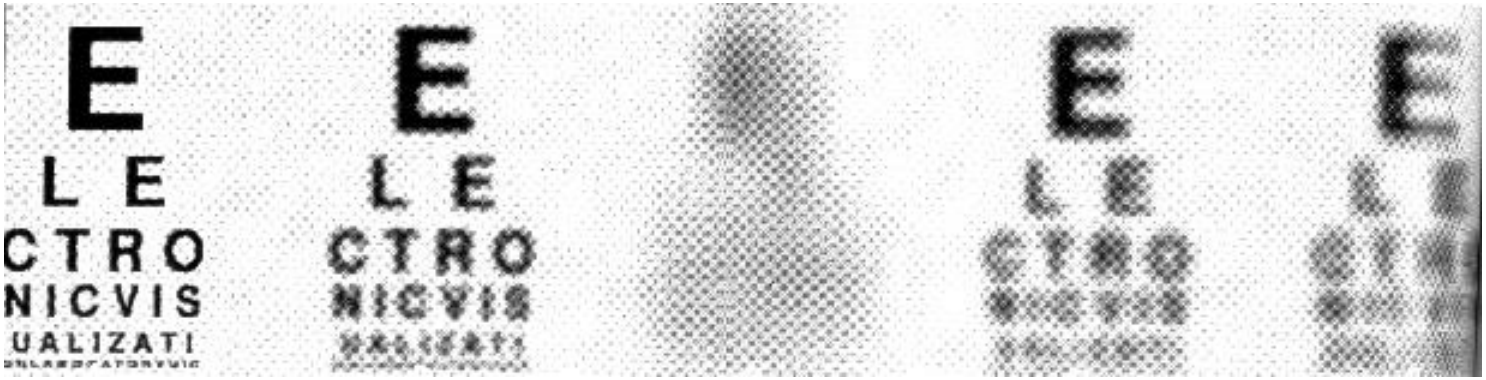
Vision Perception



- Accommodation
  - The process by which the eye increases optical power to maintain a clear image (focus) on an object as it draws near
- Visual acuity
  - Acuteness or clearness of vision, which is dependent on the sharpness of the retinal focus within the eye and the sensitivity of the interpretative faculty of the brain
- Contrast sensitivity
  - The ability to distinguish between an object and its background or detect differences between similar shades of light and dark
- Adaptation
  - The ability of the eye to adjust to various levels of darkness and light
- Color vision

Visual Perception

- Visual Acuity
  - Visual acuity is measured as the angle subtended by the human eye.
  - Snellen fraction 20/X where the viewer sees at 20 feet detail that the average person can see at X feet (20/200 is legally blind)
  - The standard definition of normal visual acuity (20/20 vision) is the ability to resolve a spatial pattern separated by an angle of 1 arc min.
  - A resolution of about 1 arc min is necessary to get to the region of peak sensitivity



20/20 CRT 20/40 '90 HMD 20/425 BOOM 20/85 CAVE 20/110

Visual Perception

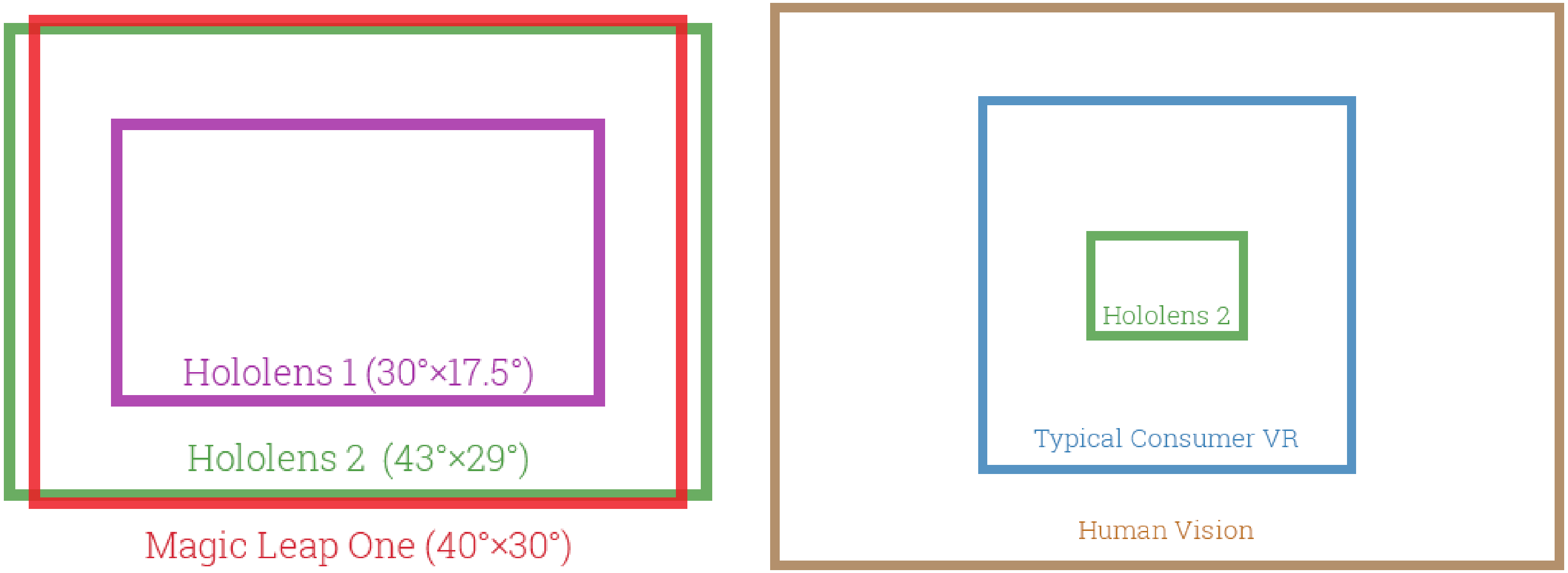
- Temporal Resolution
  - The real world doesn't flicker. Classic theatrical films and CRTs (old style TVs and monitors) do flicker because the image is constantly being refreshed.
  - We perceive flickering if the image isn't refreshed fast enough.
  - Most people stop perceiving the flicker between 15 Hz (for dark image) and 50 Hz (for bright images).
  - Some people can perceive flickering even at 60 Hz (the image being refreshed 60 times per second) for a bright display with a large field of view.
  - Very large display may require up to 85 Hz.
  - LCD panels tend to have 60 Hz or 120 Hz refresh rates these days (though manufacturers often claim to have higher rates).
  - Note that this is **the rate that the hardware refreshes**, which is (mostly) independent from the rate the graphics are being refreshed. Making sure the graphics refresh fast enough will always remain an issue.

Visual Perception

- Field of view (FOV)
  - Each eye has approximately *145 degree horizontal* (45 degree towards the nose and 100 degree to the side) and *100 degree vertical* (30 degree up and 70 degree down).
  - Most old style HMDs have a FOV of about 40 to 60.
  - Current VR headsets like **HTC VIVE** and **Oculus Rift** have **110** degree stereo FOV, the new **Quest** has **115** degree FOV which are getting close to matching human field of view.
  - **Google Glass** display has FOV of **15** degrees monoscopic in the corner of your vision.
  - **Microsoft HoloLens** has a **30** degree horizontal and **18** degree vertical FOV. (**HoloLens2 has 43 degree**)
  - **CAVE** and **CAVE2** have the FOV depends on the size and the location of the physical displays and the glasses used – 6 sided CAVEs surrounded the users with screens, but the glasses typically don't cover the complete field of view (roughly 120 horizontal and 90 vertical).

Visual Perception

- Field of view (FOV)



https://uploadvr.com/hololens-2-field-of-view/

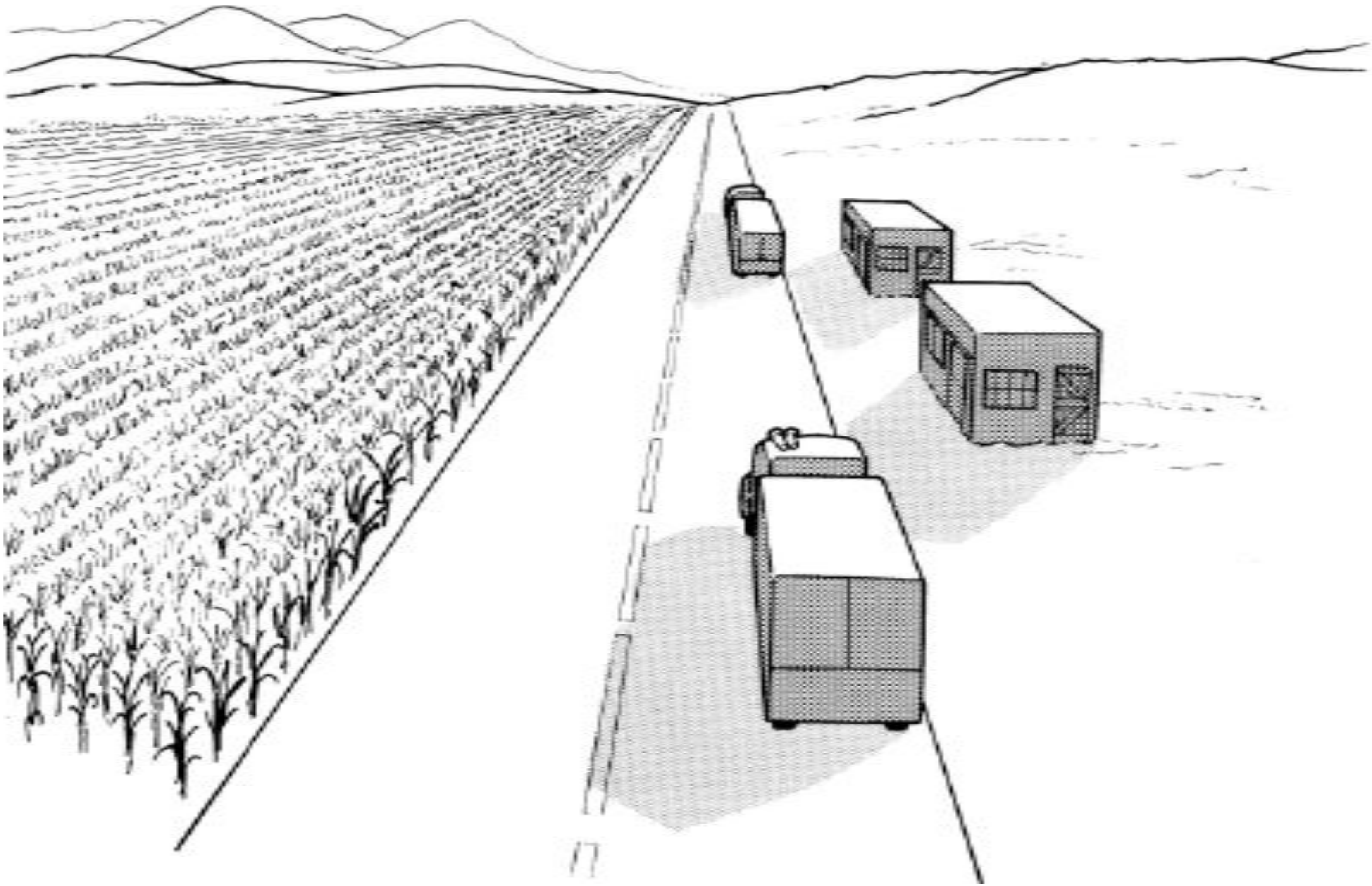
Visual Perception

- Luminance
  - The eye can detect a range of 10^14 in luminance, but cannot see across the entire range at the same time.
  - The size of our pupil automatically adjusts to the amount of light available, allowing us to shift our window of much narrower range of luminance detection across a much large range.
  - If we spend 30 minutes dark adapting we can dramatically increase our vision at the low end.
  - The eye is sensitive to ratios of intensities rather than to absolute differences. Brightness = Luminance^0.33.
  - To make something appear n times brighter the luminance must be increased by n^3.
  - Displays still cannot reproduce the full range of luminance that human can see, **but the range increases every year, and with the new focus on OLED displays and high contrast displays and direct view LED displays this is getting much better**.

Visual Perception

- Color
  - Most visual perceptual processes are driven by intensity not color.
  - The human motion system is color blind, depth perception is color blind, object recognition is color blind.
  - But uniquely colored objects are easy to find.
  - Displays still cannot reproduce the full color spectrum that human can see, **but the range increases every year, and with the new focus on OLED displays and high contrast displays and direct view LED displays this is getting much better.**
- Motion
  - Motion of the visual field causes a sense of motion even without physical motion.
  - Studies have shown that a low resolution peripheral image contributes strongly to the effect.

Visual 3D Depth Cues



Visual Depth Cues

- Perceiving “depth” with one eye closed

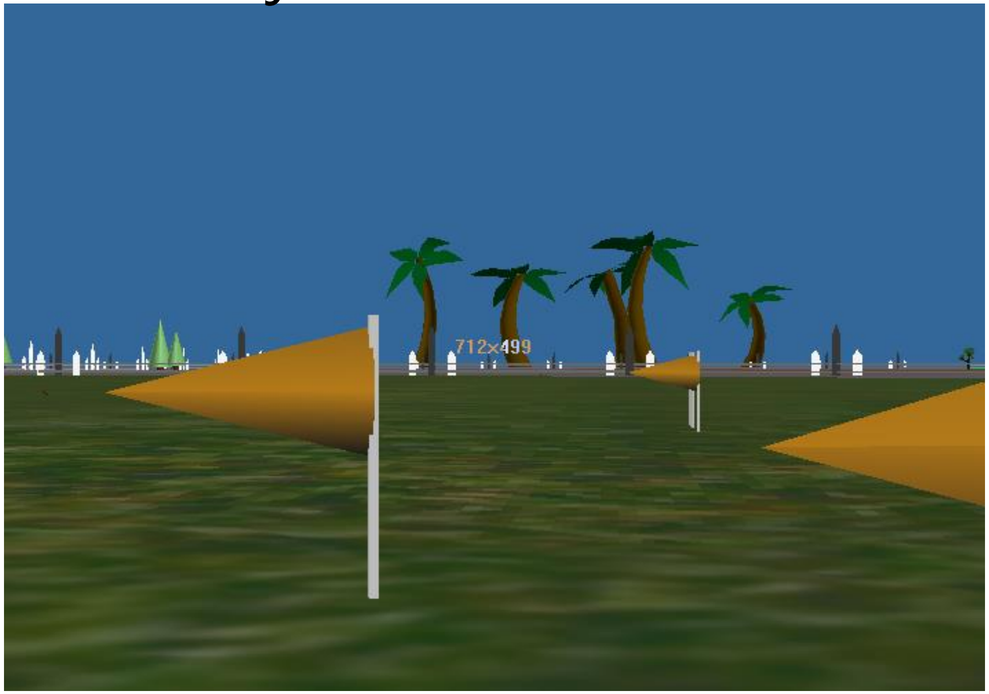
- Linear perspective
  - Objects get smaller the further away they are and parallel line converge in distance.
- Size of known objects
  - We expect certain object to be smaller than others.
- Detail (texture gradient)
  - Close objects appear in more detail, distant objects less.
- Occlusion (hidden surfaces)
  - An object that blocks another is assumed to be in the foreground.
- Lighting and Shadows
  - Closer objects are brighter, distant ones dimmer. Shadow is a form of occlusion.
- Relative motion (motion parallax due to head motion)
  - Objects further away seem to move more slowly than objects in the foreground.

Perspective

- The observance that parallel lines converge at a single vanishing point.
- Relies on the assumption that the object being viewed is constructed of parallel lines, such as most buildings.

Size

- Compare the size of objects with our memory of similar objects to approximate how far away the object is from us.
- Comparing the size of objects with respect to other objects of the same type to determine the relative distance between objects.



Detail

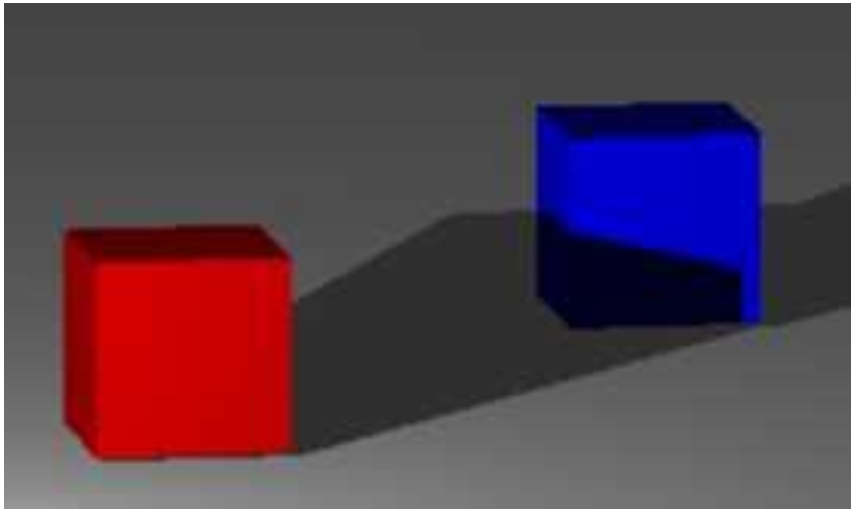
- Our eyes cannot discern as much detail of a texture at a distance as compared with up close.
- Atmospheric effects, such as haze and fog, cause more distant objects to be visually less distinct.

Occlusion

- An object occludes our view of another
- The strongest depth cue

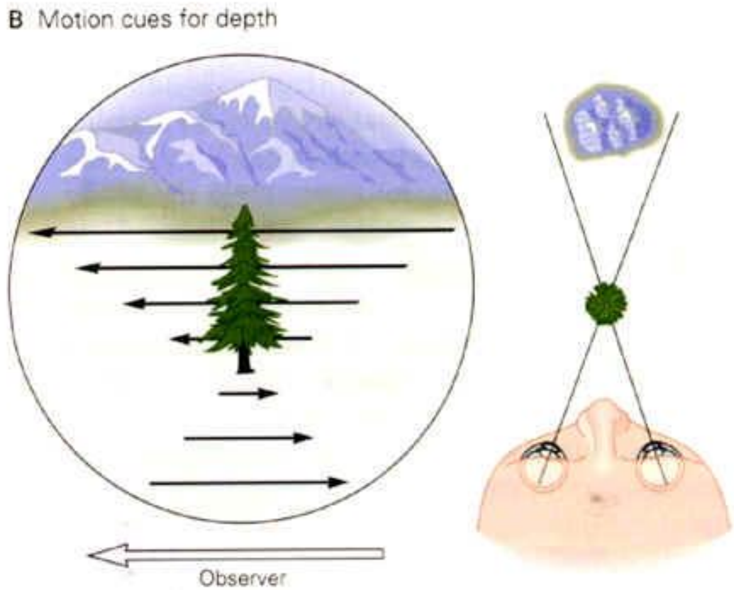
Lighting and Shadow

- Brighter objects are perceived as being closer.
- With one source of light, all shadows lie in same direction.
- The object covered by the shadow is perceived to be further away than the object in the light.
- A form of shading that indicate the positional relationship between two objects.



Motion Parallax

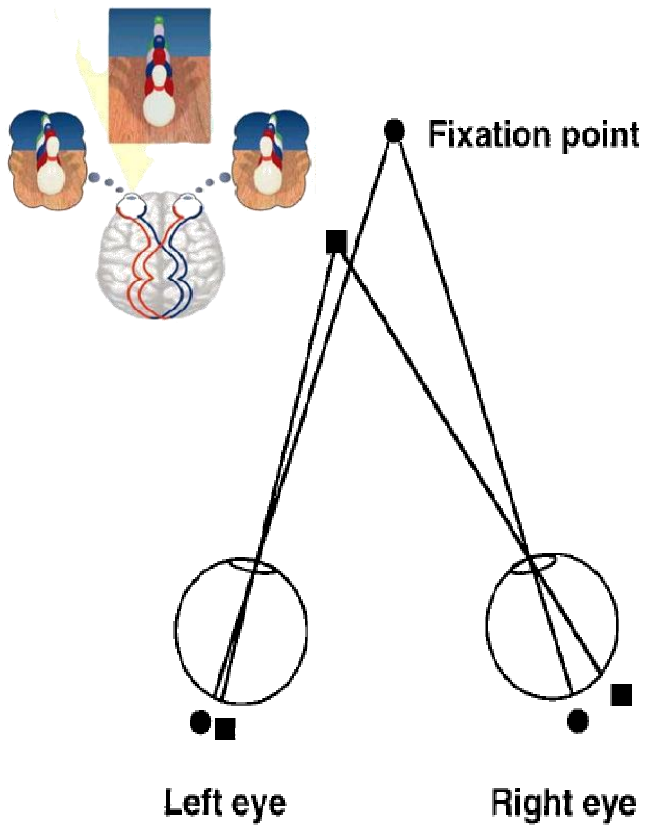
- As an observer moves, nearby objects appear to move rapidly while far objects appear to move slowly.
- Come from the parallax created by the changing relative position between the head and the object being observed.
- Generally more important than stereoscopy for VR.



Visual Depth Cues
- Using both eyes

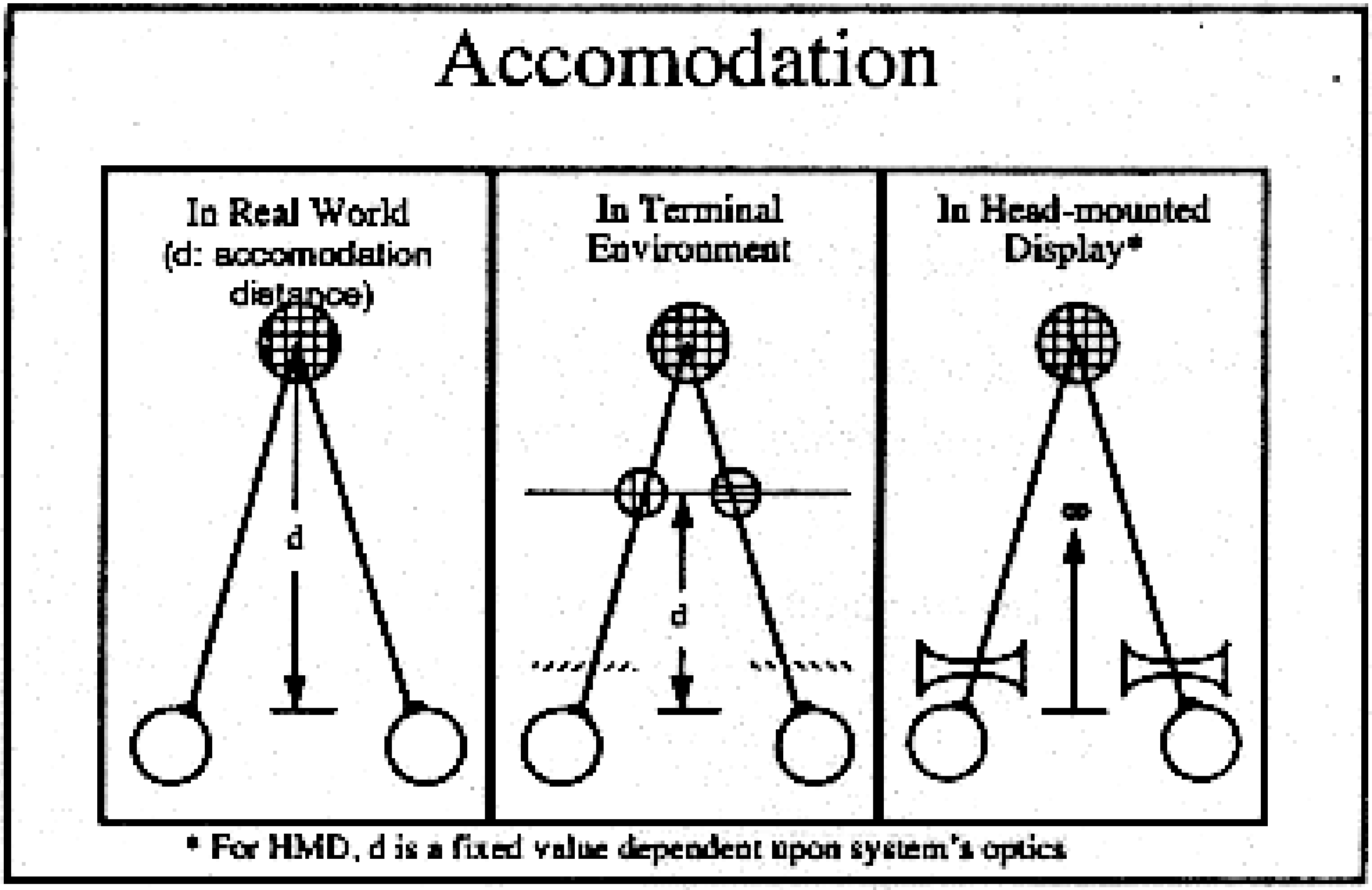
- Binocular cues: **binocular disparity (stereopsis)**
  - This is the difference in the images projected onto the back of the eye (and then onto the visual cortex) because the eyes are separated horizontally by the interocular distance.
- Oculomotor cues: **accommodation & convergence**
  - Based on information from muscles in the eye
  - Accommodation (focus)
    - This is the muscle tension needed to ***change the focal length*** of the eye lens in order to focus at a particular depth.
  - Convergence
    - This is the muscle tension required to ***rotate each eye*** so that it is facing the focal point.
  - Accommodation and Convergence work together (when eyes converge to a certain distance, automatically accommodates and vice versa)

Stereoscopy

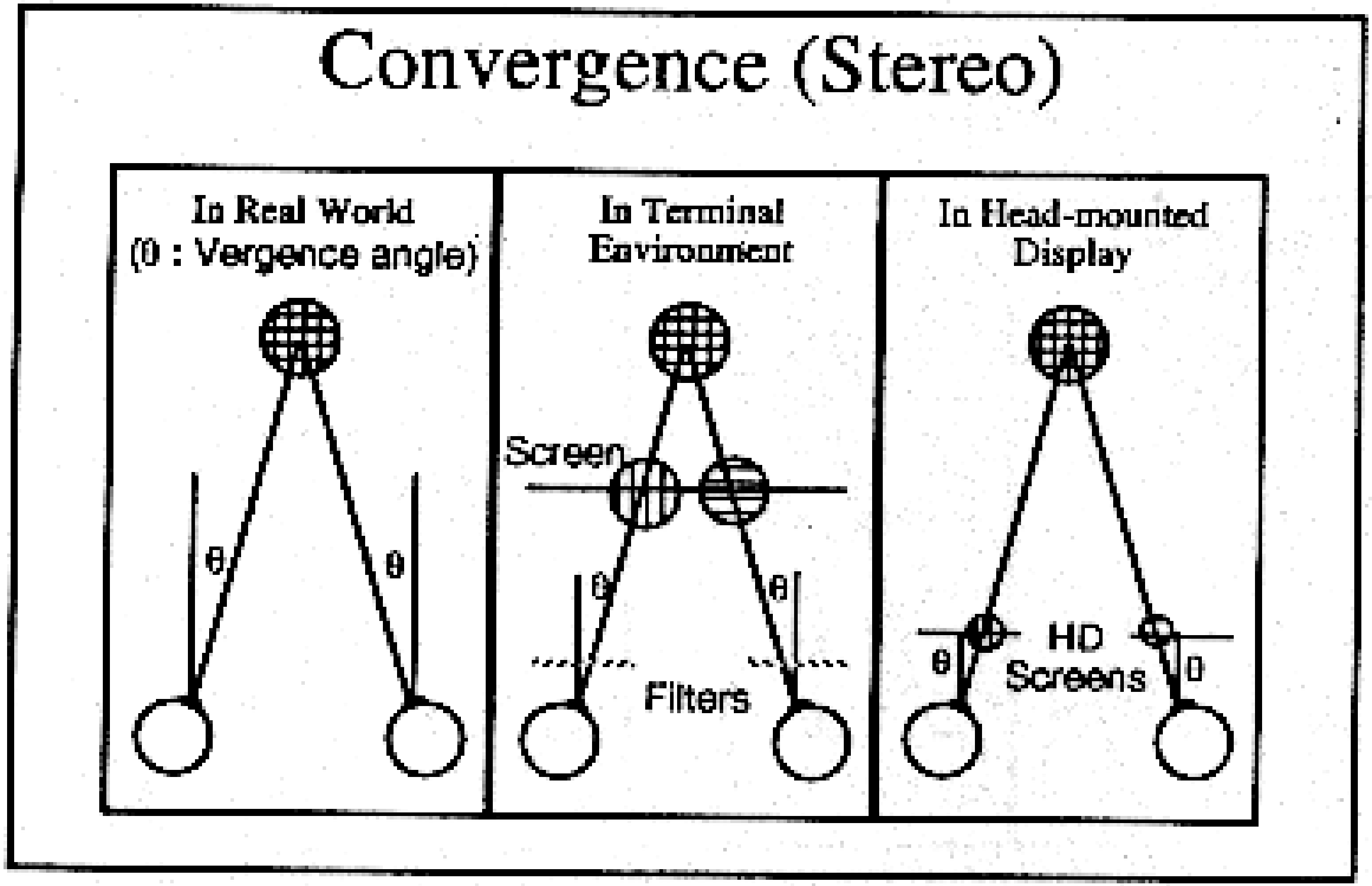


- Binocular vision occurs when two eyes look at the same thing at a slightly different angle, resulting in two slightly different images.
- The brain must match points between the two separate images seen by the two eyes.
- The slight difference between the viewpoints of your two eyes is called binocular disparity
- Stereopsis is depth perception due to binocular disparity
- Possibly 12% of people have no stereo vision or some problem with stereo vision.

Accommodation (focus)



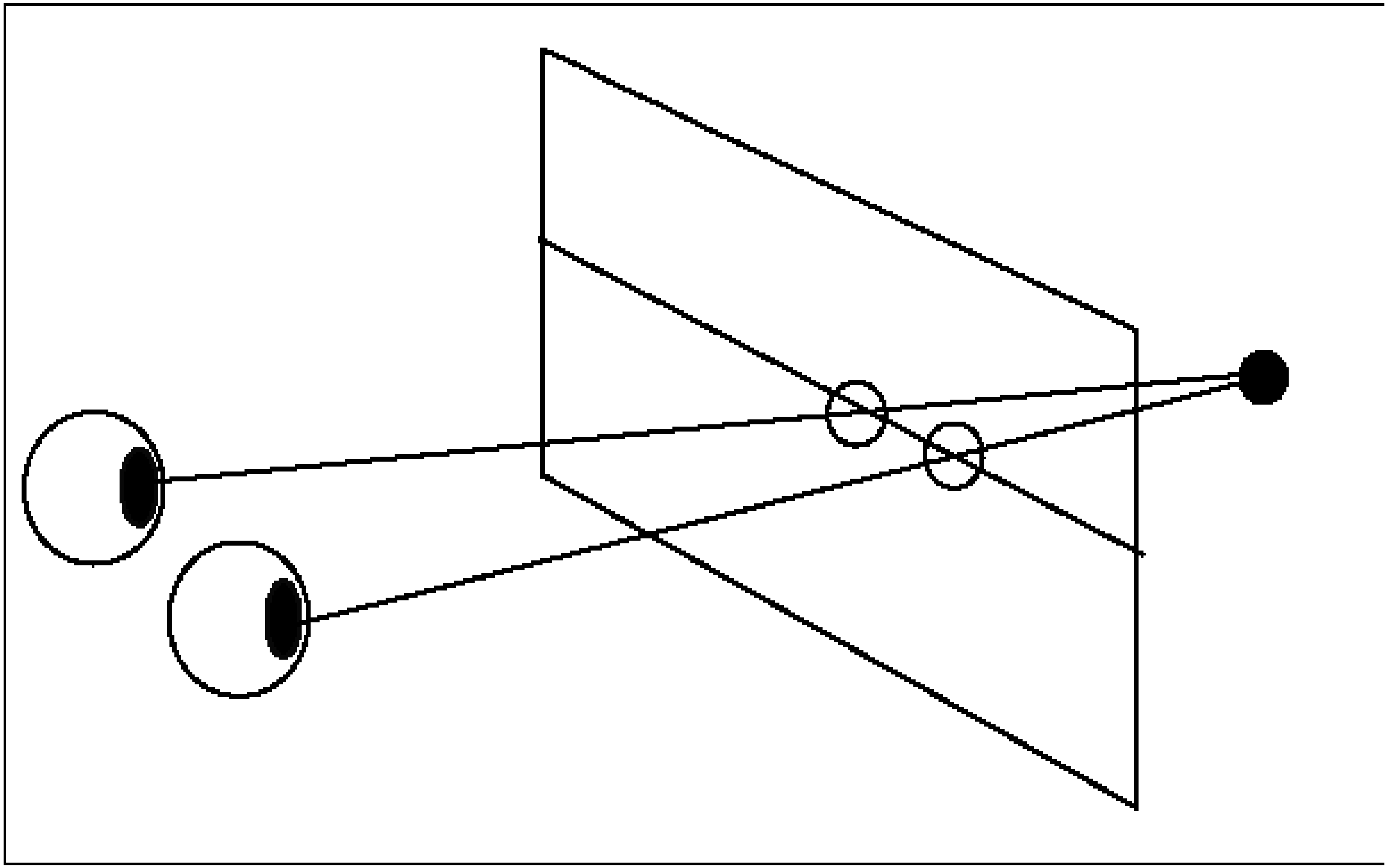
Convergence



Some Terminology

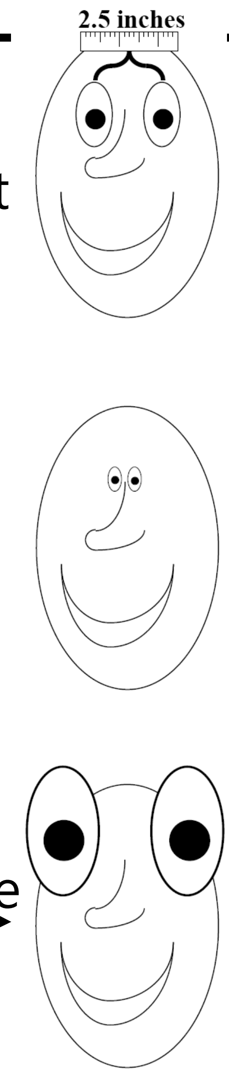
- Horizontal Parallax (Binocular Disparity)
  - When the retinal images of an object fall on disparate points on the two retinas, these points differ only in their horizontal position.
  - The value given by R – L
- Stereo Window (Stereo Plane)
  - The point at which there is no difference in parallax between the two eye views
  - Usually at the same depth as the monitor screen or the projection surface.
- Homologous Points
  - Points which correspond to each other in the separate eye views.
- Vertical Displacement
  - Vertical parallax between homologous points relative to the line that the two eyes form.

Homologous Points



Some Terminology

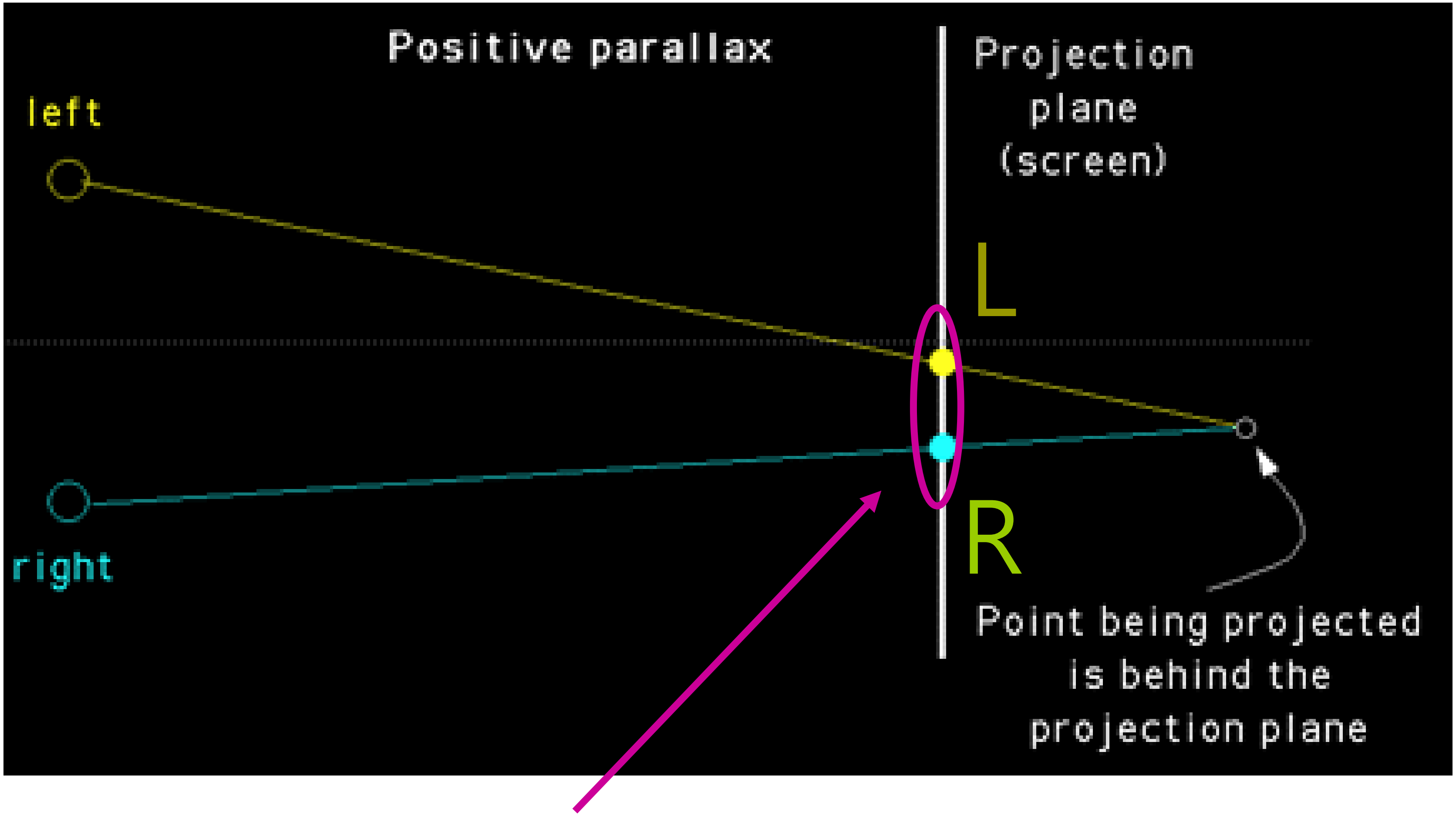
- Interocular Distance
  - The distance between the left and right eyes, usually about 2.5 inches (i.e., 6.5 cm)
- Hypostereo/Giantism
  - Decreasing the distance between the left and right eyes to show stereoscopic detail on small items
- Hyperstereo/Lilliputism
  - Increasing the distance between the left and right eyes to show stereoscopic detail in large scenes
- Interocular Crosstalk (Ghosting)
  - Each eye should only see it's view but sometimes it can see part of the other eye view as well. This is distracting and causes eye fatigue.



Some Terminology

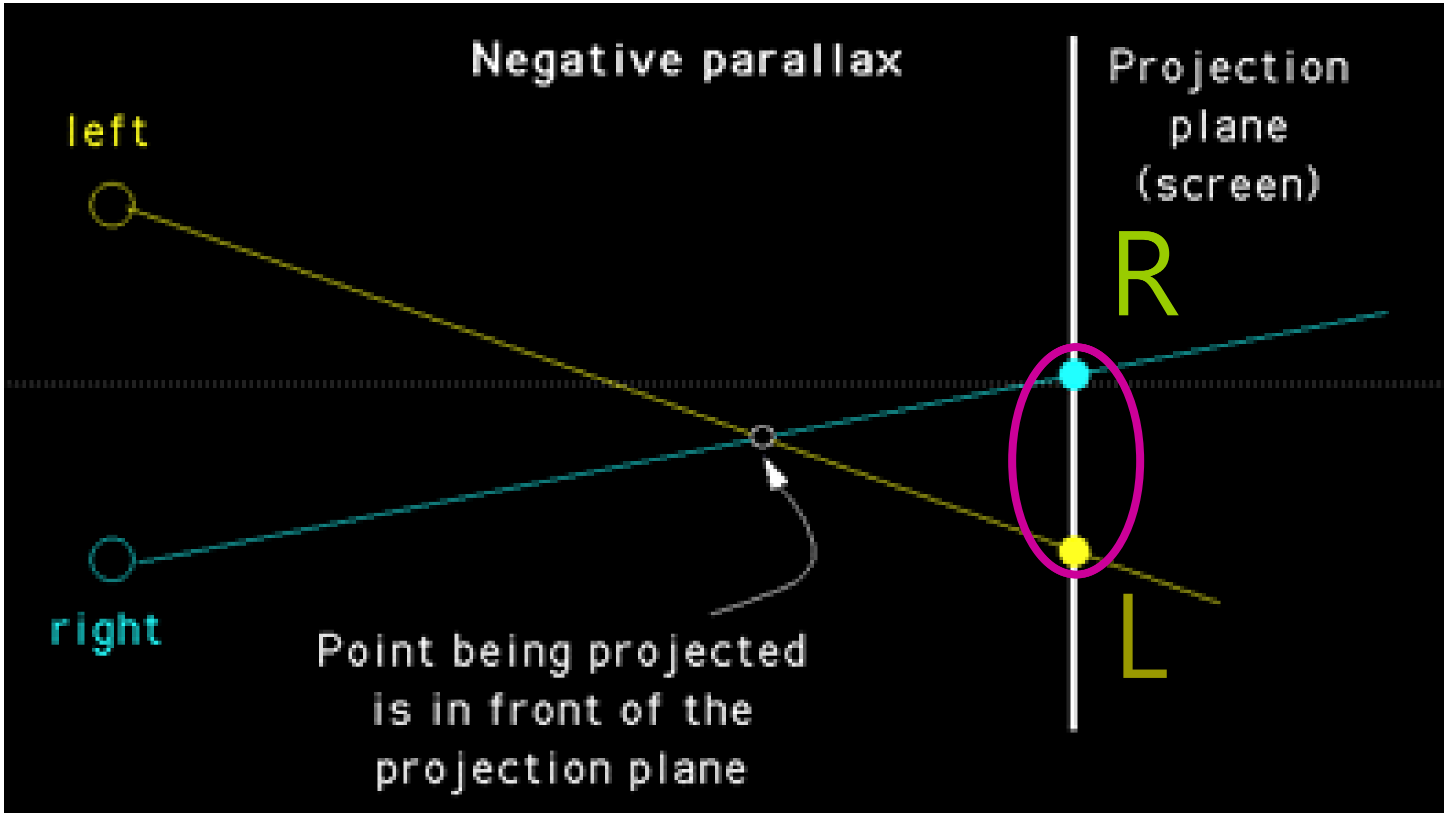
- Positive Parallax
  - The point lies behind the stereo window (On the opposite side from the observer)
- Negative Parallax
  - The point lies in front of the stereo window (On the same side as the observer)
- Zero Parallax
  - The point is at the same depth as the stereo window (Both eyes see the same image)

Positive Parallax
Accommodation-convergence mismatch



The left and right eye images projected on the screen

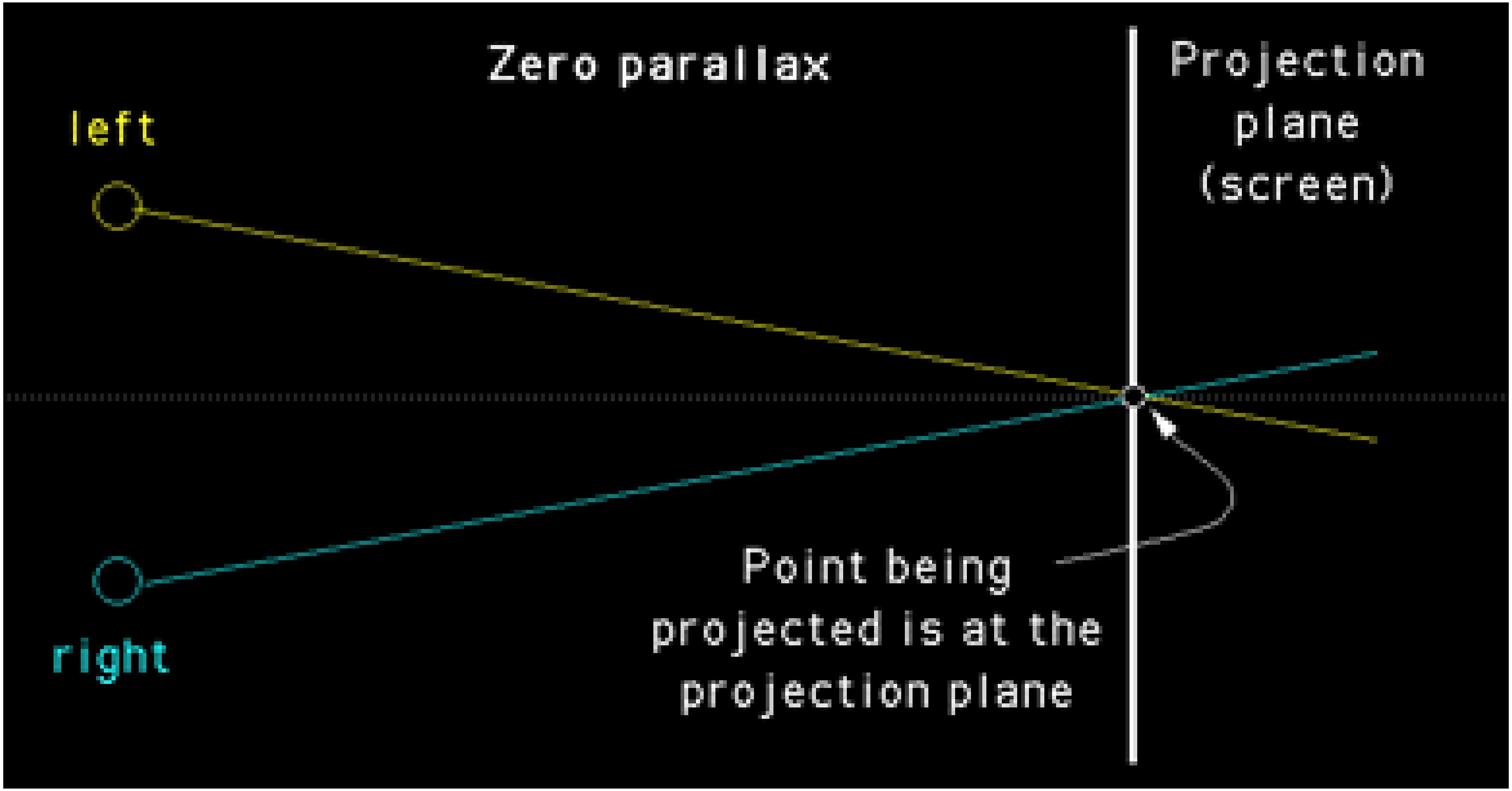
Negative Parallax
Accommodation-convergence mismatch



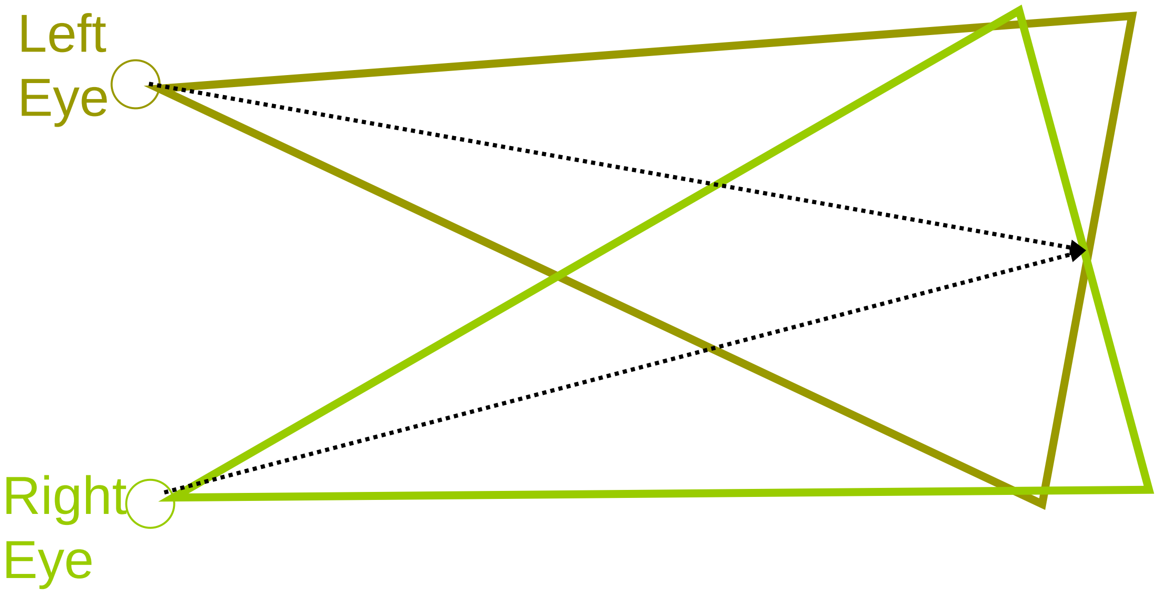
- If objects are too close in front of the projection plane, negative parallax will increase.
- If negative parallax is wider than eye separation, then result is pain.

Zero Parallax

When the object is actually on the screen

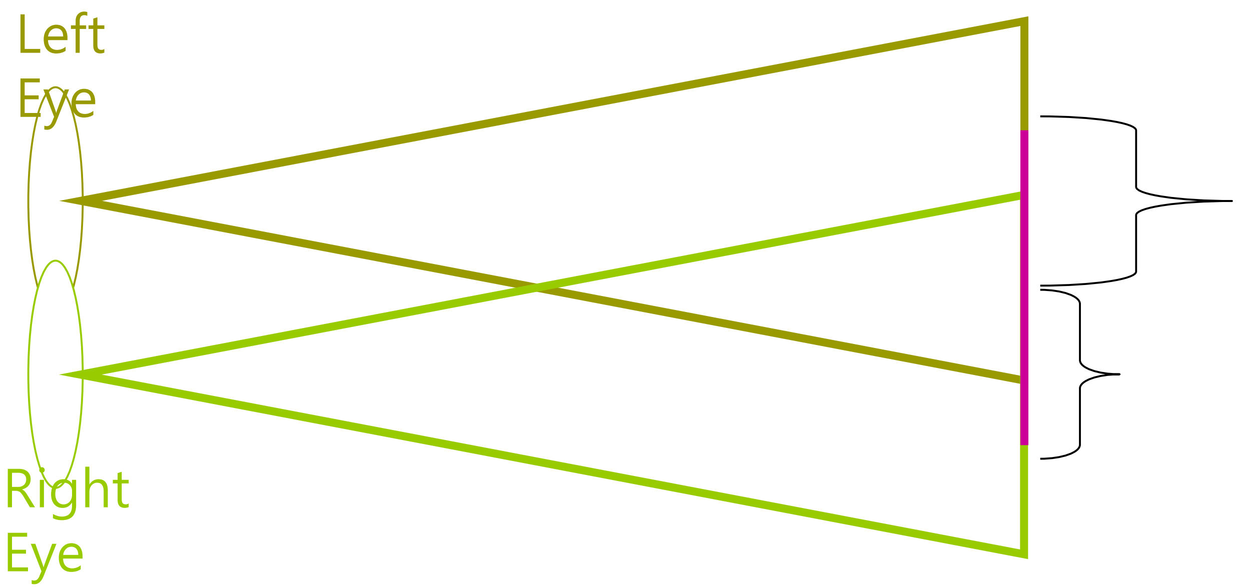


Stereo Approximation



Viewing a point in a scene from two difference camera positions produces differing view planes

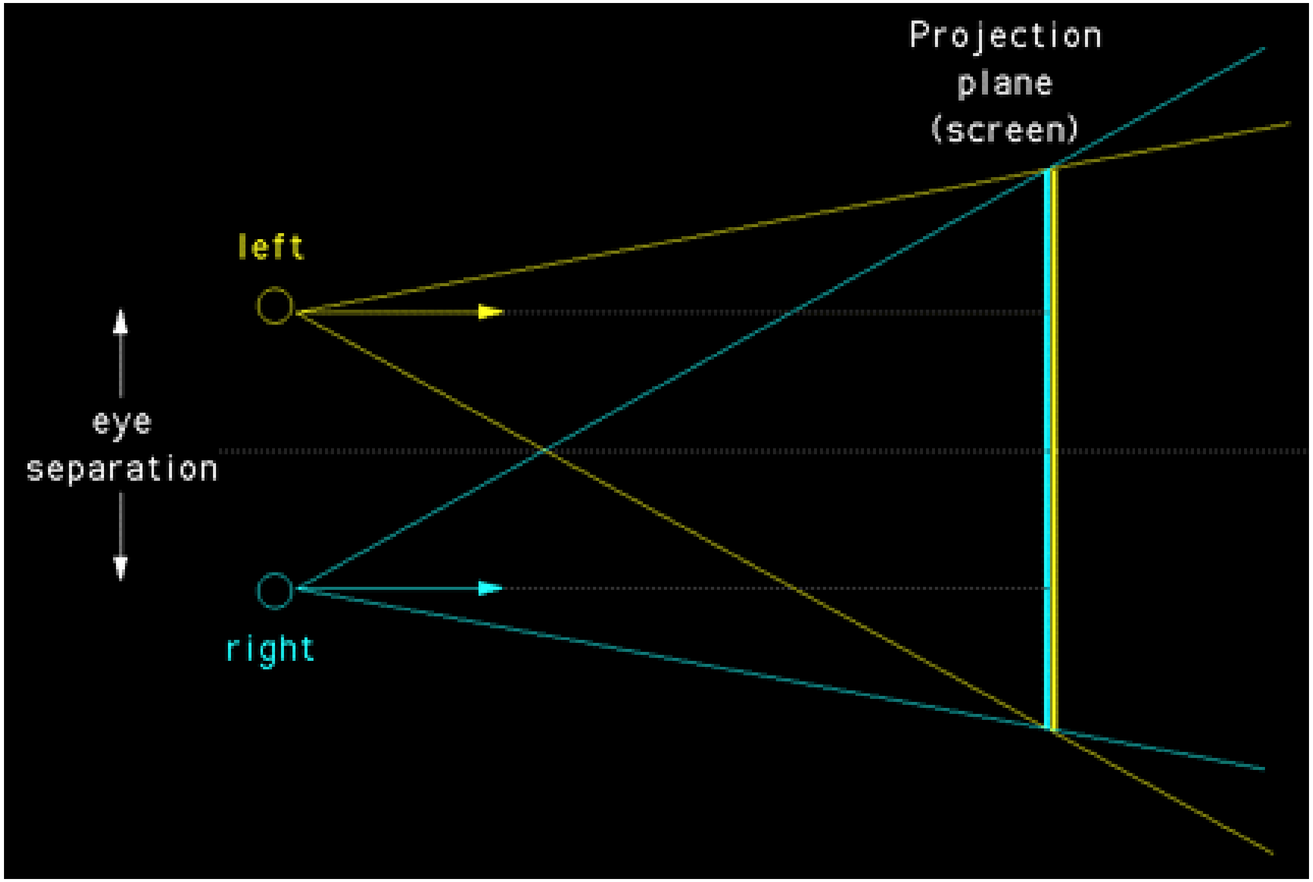
Stereo Approximation



Using parallel views (i.e., symmetric view frustums) produces a single view plane, but images must be trimmed to area of overlap - Projection Planes are not the same

- Some software (e.g. Blitz3D) does not have an easy way (yet) to create asymmetric view frustums.
- There is potential for eye discomfort for objects that are too close because an object may appear to be cut off at the edges for one of the eyes.
- Enlarging eye separation makes the problem worse.

Correct Stereo Computer Graphics

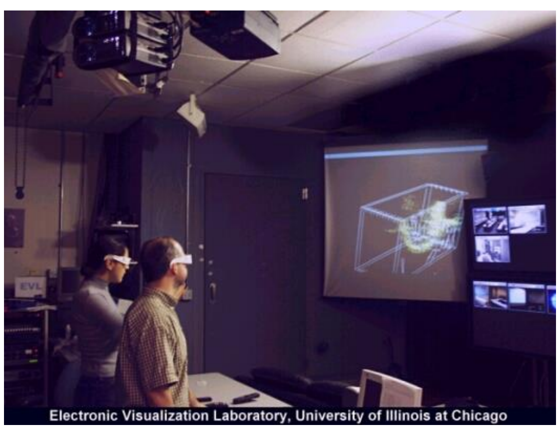


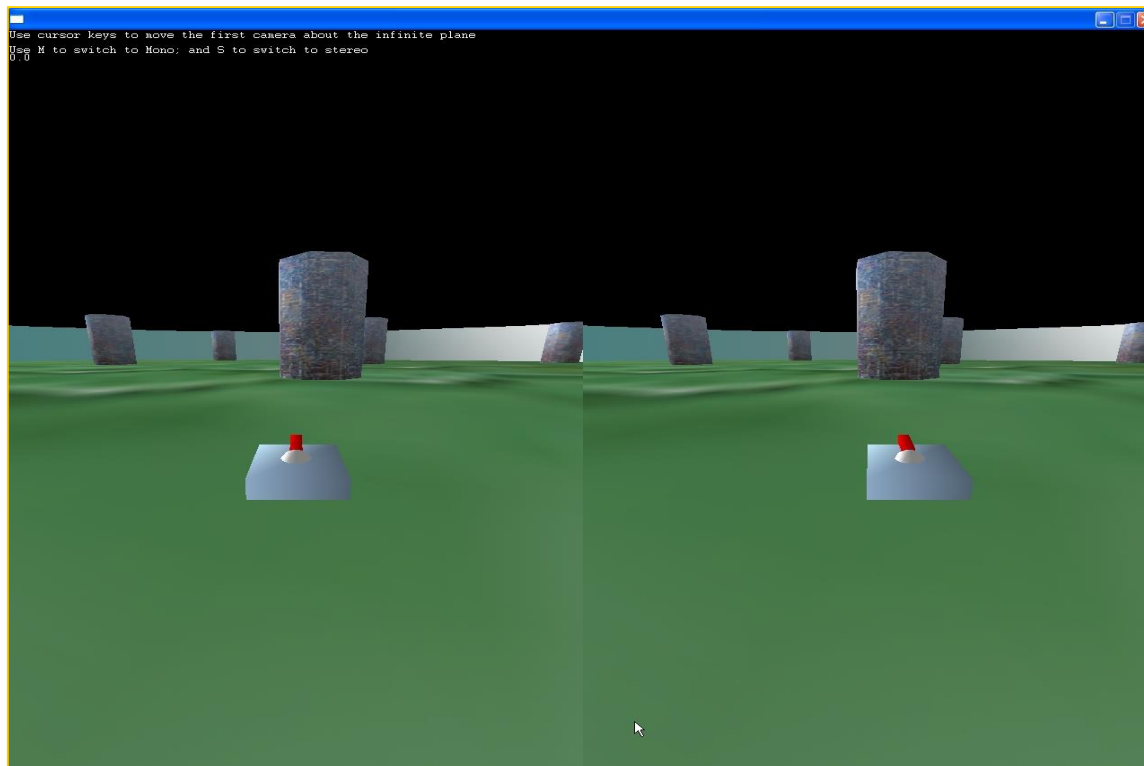
Asymmetric View Frustum

The correct approach using **parallel views and asymmetric view frustrum** produces a single viewplane and overlapped image

Stereo Images on the GeoWall

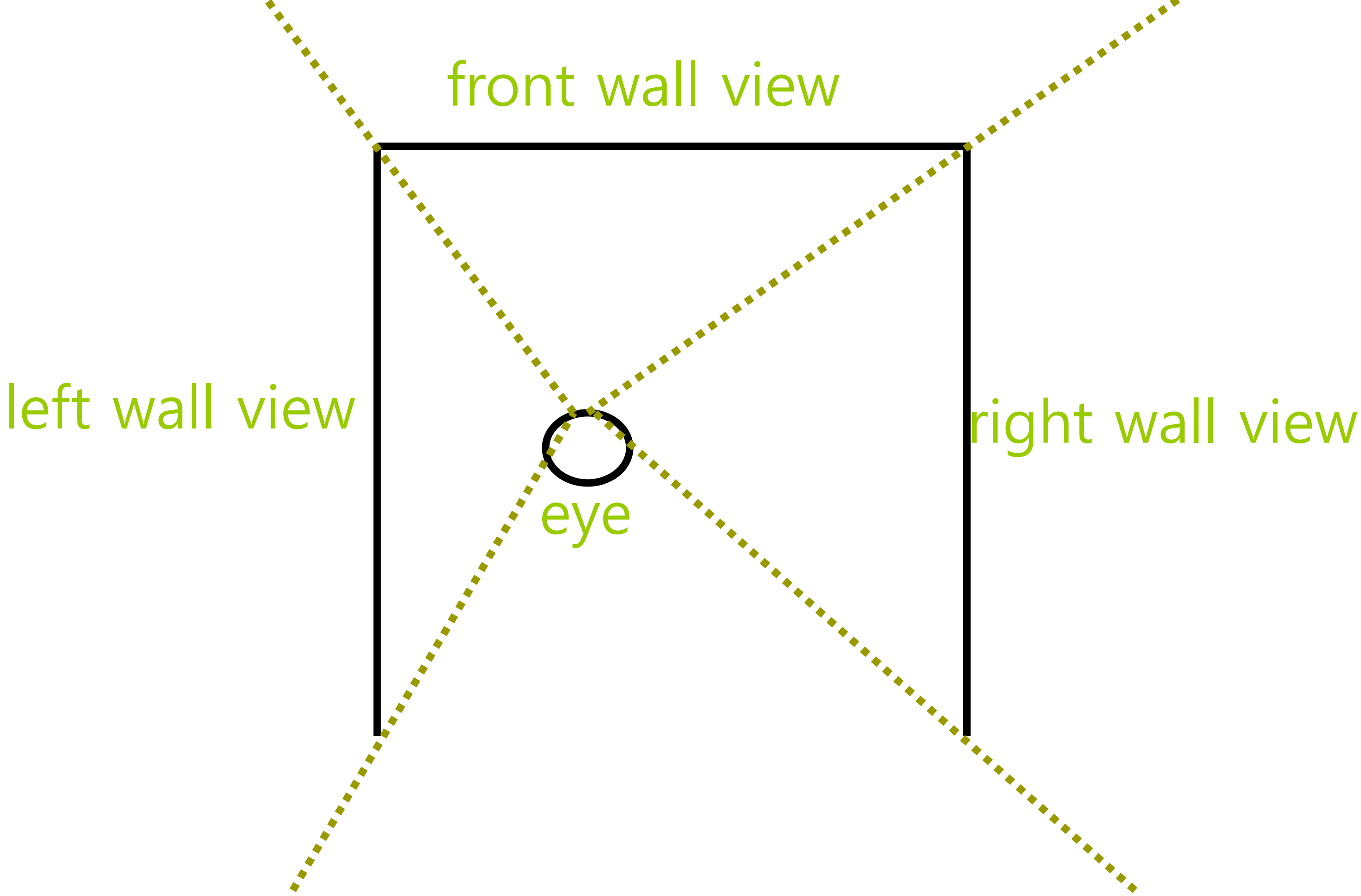
- Creates 1 wide window 2048x768 and creates 2 viewports (1 for left eye image, 1 for right eye image)
- Each viewport goes to 1 of the graphics card's outputs to a projector.


Electronic Visualization Laboratory, University of Illinois at Chicago

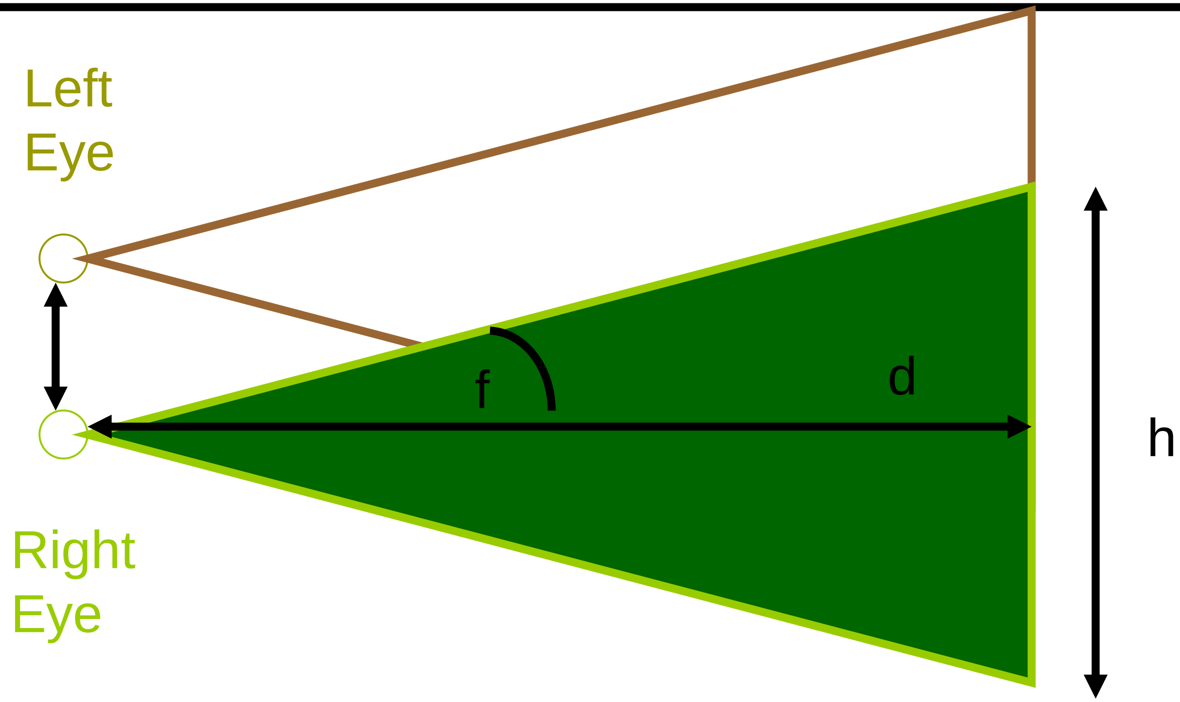


Off-axis Perspective Projection in a CAVE

In CAVEs, the view frustum will often fall off center.



Making the virtual world look true to size

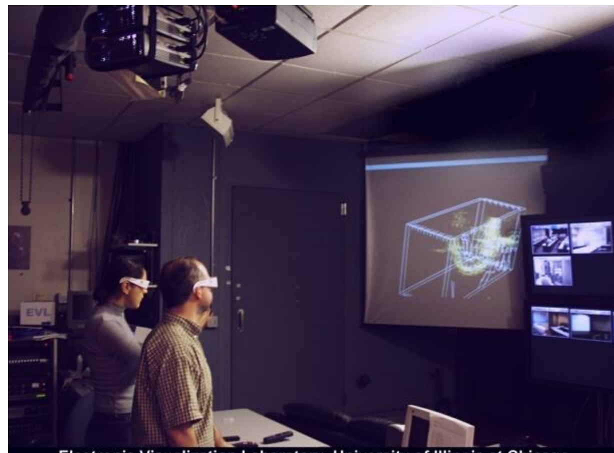


- Set camera properties to be the same as real world properties:
  - Set user's distance to screen (i.e. focal length d)
  - Measure the screen's height (h)
  - Compute the field of view (f = 2*atan(h/2d))
  - Use real world eye separation distance (2.5 inches)

How to Generate Stereo Images

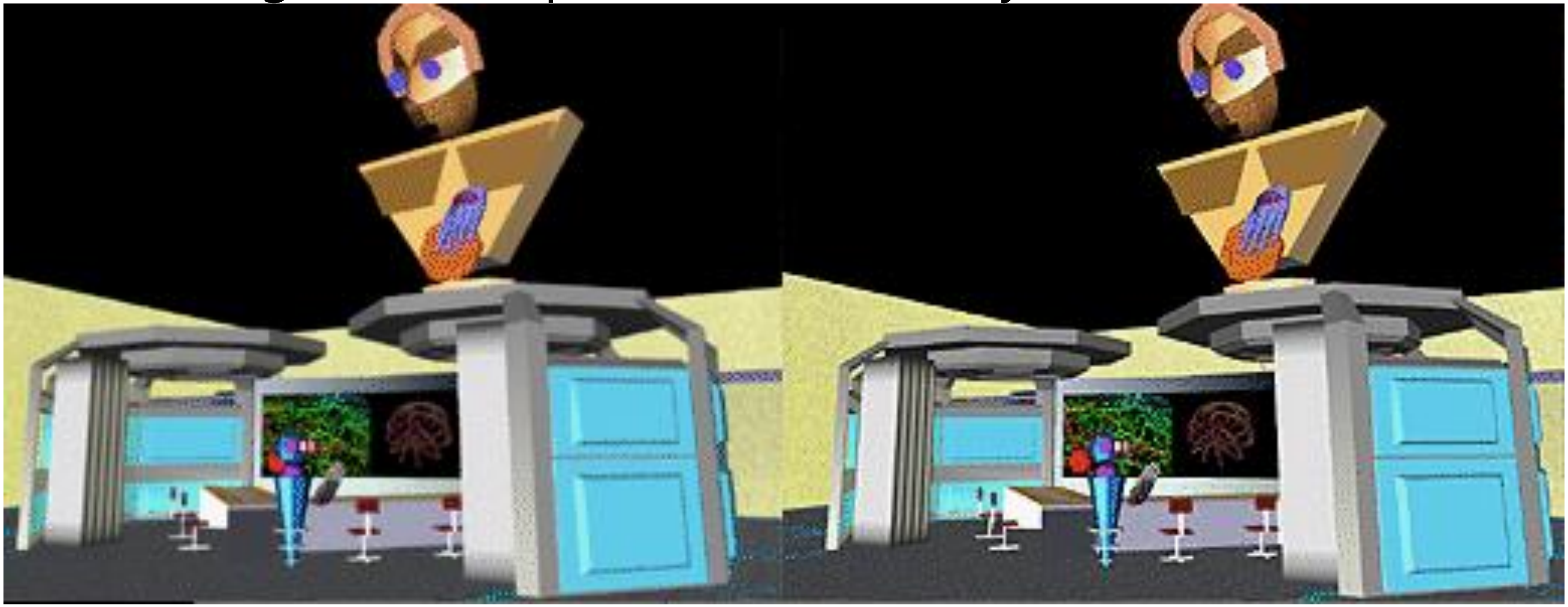
Present a distinct image to each eye:

- Free-viewing
- Optics (lenses)
- Chromadepth
- Pulfrich Effect
- Anaglyph (color)
- Polarization
- Active Shuttering
- Autostereo



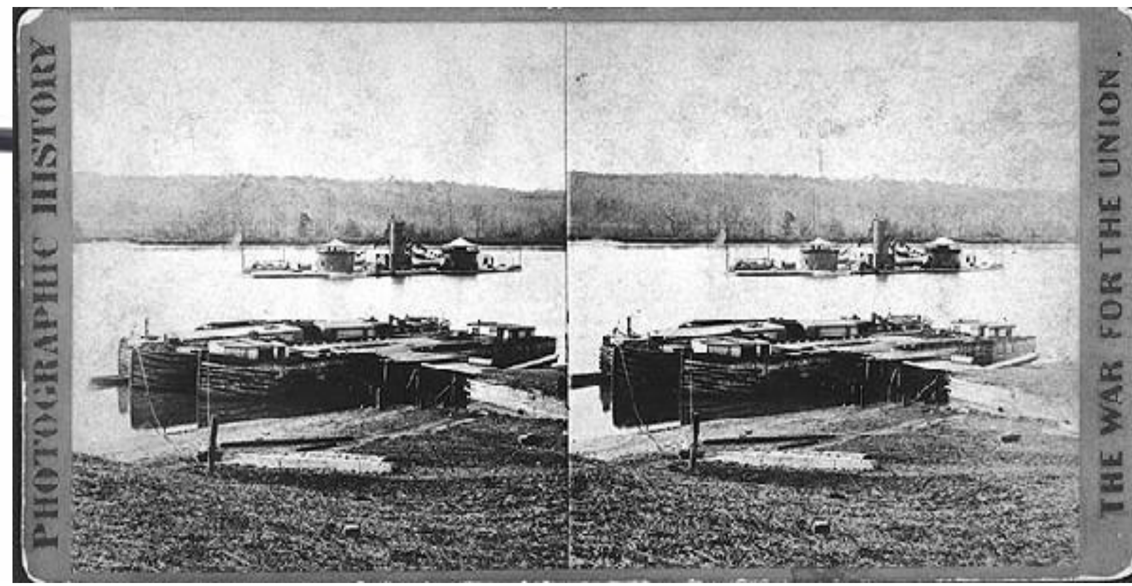
Free-viewing

- Two slightly different images are displayed next to each other.
- The viewer must focus his or her eyes properly to fuse the two images: either parallel or cross-eyed.



Optics

- Use lenses and physical separation, present a separate image to each eye.



Stereoscope, invented by Charles Wheatstone in early 1800s

Optics

Viewmaster™

Slidemaster

Optics

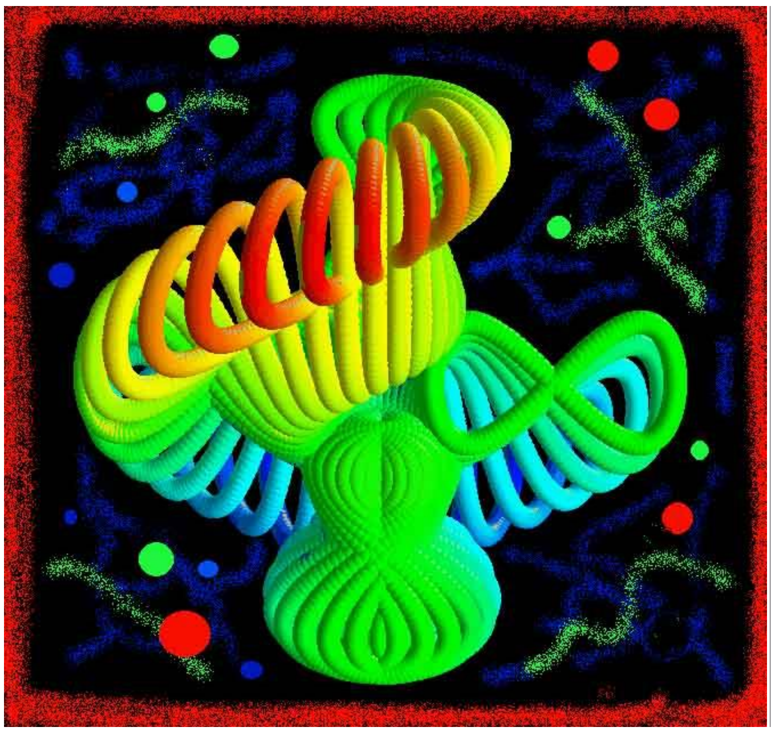
2 computer monitors: one for each eye

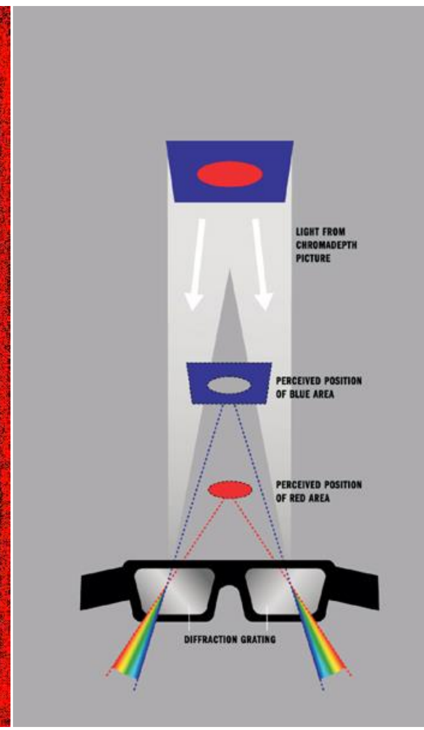
Head Mounted Display

BOOM

Chromadepth

- Special filters that cause different colors to appear at different depths.
- Red objects appear close; blue objects appear distant.





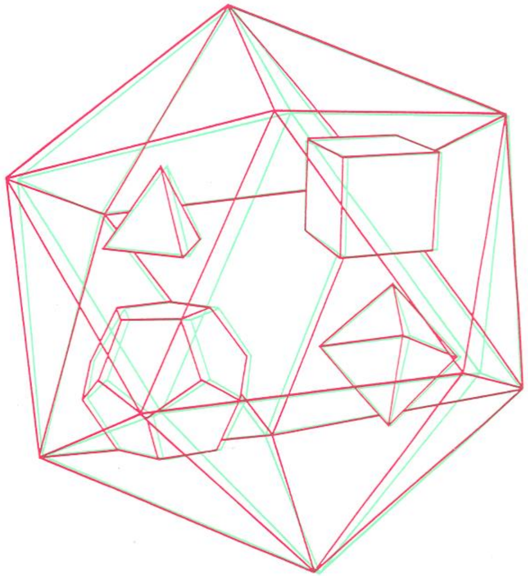
Pulfrich Effect

- Physiological effect discovered by astronomer, Carl Pulfrich.
- Pulfrich effect glass have one dark lens and one clear lens.
- Images viewed through a darkened lens reach the brain **slower** than those viewed through a clear lens.
- When something moves across the visual field, the brain fuses **two images from slightly different times**. Motion is thus converted into stereo parallax.

Pulfrich glasses as used on broadcast-TV

Anaglyph

- Colored filtered are used – one eye sees just **red** elements, other eye sees **blue (or green or cyan)** elements.
- The colored lenses make one image more visible to one of your eyes and less visible to your other eye.



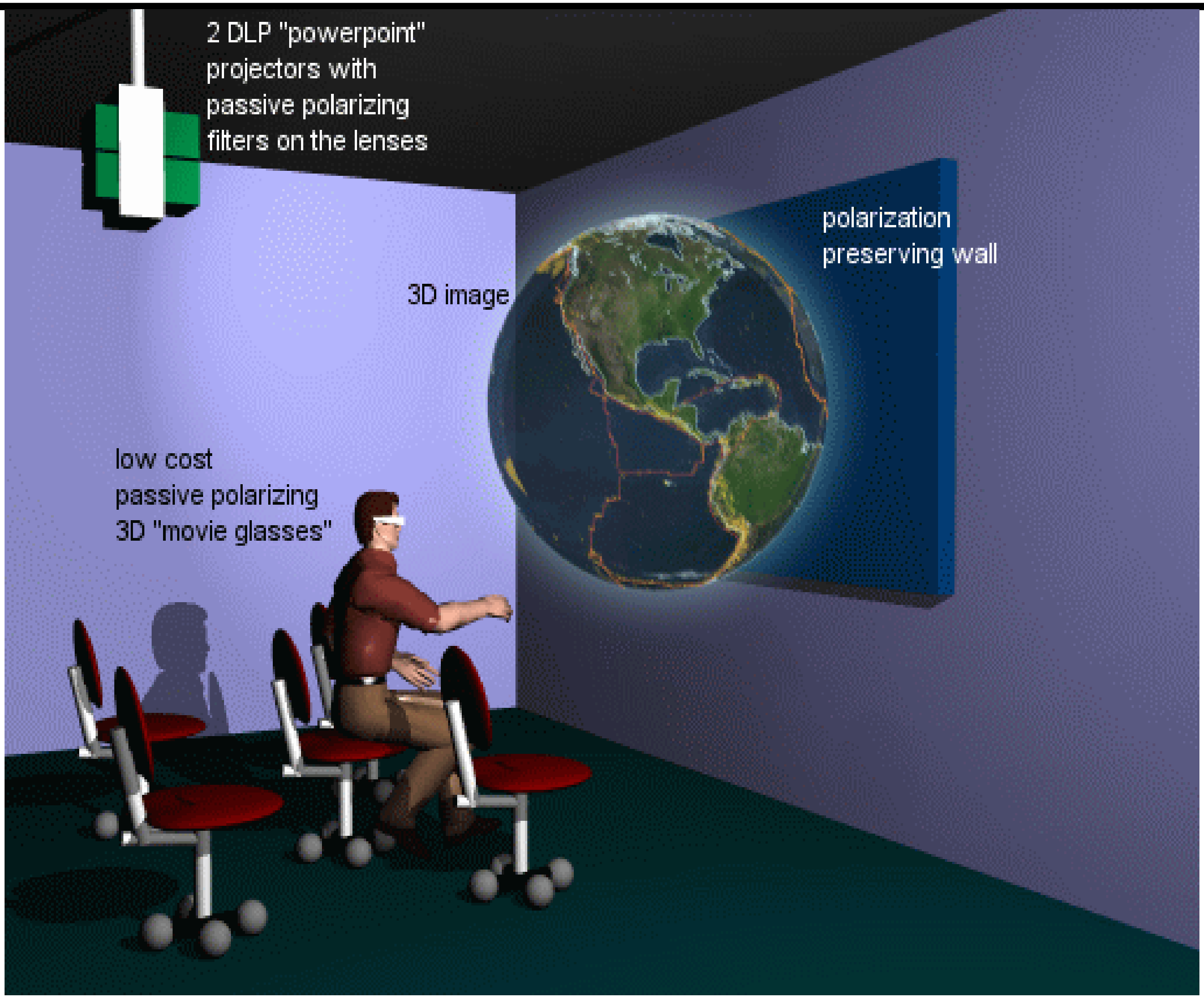
Anaglyph

- If you have a pair of red/cyan glasses and a correctly calibrated display then this image will become 3D.

Passive Polarization

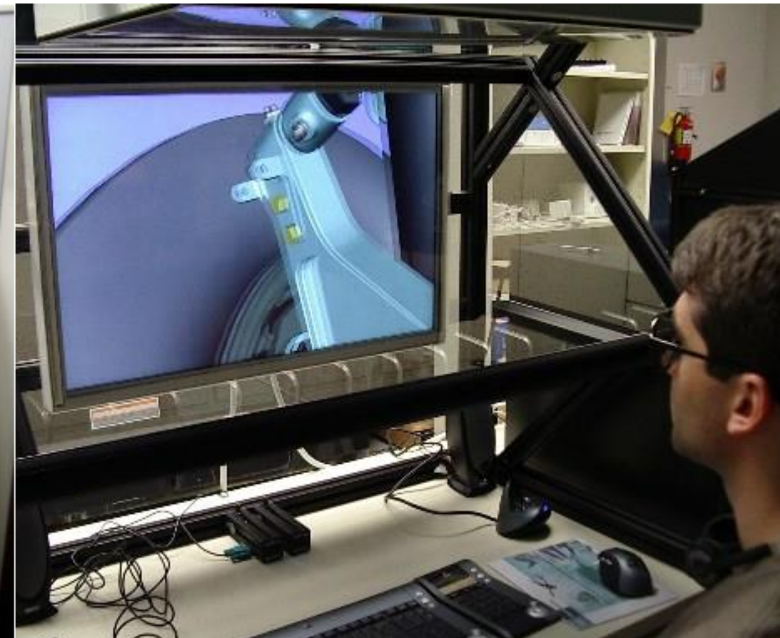
- Today we can also put polarizing material on the front of our flat panel displays in alternating the left and right eye images, so a single video (in color or B/W) can contain imagery for both eyes, though in half resolution each.

Passive Polarization



GeoWall
@EVL

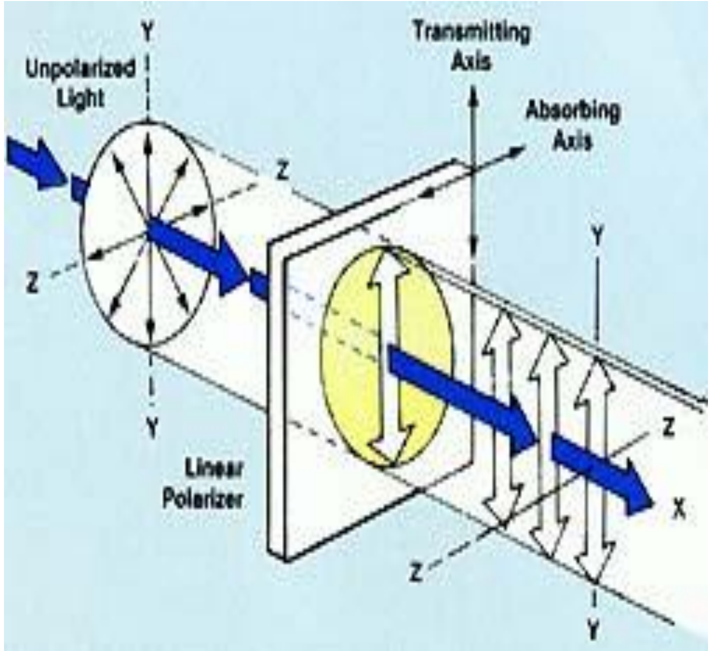
Passive Polarization



ImmeraDesk4@EVL
– Circular Polarization

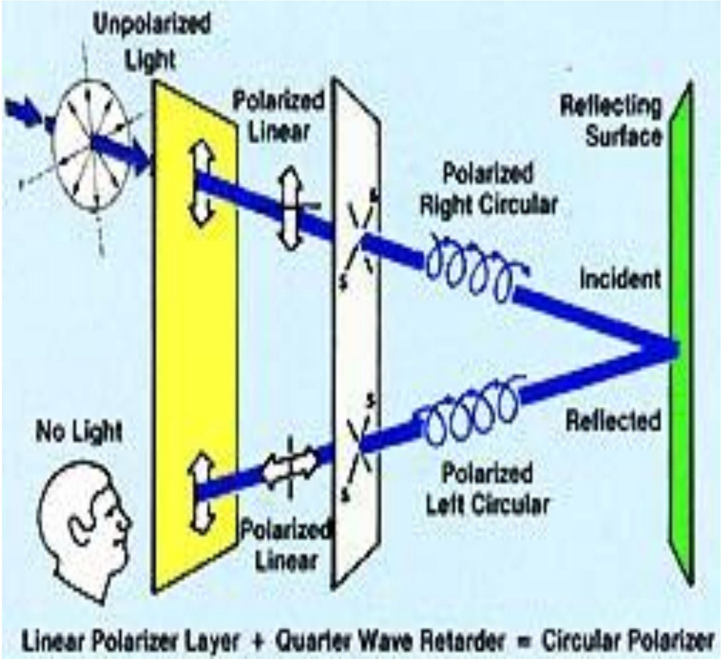
iDesk
– Linear Polarization

Linear Polarization



- A single “ray” of light has a particular polarization direction, perpendicular to direction of propagation.
- Ordinary light usually is polarized equally in all directions.
- A polarizing filter allows only light polarized a certain direction to pass through
- Less expensive.
- Problem: tilting the viewer’s head affects filtering and hurts stereo effect.

Circular Polarization



- Combining a linear polarizer and a quarter-wave retarder produces circular polarization.
- Circular polarization can be clockwise or counter-clockwise.
- Circular polarization is immune to the "head-tilt problem."
- Works better because light is circularly polarized.
- Problem: Many project screen materials de-polarize light; mirrors can also de-polarize light, at larger angles of reflection; LCD projects polarize light internally (green one way, red & blue another way)

Active Shutter Glasses

- Glasses have liquid crystal lenses which can be darkened & cleared rapidly - at any time one lens is clear and one is dark.
- Glasses are synchronized with video display - one eye sees odd frames, other eye sees even frames.
- Requires fast video refresh rate (> 90Hz) to prevent flicker.
- LCD projects are not capable of high frequencies. Affordable DLP projectors not programmed to support high frequencies.

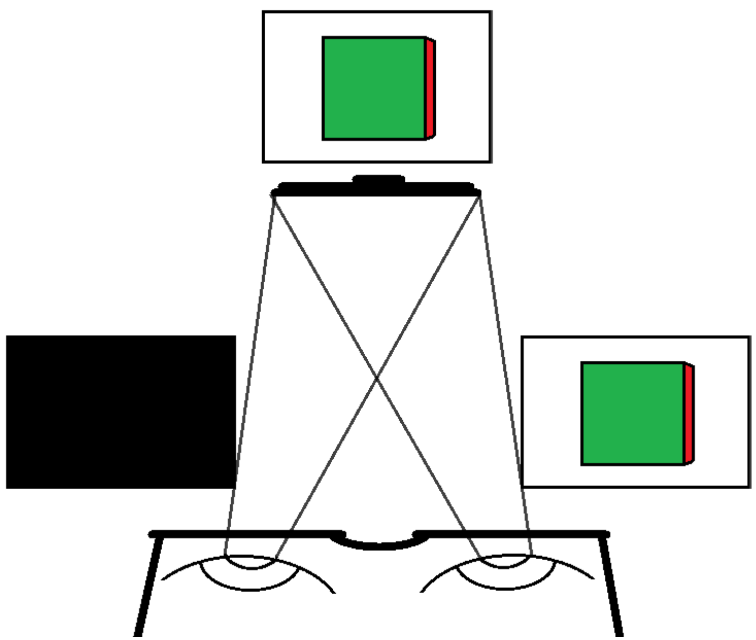
Active vs Passive 3D TV

- Active 3D was first widely introduced in 2010 by most TV makers, while passive 3D widely debuted in 2011. In 2017, 3D TVs are all but gone.
- A 3D TV uses either active or passive 3D.

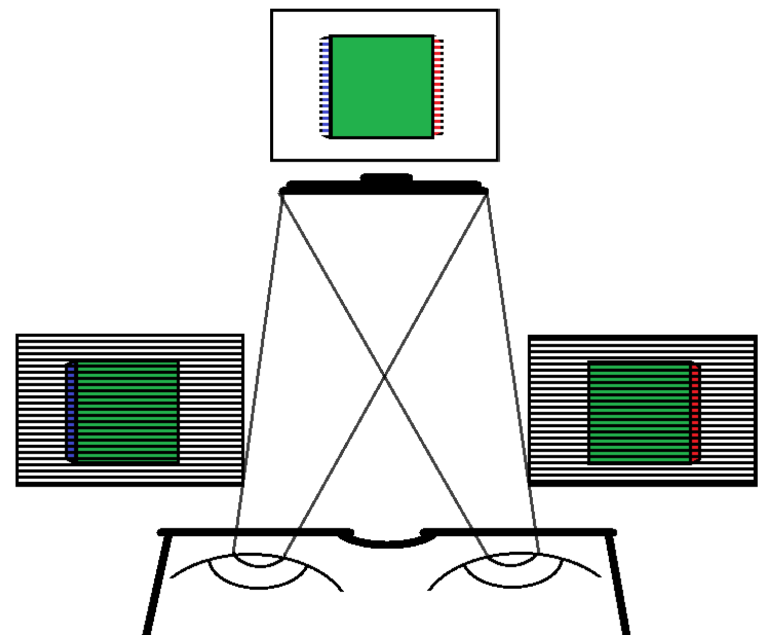
	Active shutter 3D TV	Passive 3D TV
Crosstalk	Poor	Decent
Resolution	Great	Good
Brigthness	Poor	Poor
Motion	Mediocre	Great
Comfort	Flickering can cause hea daches	Great
Availability	Rare	Rare
Glasses	Expensive, require batter ies	Inexpensive, no batteries required

http://www.rtings.com/tv/learn/3d-tvs-active-3d-vs-passive-3d
https://www.cnet.com/news/cnets-guide-to-3d-tv-what-you-still-need-to-know/

Active vs Passive 3D TV



Active Shutter 3D



Passive Polarization 3D

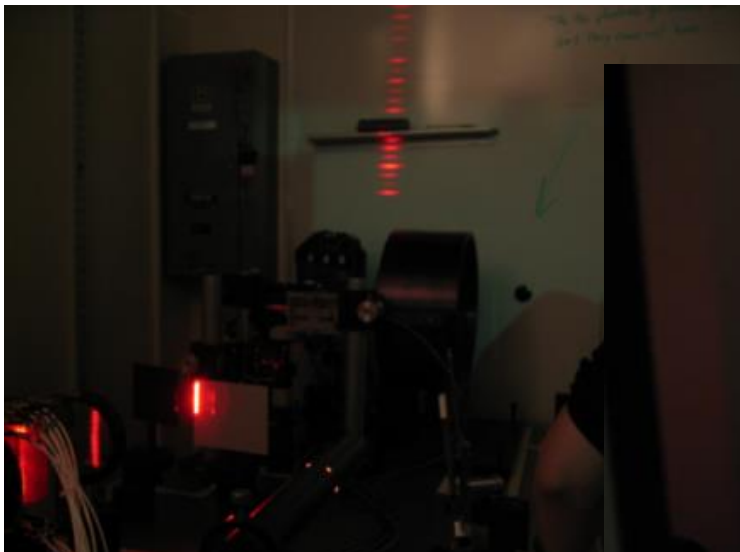
http://www.rtings.com/tv/learn/3d-tvs-active-3d-vs-passive-3d

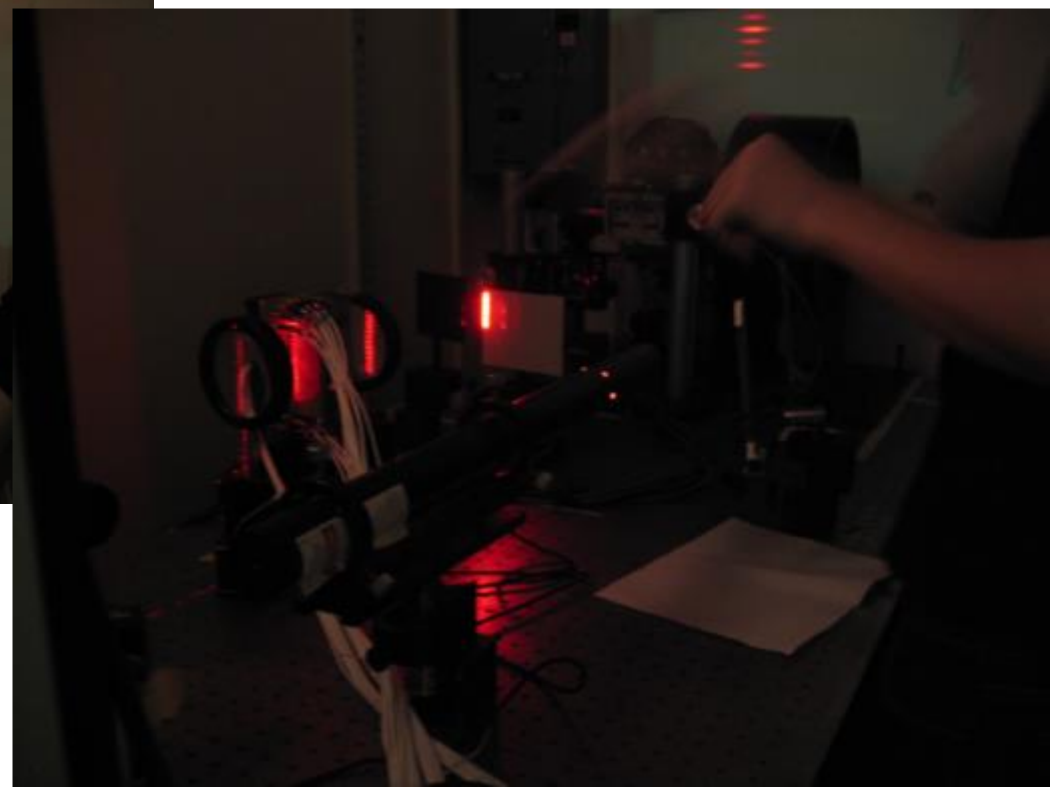
Autostereo

- Glass-free stereo
  - Image broken into sets of vertical strips. Each set is a different eye-view
- Autostereoscopic
  - Parallax barrier: Barrier strip (PHSCologram, Synthagram, etc) separate layer with strips that block all but one image from any viewpoint
  - Lenticular: lens like stripes
  - Lenslet: Integral photograph or integram
- 3D displays
  - Hologram
  - Volumetric
  - Stereoscopic: Active stereo, Passive stereo, Autostereoscopic

Hologram

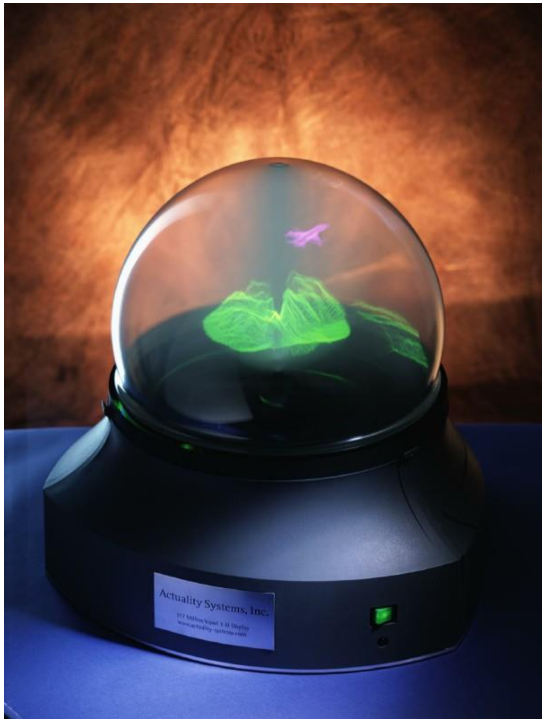
- MARK-II @ MIT Media Lab (2004)





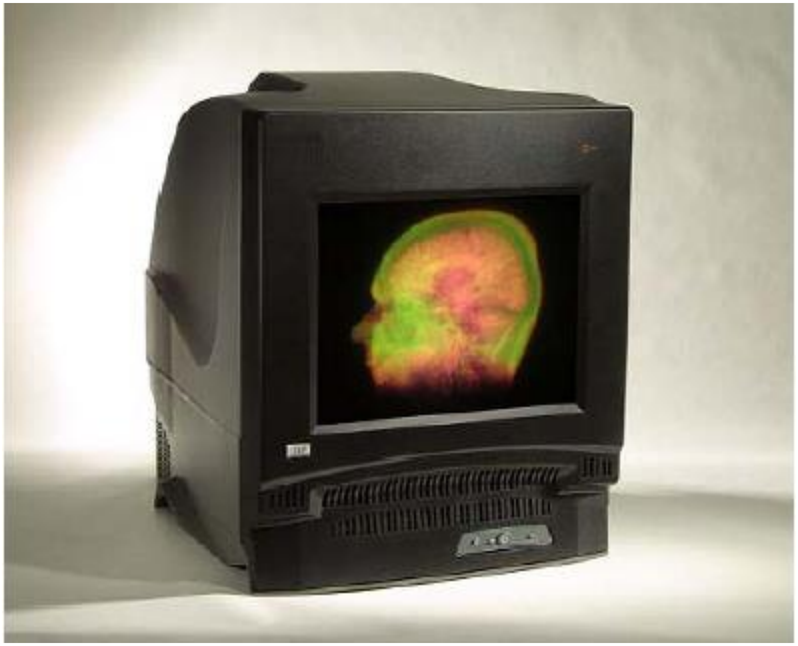
Volumetric Display

- Spinning Screen Display



Actuality Systems

- Slice-Stacking Display



LightSpace Tech

Autostereo 3D Display

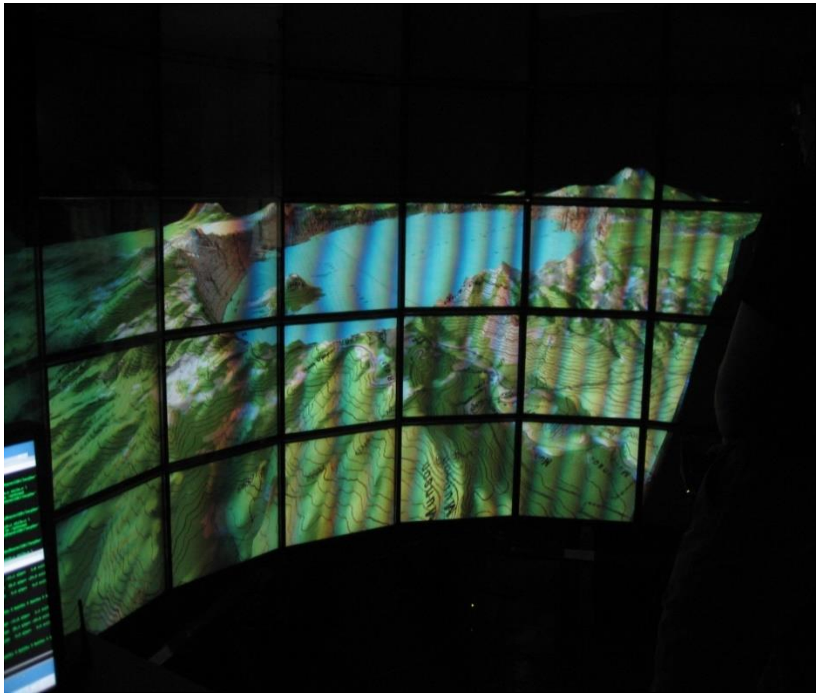
Pavonine, 17"/19" Dimen
-Backlight switchable barrier

Philips, 42" WOWvx 42-3D6C01
-Lenticular, support for multiusers

Sharp, Actius RD3D Notebook
-Backlight switchable barrier

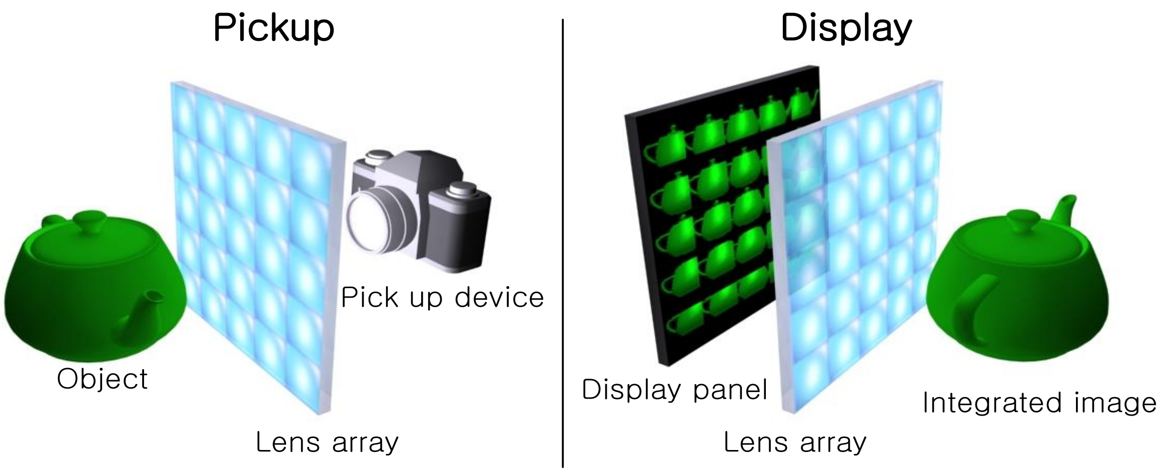
Autostereo 3D Display

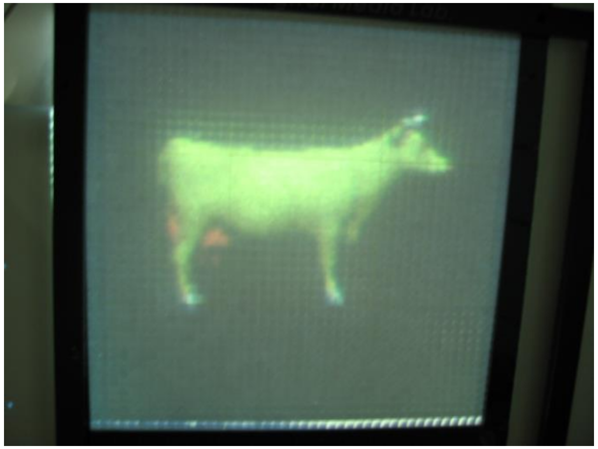
- Varrier Tiled Auto-Stereoscopic LCD Display



Autostereo 3D Display

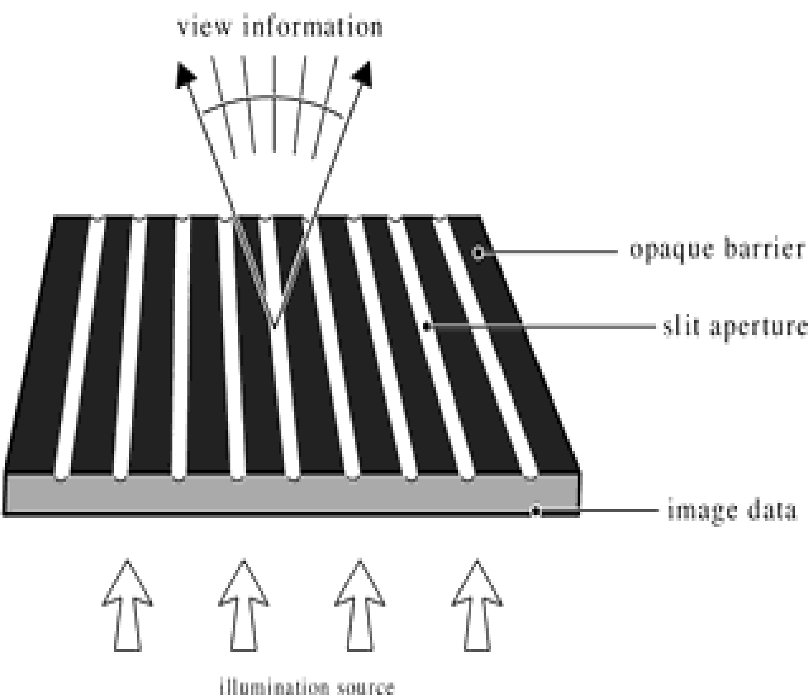
- Integral-Imaging System

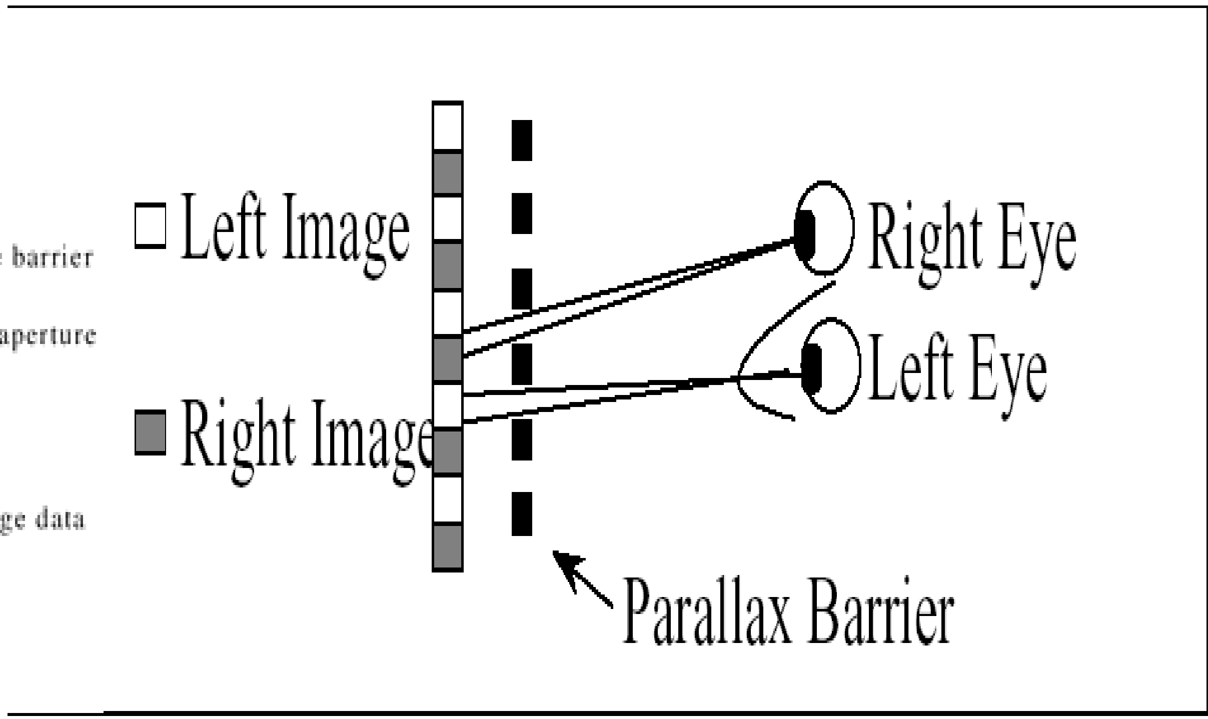




Parallax Barrier

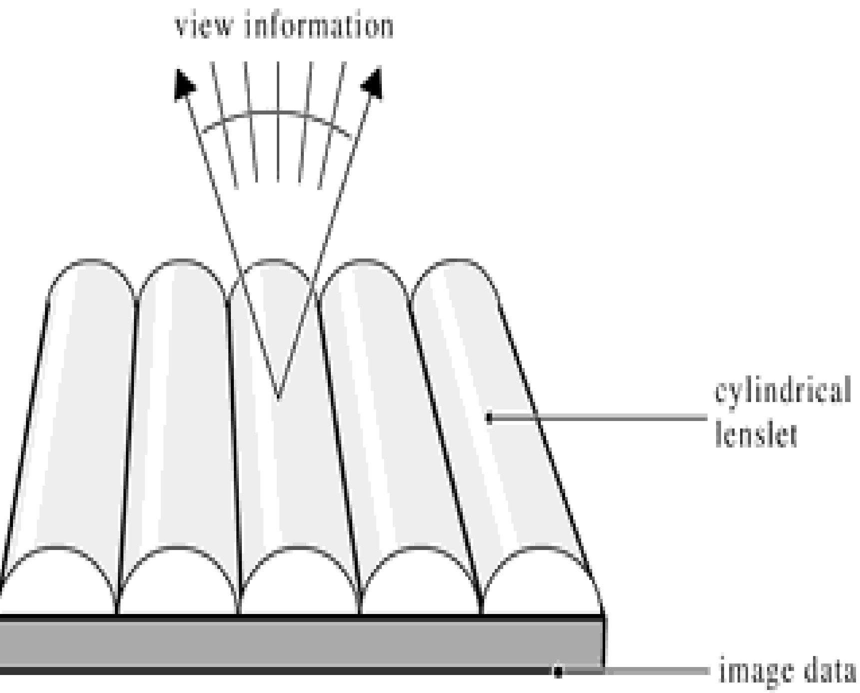
- A vertical slit plat placed in front of a specially prepared image made of strips of alternating left and right eye views

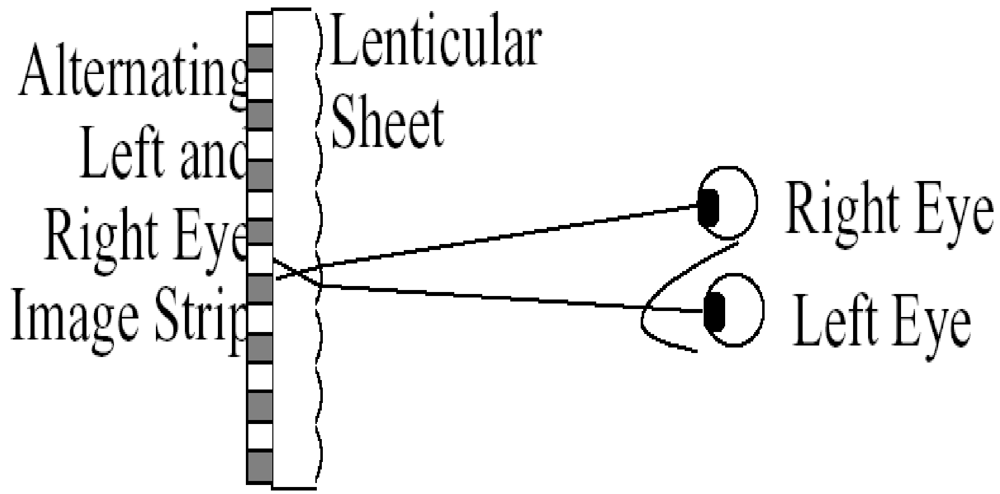




Lenticular

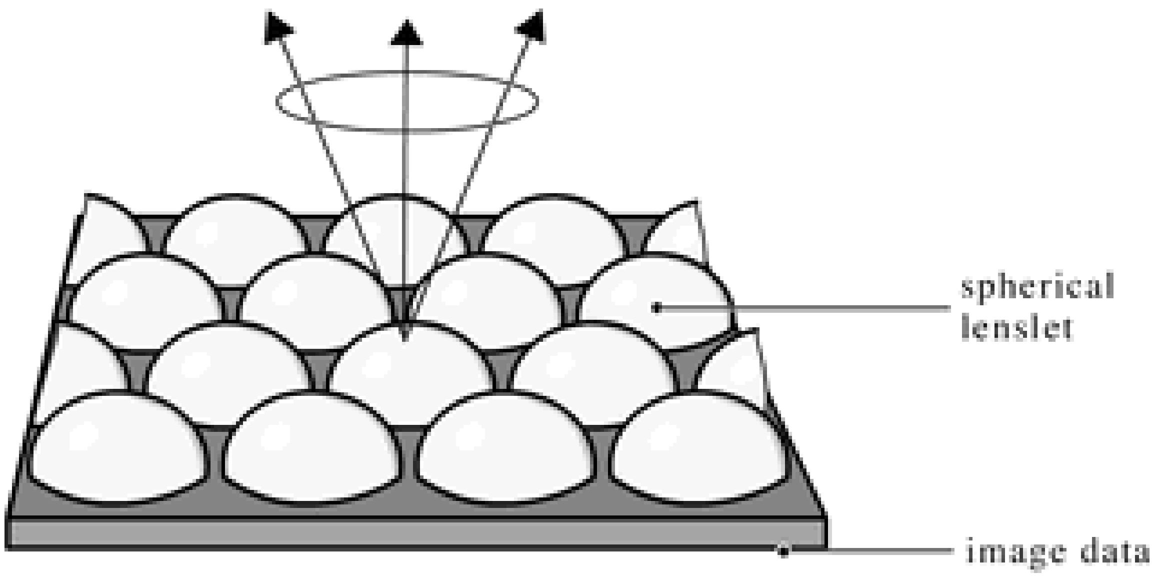
- Need no special viewing equipment
- Made from strips of cylindrical lenses



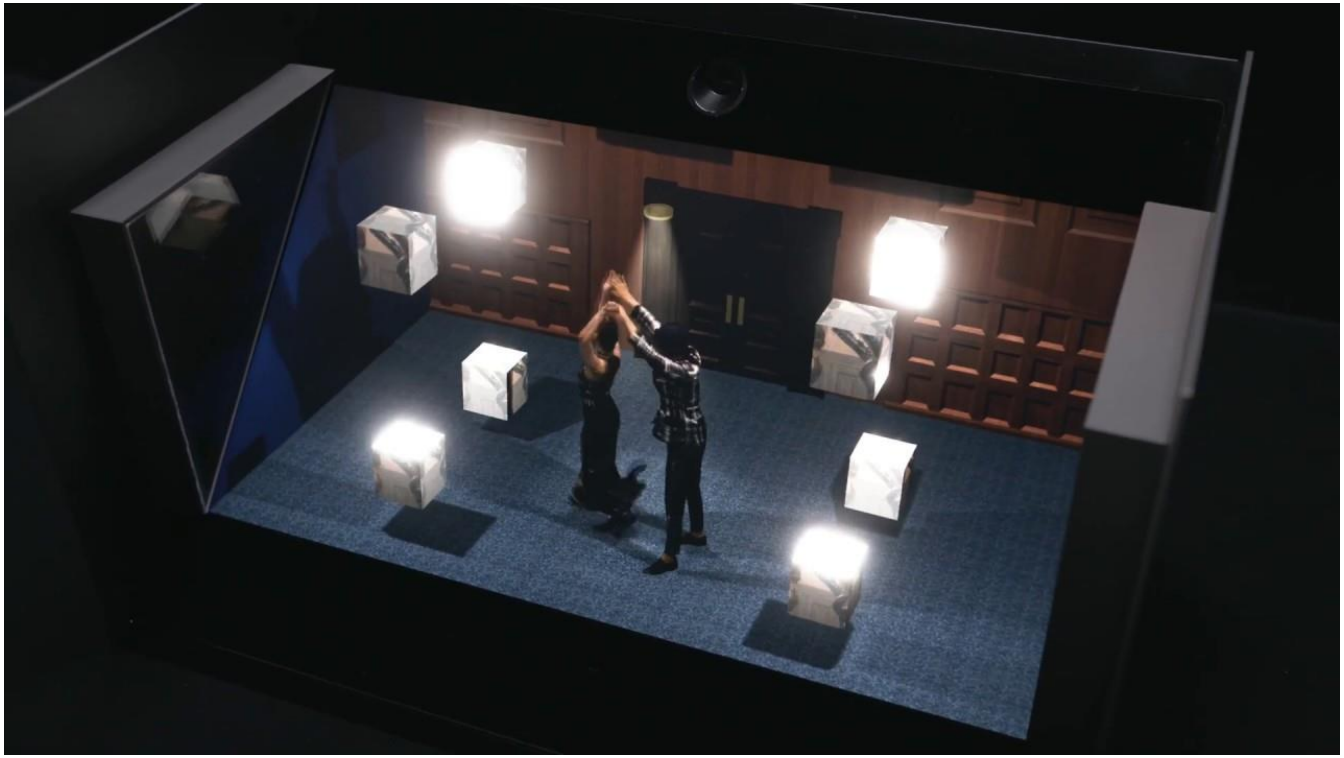


Lenslet

- Uses spherical lenses instead of cylindrical ones to present horizontally and vertically varying directional information, thus producing a full parallax image



Autostereo 3D Display



Sony at CES 2020: VISION-S & Eye-Sensing Light Field Display
https://medium.com/ces-2020-posterscopes-highlights/sony-eyesensing-light-field-display-afa5699e9194
https://www.youtube.com/watch?v=3S9zVMhLd6s

Autostereo 3D Display

"Iceland Landscape" by Sergey Kuydin

Looking Glass Factory, 8K Holographic TV that use a version of light-field technology for a 3D effect without glasses
https://www.youtube.com/watch?v=mxhcPm6PwME

Stereo Visuals for Multiple Viewers

- With the room scale or spatially immersive displays like CAVEs, there are typically multiple users, but usually only one user being head tracked. This means everyone is seeing through this one person's eyes, meaning the farther you are standing from this person the less correct the visuals are. The visuals are also moving based on that tracked person's movements, so if that person is moving around a lot the visuals are moving around a lot.
- In a classic 4-wall CAVE and a tracked user looking at the front wall, the imagery on the left and right walls will be monoscopic as the tracked user looking at the front wall, this means that stereo on the back wall is reversed. While correct for the one tracked user, this correct head tracking can cause issues for other users.

Stereo Visuals for Multiple Viewers

- For a single large screen the users are all typically looking at the (single) screen so head tracked stereo visuals are reasonably correct most of the time.

Stereo Visuals for Multiple Viewers

- One solution is to use the tracked user's head position to generate (rotated) tracked user eye positions independently for each wall to maintain correct stereo on the assumption that the tracked user's eyes are 'looking at' each wall simultaneously.
- This is slightly less correct for the one tracked user, but much more comfortable for everyone else who don't have stereo disappearing or reversing as the tracked user moves and turns.

How to Choose the Right VR Displays

- To make sure your visuals look good, its very important to keep in mind what kind of display you will be using, the space that it will be used in, who will be using it, and what kinds of things they will be doing - are these designers interacting with a new car model, or museum visitors exploring an ancient site?
- Projection-based systems, even modern laser based 4K ones, can give much larger borderless fields of view, but typically need to be in dimly lit or dark rooms. If the system is front-projection then how close will the user be able to get to the display before they begin to cast shadows on the screen? If its rear-projection from behind the screen then how much space are you prepared to waste behind the screen.

How to Choose the Right VR Displays

- Large flat panel displays have a different problem - they are designed for on-axis TV viewing and the further you are off-axis (horizontal or vertical) increases the chance that you will see degraded colour / contrast / stereo vision. They also tend to have borders which can be distracting when they are tiled. They are also thin so you cant stand on them without breaking them.
- Head mounted VR displays avoid issues of dark rooms and off-axis viewing but you still need enough space for the user to move around in and you need to make sure the user doesn't hurt himself/herself while moving around without seeing the real world.

How to Choose the Right VR Displays

- Head mounted AR displays allow the user to see the real world, making them safer than VR displays, but as these displays may be used in a dim room or in bright sunlight the graphics need to be visible across that range of use cases, similar to how you want to be able to use your phone or smart watch in a variety of settings, so the contrast and brightness ranges need to be greater than for displays that are only used indoors.

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Tech > Gaming

Best VR Headsets of 2023: Maybe a Good Time to Wait

The Quest 2 and PSVR 2 top our list, but with Apple arriving on the scene, the landscape's changing fast.

Scott Stein
June 13, 2023 5:00 a.m. PT

10 min read

Meta Quest 2
Best (and still most affordable) VR headset
$300 at Best Buy

PlayStation VR 2
Best high-end console gaming VR headset
$549 at Walmart

Meta Quest Pro
Work-focused pro tool
$1,000 at Best Buy

HTC Vive XR Elite
Futuristic hardware let down by software
$877 at Amazon

HP Reverb G2
Best-looking PC VR headset
$399 at HP

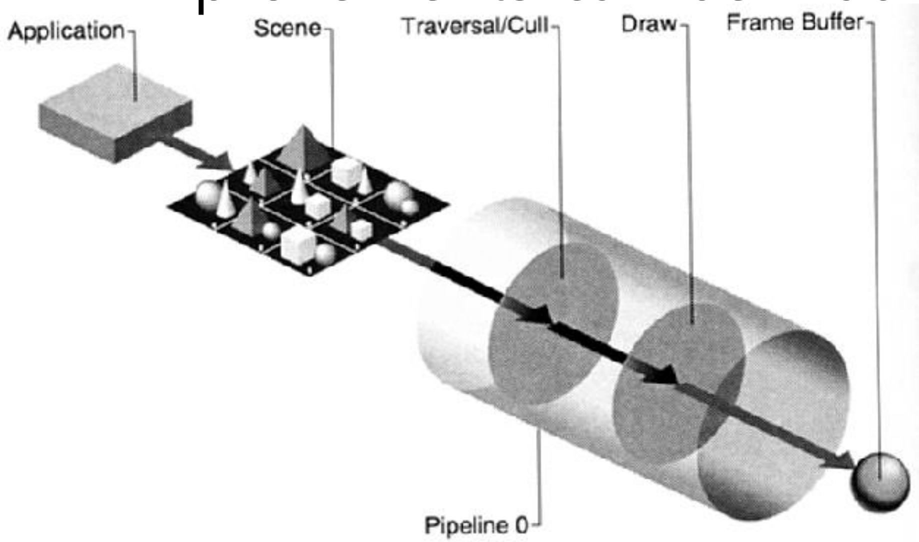
https://www.cnet.com/tech/gaming/best-vr-headsets/

How to Generate Graphics Quickly

- Naive Approach
  - poll head & hand sensor
  - get button press or other state change
  - update virtual world
  - draw world for left & right eye
  - display images to the users
- In VR systems like the CAVE this is more complicated because the scene must be drawn for the left and right eye on multiple projection places.
- The rate that images are drawn will always be based on the update rate. We tend to run at either 96hz or 120hz (48hz or 60hz per eye) which gives flicker free images based on most people's temporal resolution.

How to Generate Graphics Quickly

- In the 1990s Silicon Graphics (the folks who created GL, and would go on to found nVidia) optimized graphics through a pipelined approach and overlapping different parts of the pipeline.
- And then it helps to have tools to help visualize how long each part of the process takes and where improvements can be made.



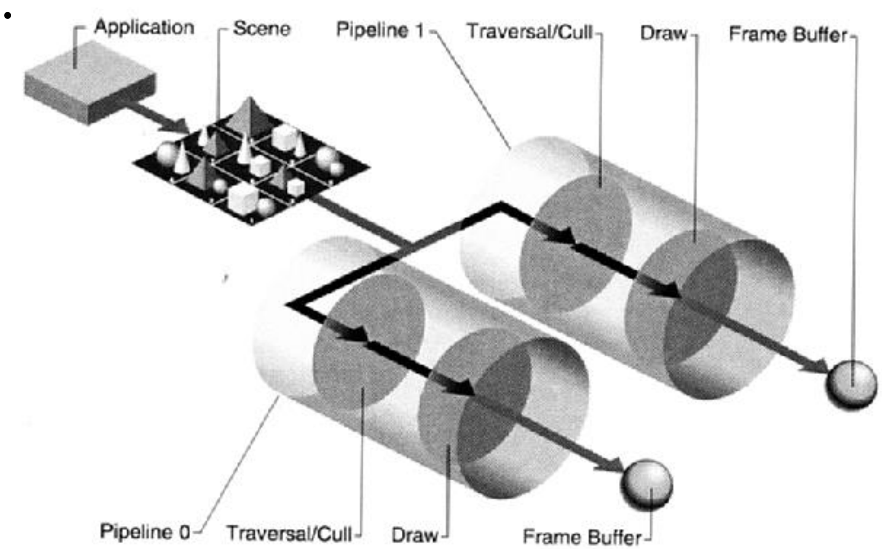


Image from SGI Performer manual

How to Generate Graphics Quickly

- The following image show a-application, c-cull, d-draw in the same color for the same frame,
  - E.g., when its drawing frame 5 its culling frame 4 and doing the application phase of frame 3. In this case the application is spending almost all its time drawing, so it has time to do more application work or culling which might improve the overall experience.
  - Unity has a similar tool with its Profiler https://docs.unity3d.com/Manual/ProfilerWindow.html

How to Generate Graphics Quickly

- While in videogames it is good to maintain a particular frame rate, in VR and AR it is much more important to do that.
- Current game engines are pretty good at optimizing what is drawn based on where the user is in the scene. If you create your own software from scratch you will need to take care of those things.
- Models can be replaced by models with less detail
- 3D models of far away objects can be replaced by texture mapped billboards
- The horizon can be moved in - moving in Z-far and perhaps covering this with fog.
- A less complex lighting model can be used.

Updating Visuals based on Head Tracking

- Naively we would like to update the graphics every frame in order to use the most recent head positions.
- Since there will be jitter in the tracker values and latencies in getting information from the tracking hardware to deal with, this may result in the computer generated image jittering.
- One way to avoid this is to only update the image when the head has moved (or rotated) a certain amount so the software knows that the motion was intentional.

Updating Visuals based on Head Tracking

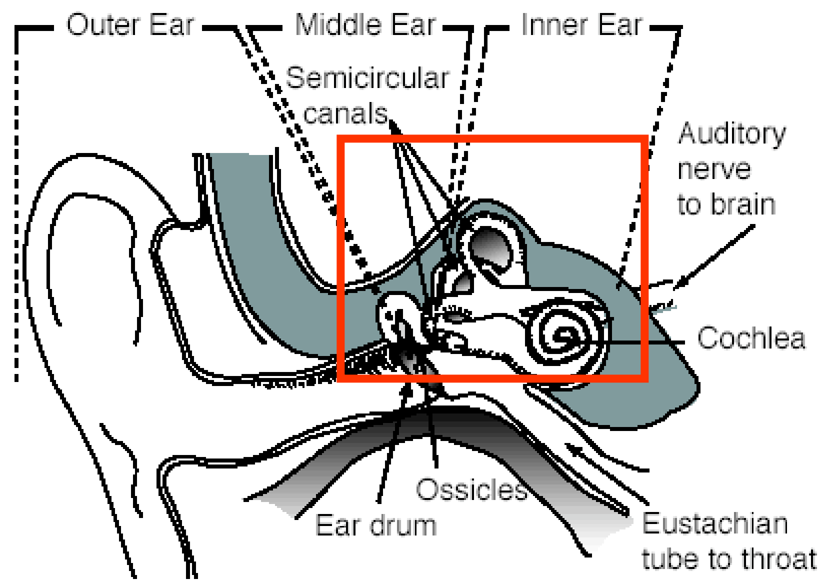
- Another common option is to interpolate between the previous and current position and rotation in order to smooth out this motion. This results in smoother transitions but will also increase the lag slightly.
- Another option is to extrapolate into the future by predicting how the user is going to move in the next couple seconds and proactively render for the position you believe the user will be in since people typically do not move their heads too abruptly.

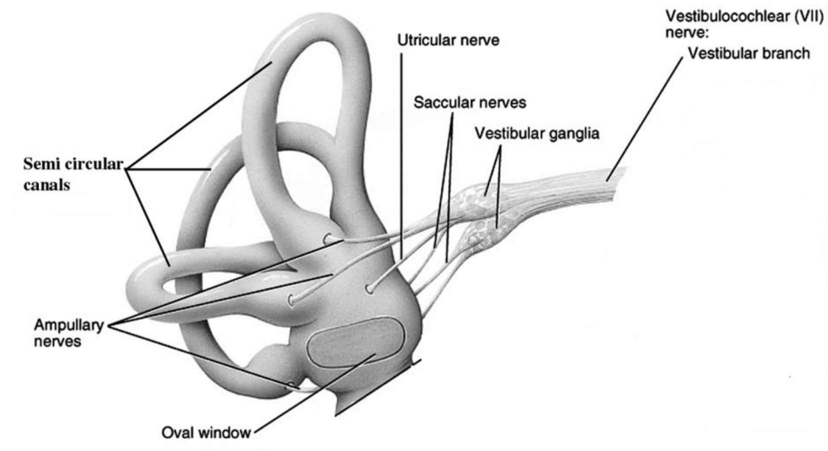
Simulator Sickness

- A small percentage of people gets sick from immersive VR. This percentage will increase as latency increases.
- Symptoms
  - Nausea, blurred vision, difficulty concentrating, headache, drowsiness, discomfort, dizziness, fatigue
- Causes
  - Still unknown but one common hypothesis is mismatch between visual motion (what your eyes tell you) and the vestibular system (what your ears tell you)
  - HMDs are more likely to cause it than projection VR systems
  - Low resolution, low frame rate, high latency are also like causes
  - Another hypothesis deals with the lack of a rest frame. When a user views images on a screen with an obvious border that border locates the user in the real world. Without that border the user loses his/her link to the real world and the affects of motion in the virtual worlds are more pronounced.

Simulator Sickness

- The organ of the inner ear containing three semicircular ducts at right angles to one another.
- Responsible for maintaining the body’s orientation in space, balance, and posture; regulates locomotion and other movements and keeps objects in visual focus as the body moves.





Remedies for Simulator Sickness

- Close your eyes.
- Or take a walk around the block if you can do it without falling over.
- Break the illusion of motion by NOT covering your entire field of view with the screen. (i.e. sit back so that you can see the edges of your monitor)
- Do not play in a dark room- for the same reason as above.
- Avoid scenes where you are rolling about the Z axis.
- Higher frame rates can actually INCREASE the sense of motion.
- But the jarring effect from lower frame rates can cause eye strain.

Reference

- http://www.evl.uic.edu/aej/528/
- Dennis Proffitts SIGGRAPH’94 Developing Advanced VR Applications course notes
- Lou Harrison SIGGRAPH’97 Stereo Computer Graphics for Virtual Reality notes
- http://www.siggraph.org/education/materials/HyperVis/virtual.env/percept.iss/percept.htm
- http://www.wmin.ac.uk/ITRG/IS/DPI/HIW/Human%20Visual%20System.pdf
- http://www.3dglassesonline.com/
- http://web.cs.wpi.edu/~matt/courses/cs563/talks/stereohtml/stereo.html
- http://web.media.mit.edu/~halazar/autostereo/autostereo.html
- http://www.mlab.uiah.fi/nmc/stereo/masters/eng/vocabulary.html
- https://venturebeat.com/2018/07/31/magic-leap-ones-field-of-view-leak-signals-another-ar-disappointment/