Vision & Visuals

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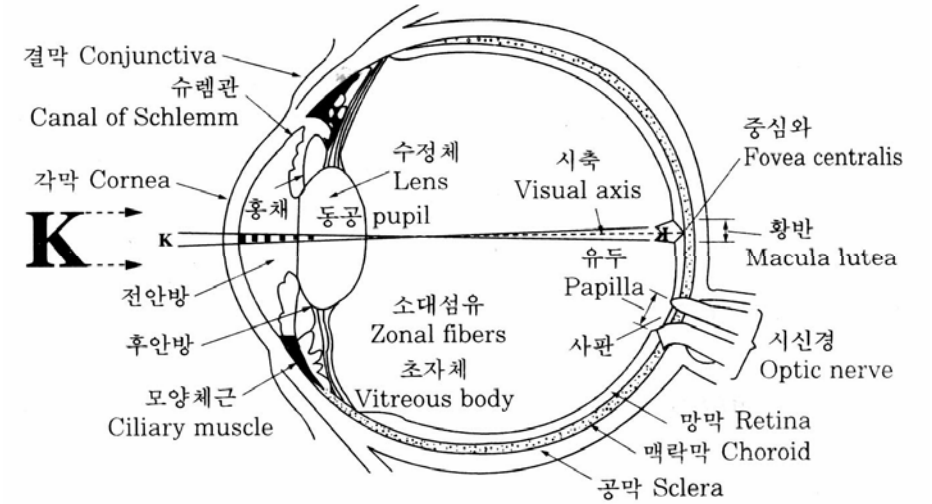
Overview

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

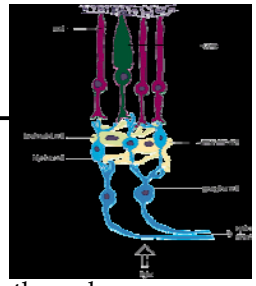
Human Visual System



Human Eyes

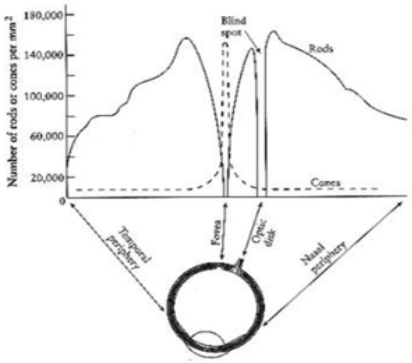
- Light is focused by the cornea and the lens onto the retina
- Light passing through the center of the cornea and the lens hits the fovea (or Macula)
- Iris permits the eye to adapt to varying light levels, controlling the amount of light entering the eye.
- Retina is optically receptive layer like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

Photoreceptors (Rods & Cones)



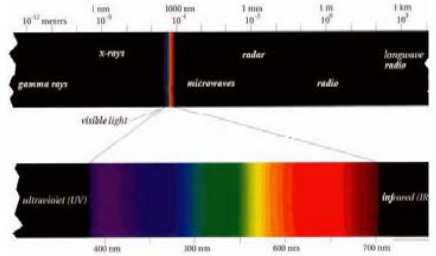
- Rods
  - Operate at lower illumination levels
  - Luminance-only
  - The most sensitive to light
  - At night where the cones cannot detect the light, the rods provide us with a **black and white** view of the world
  - The rods are also more sensitive to the blue end of the spectrum
- Cones
  - operate 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



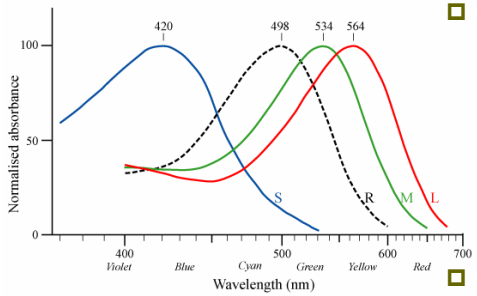
- Rods & Cones Distribution
- Fovea
  - only cone receptors with very high density
  - no rods
  - no S-cones (blue cones)
  - responsible for high visual acuity
- Blind Spot
  - no receptors
  - Axons of all ganglion cells pass through the blind spot on the way to the brain

Visual Spectrum



- We perceive electromagnetic energy having wavelengths in the range 400 nm ~ 700 nm as visible light.
- ~450nm : violet
  458nm ~ 480nm : blue
  510nm ~ 550nm : green
  570nm ~ 590nm : yellow
  590nm ~ 630nm : orange
  630nm ~ : red

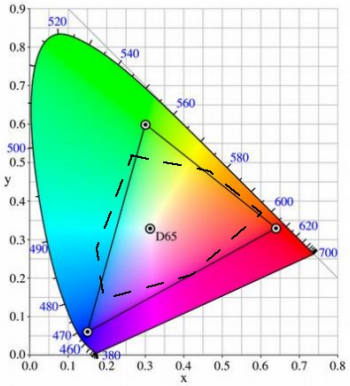
Color Perception



Spectral Sensitivity of Cones

- There are three types of cones, referred to as **S, M, and L**. They are roughly equivalent to blue, green, and red sensors. Their peak sensitivities are located at 420 nm, 534 nm, 564 nm.
- Color perception results from the simultaneous stimulation of the 3 cone types.
- Colorblindness results from a deficiency of one cone type.

Chromatic Color

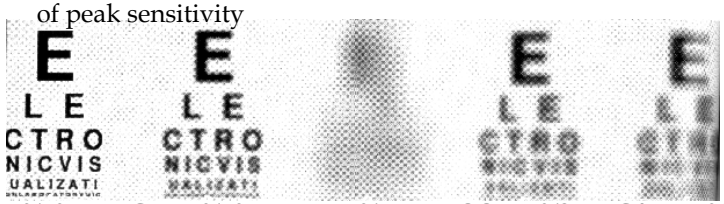


CIE (Commission Internationale d'Eclairage) Chromaticity Diagram

- Hue
  - distinguishes between colors
- Saturation
  - how far is the color from a gray of equal intensity
  - vivid colors (red, blue) are highly saturated, further from gray
  - pastel colors (pink, sky blue) are lightly saturated, closer to gray
- Brightness
  - perceived the intensity of a luminous object

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
  - 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 HMD 20/425 BOOM 20/85 CAVE 20/110

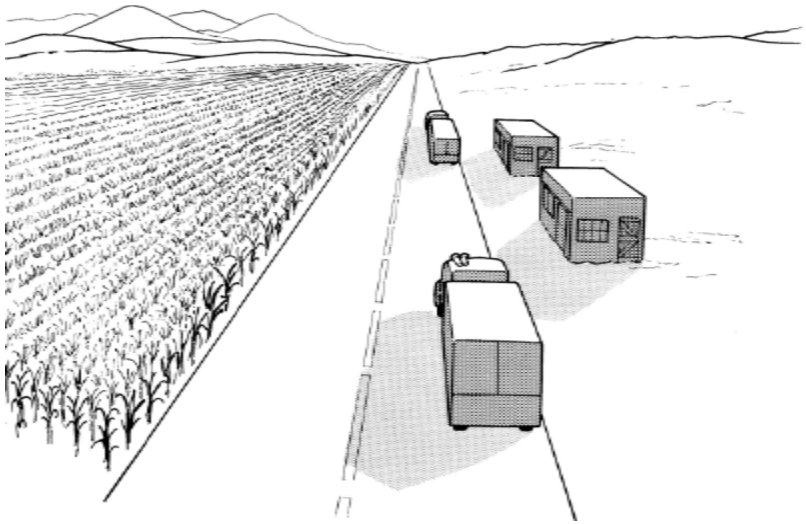
Visual Perception

- Temporal Resolution
  - The real world doesn't flicker. CRTs do flicker because the image is constantly being refreshed.
  - We perceive flickering if the image on CRT 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 flicking even at 60 Hz for a bright display with a large field of view.
  - Very large display may require up to 85 Hz.
- Luminance
  - The eye has a dynamic range of 7 orders of magnitude.
  - 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.

Visual Perception

- Color
  - Most visual perceptual processes are driven by intensity not color.
  - Motion system is color blind, depth perception is color blind, object recognition is color blind
  - But uniquely colored objects are easy to find
- Field of view (FOV)
  - Each eye has a horizontal fov of 150° (60° towards the nose and 90° to the side) and a vertical fov of 120° (50° up and 70° down).
  - Most HMDs have a FOV of about 40 to 60.
- 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

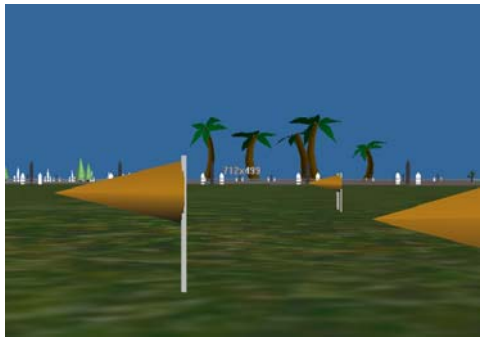
- Linear perspective
  - Objects get smaller the further away they are and parallel line converge in distance.
- Size of known objects
  - We expect certain object to be smaller than others.
- Detail (texture gradient)
  - Close objects appear in more detail, distant objects less.
- Occlusion (hidden 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.

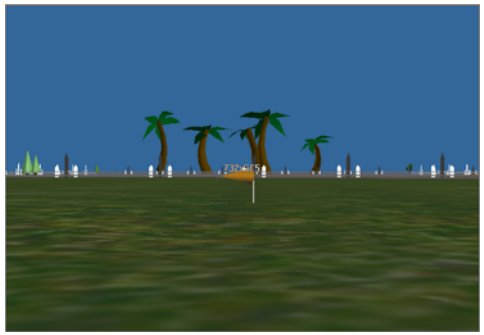
Size

- 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.

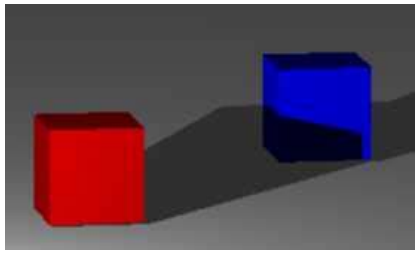


Occlusion

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

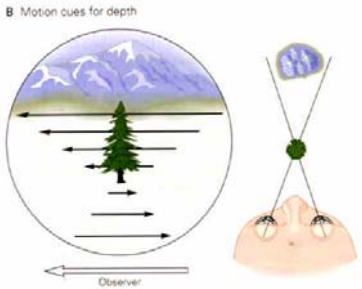
Lighting and Shadow

- 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

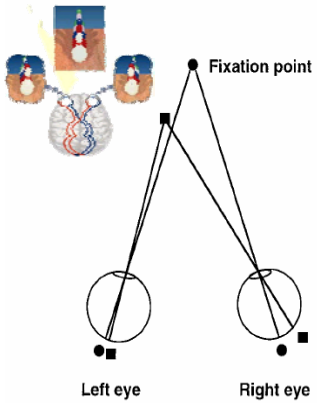
- As an observer moves, nearby objects appear to move rapidly while far objects appear to move slowly.
- Come from the parallax created by the changing relative position between the head and the object being observed.
- Generally more important than stereoscopy for VR.



Visual Depth Cues
- Using both eyes

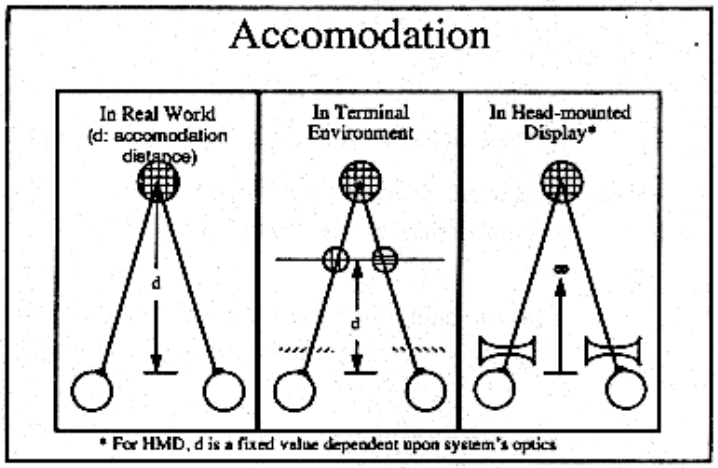
- Binocular cues: binocular disparity (stereopsis)
  - This is the difference in the images projected onto the back of the eye (and then onto the visual cortex) because the eyes are separated horizontally by the interocular distance.
- Oculomotor cues: accommodation & convergence
  - Based on information 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

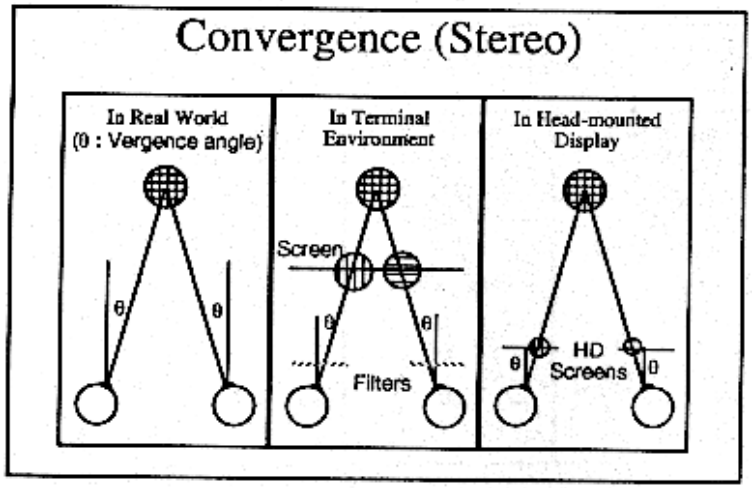


- Binocular vision occurs when two eyes look at the same thing at a slightly different angle, resulting in two slightly different images.
- The brain must match points between the two separate images seen by the two eyes.
- The slight difference between the viewpoints of your two eyes is called binocular 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)



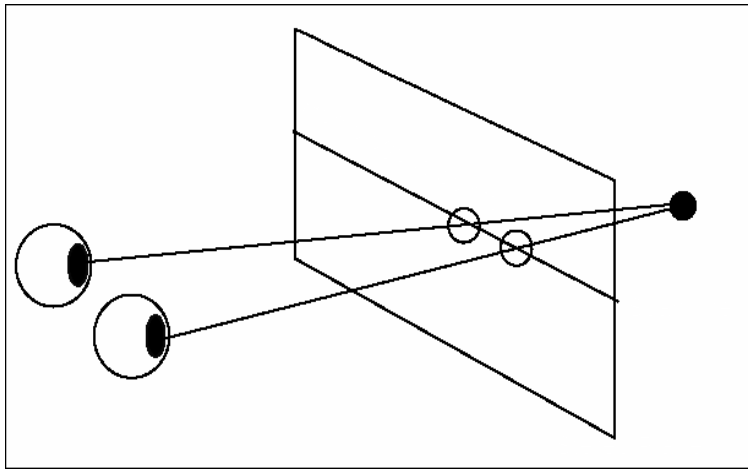
Convergence



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



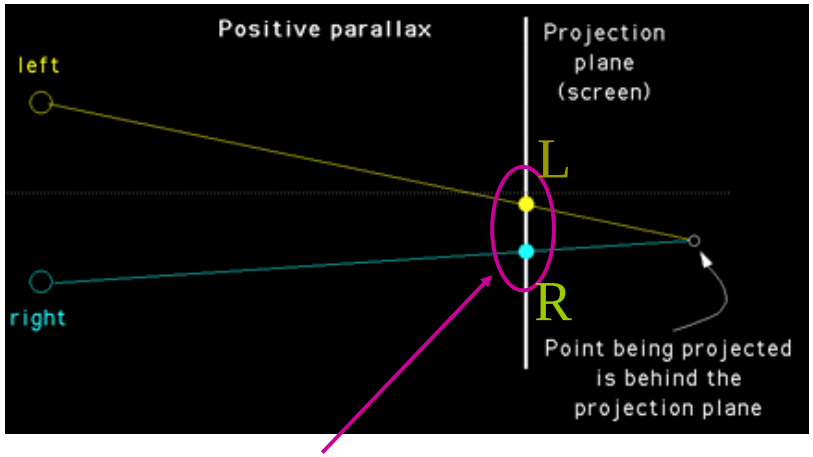
Some Terminology

- 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

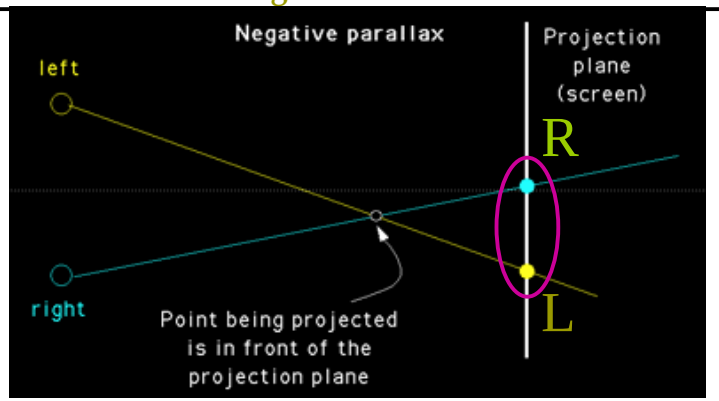
- Positive Parallax
  - The point lies behind the stereo window (On the opposite side from the observer)
- Negative Parallax
  - The point lies in front of the stereo window (On the same side as the observer)
- Zero Parallax
  - The point is at the same depth as the stereo window (Both eyes see the same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

Positive Parallax
Accommodation-convergence mismatch



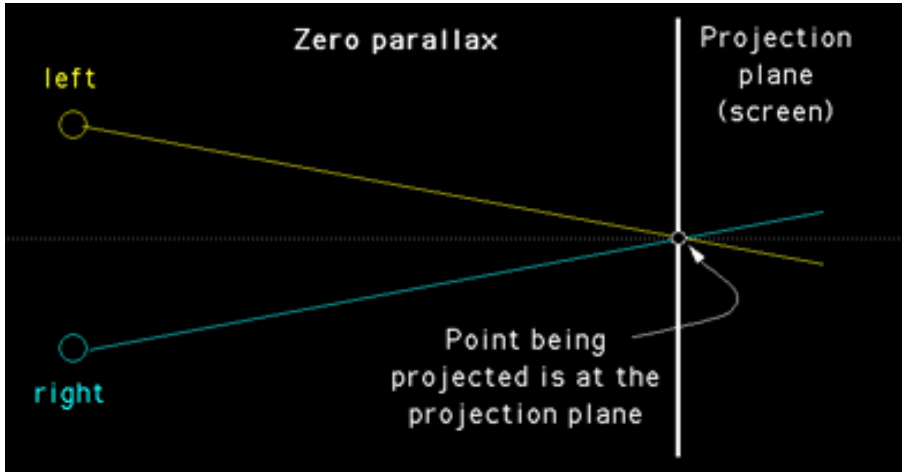
The left and right eye images projected on the screen

Negative Parallax
Accommodation-convergence mismatch

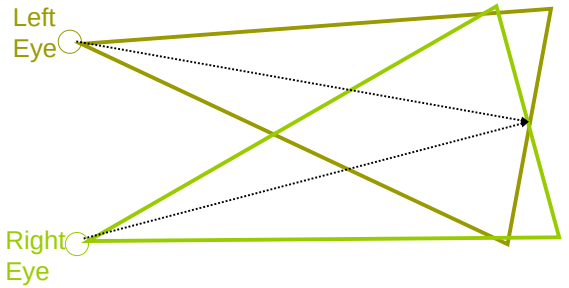


- If Objects are too close in front of the projection plane, negative parallax will increase.
- If negative parallax is wider than eye separation, then result is pain.

Zero Parallax
When the object is actually on the screen

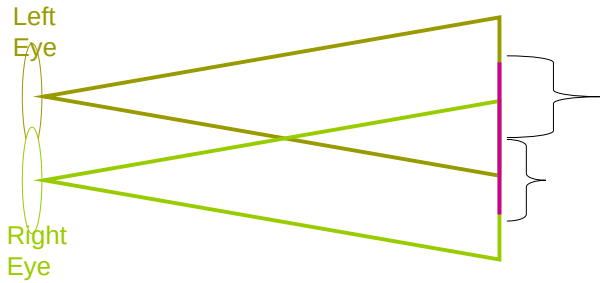


Stereo Approximation



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

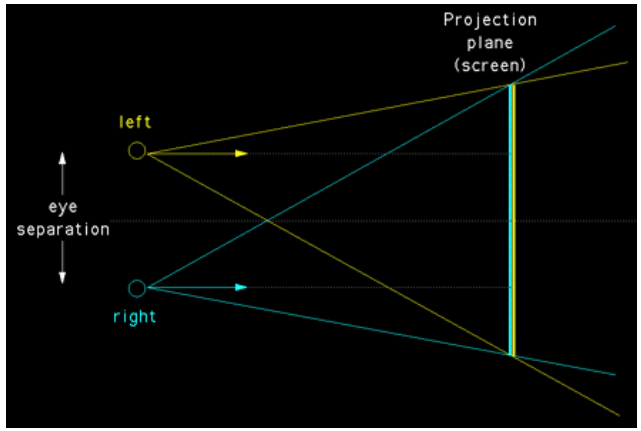
Stereo Approximation



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

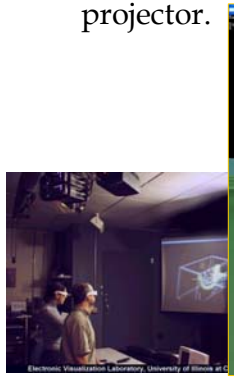


The correct approach using **parallel views and asymmetric view frustrum** produces a single viewplane and overlapped image

Asymmetric View Frustum

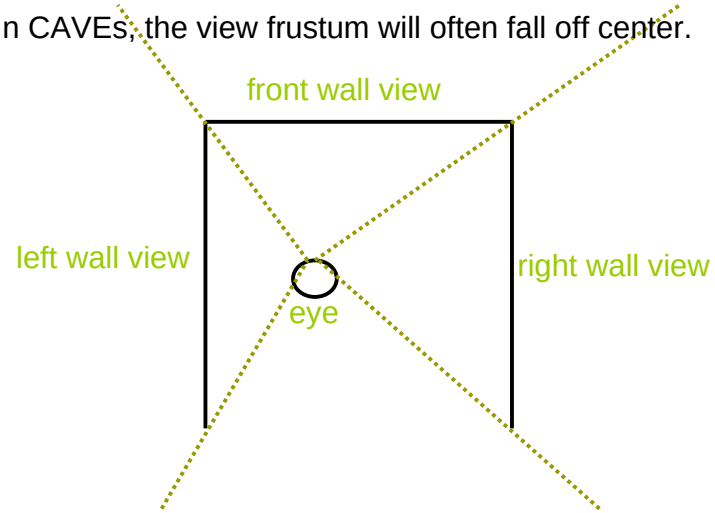
Stereo Images on the GeoWall

- 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.

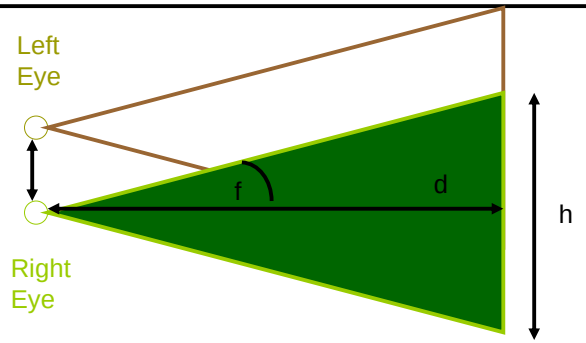


Off-axis Perspective Projection in a CAVE

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)

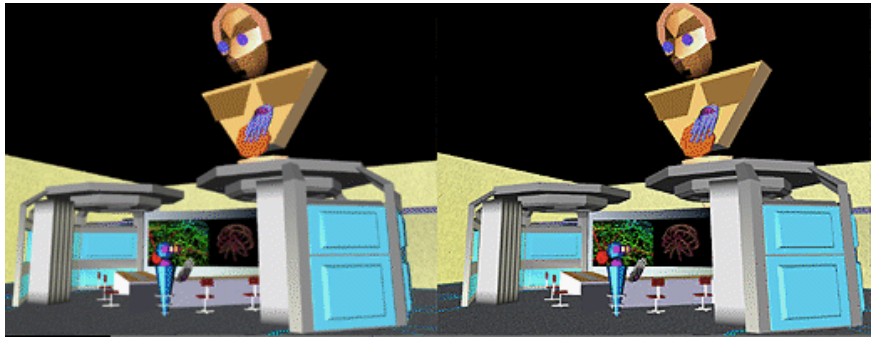
How to Generate Stereo Images

Present a distinct image to each eye:

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

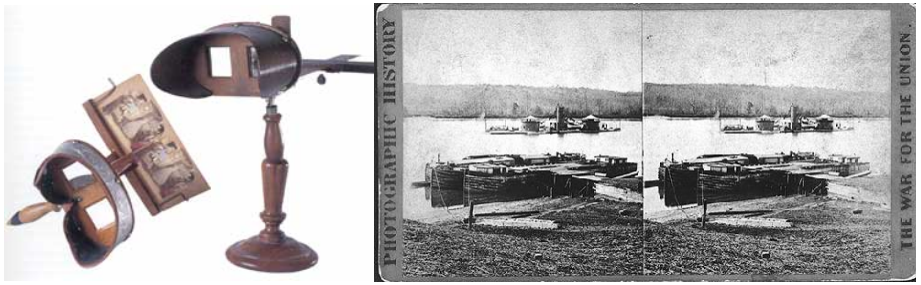
Free-viewing

- 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

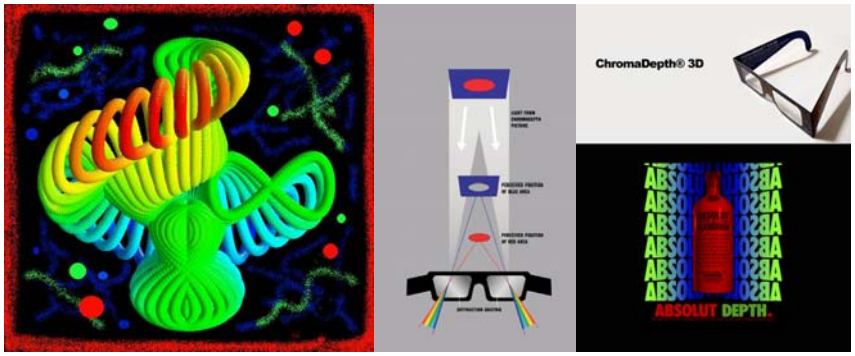
2 computer monitors: one for each eye

HMD

BOOM

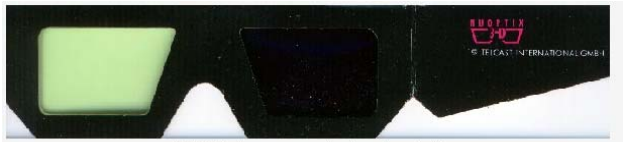
Chromadepth

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



Pulfrich Effect

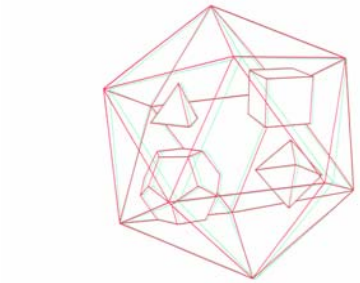
- Physiological effect discovered by astronomer, Carl Pulfrich.
- Pulfrich effect glass have one dark lens and one clear lens.
- Images viewed through a darkened lens reach the brain **slower** than those viewed through a clear lens.
- When something moves across the visual field, the brain fuses **two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

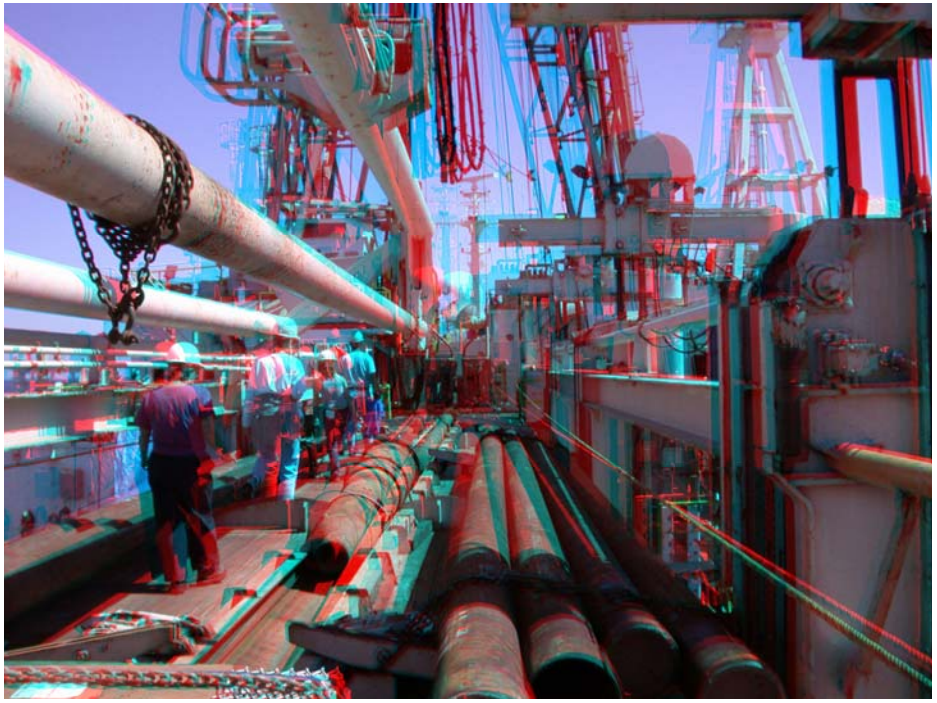


Pulfrich glasses as used on broadcast-TV

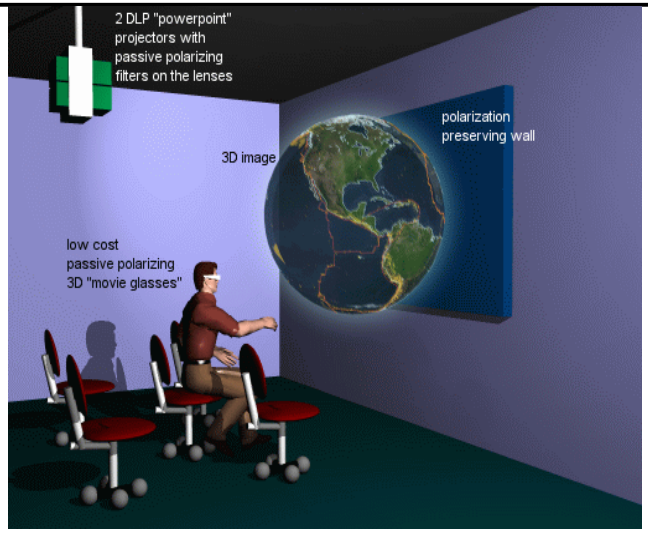
Anaglyph

- 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.





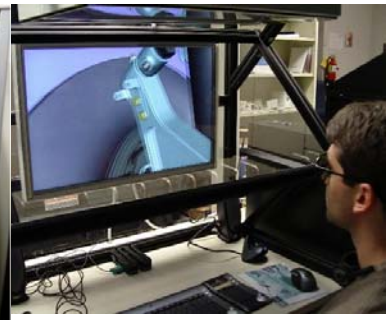
Passive Polarization



GeoWall @EVL

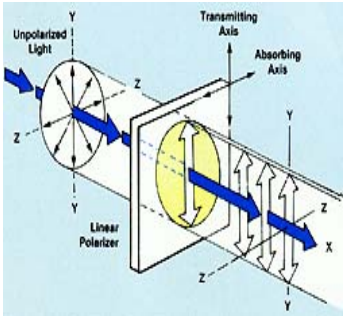
Passive Polarization

iDesk
– Linear Polarization



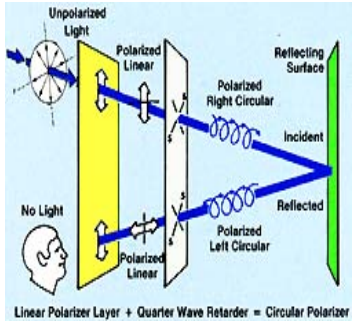
ImmeraDesk4@EVL
– Circular Polarization

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

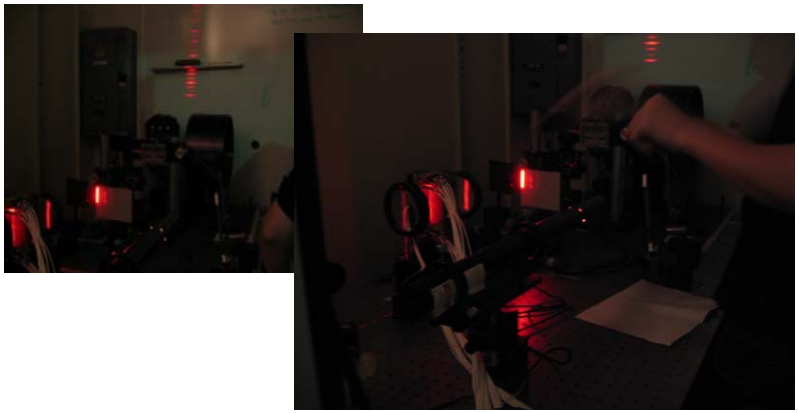
- Glasses have liquid crystal lenses which can be darkened & cleared rapidly - at any time one lens is clear and one is dark.
- Glasses are synchronized with video display - one eye sees odd frames, other eye sees even frames.
- Requires fast video refresh rate (> 90Hz) to prevent flicker.
- LCD projects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

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

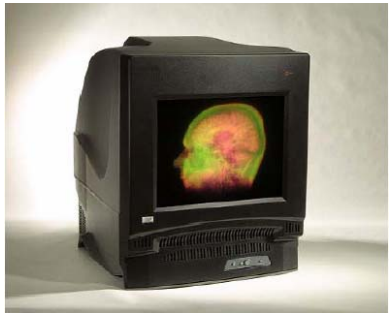
- MARK-II @ MIT Media Lab



Volumetric Display

- Spinning Screen Display
- Slice-Stacking Display

Actuality Systems



LightSpace Tech

Autostereo 3D Display

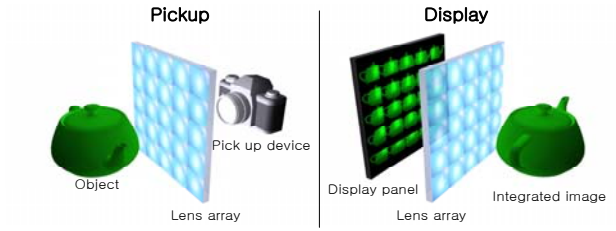
Pavonine, 17''/19'' Dimen
-Backlight switchable barrier

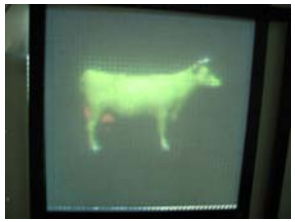
Philips, 42" WOWvx 42-3D6C01
-Lenticular, support for multiusers

Sharp, Actius RD3D Notebook
-Backlight switchable barrier

Autostereo 3D Display

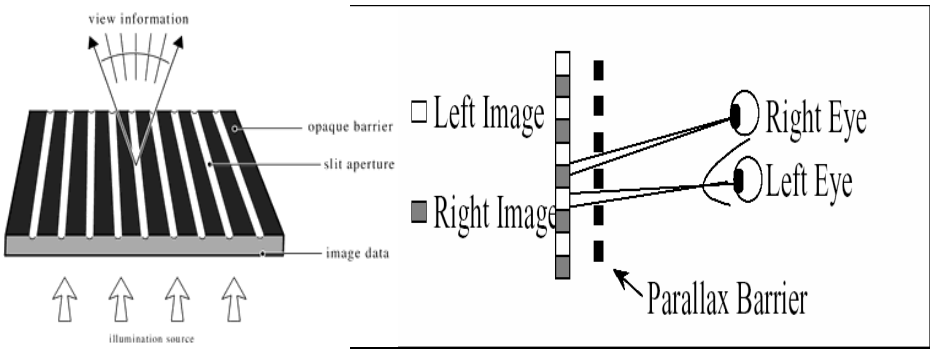
- Integral-Imaging System





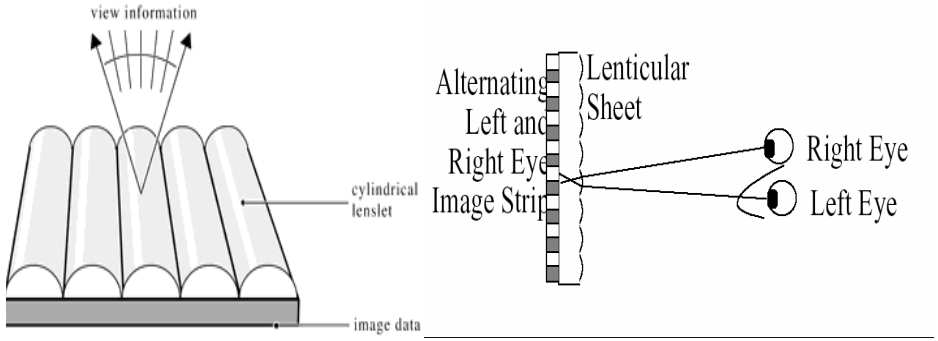
Parallax Barrier

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



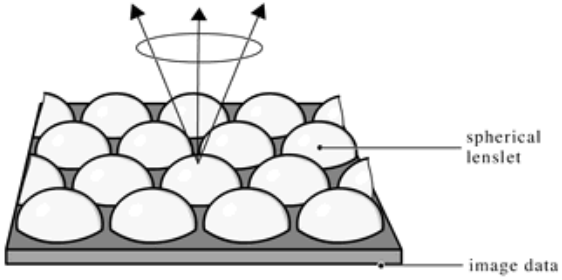
Lenticular

- 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



How to Generate Graphics Quickly

- Naive Approach
  - poll head & hand sensor
  - update virtual world
  - draw world for left & right eye
  - display images
- 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

- Often when moving through a virtual world, the world will seem to speed up or slow down based on the complexity of the scene.
- 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

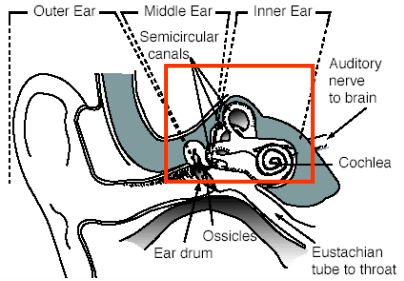
- Update the graphics every frame in order to use the most recent head positions.
- Since there will be jitter in the tracker values and latencies to deal with in magnetic tracking, this may result in the image jittering.
- One way to avoid this is to only update the image when the head has moved (or rotated) a certain amount
- Another 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

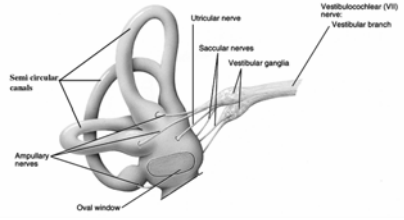
Simulator Sickness

- 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

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