Virtual Reality Display Systems

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Outline

1. Characteristics of Immersive Displays
2. Stereo Rendering

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1. **Characteristics of Immersive Displays**
2. Stereo Rendering

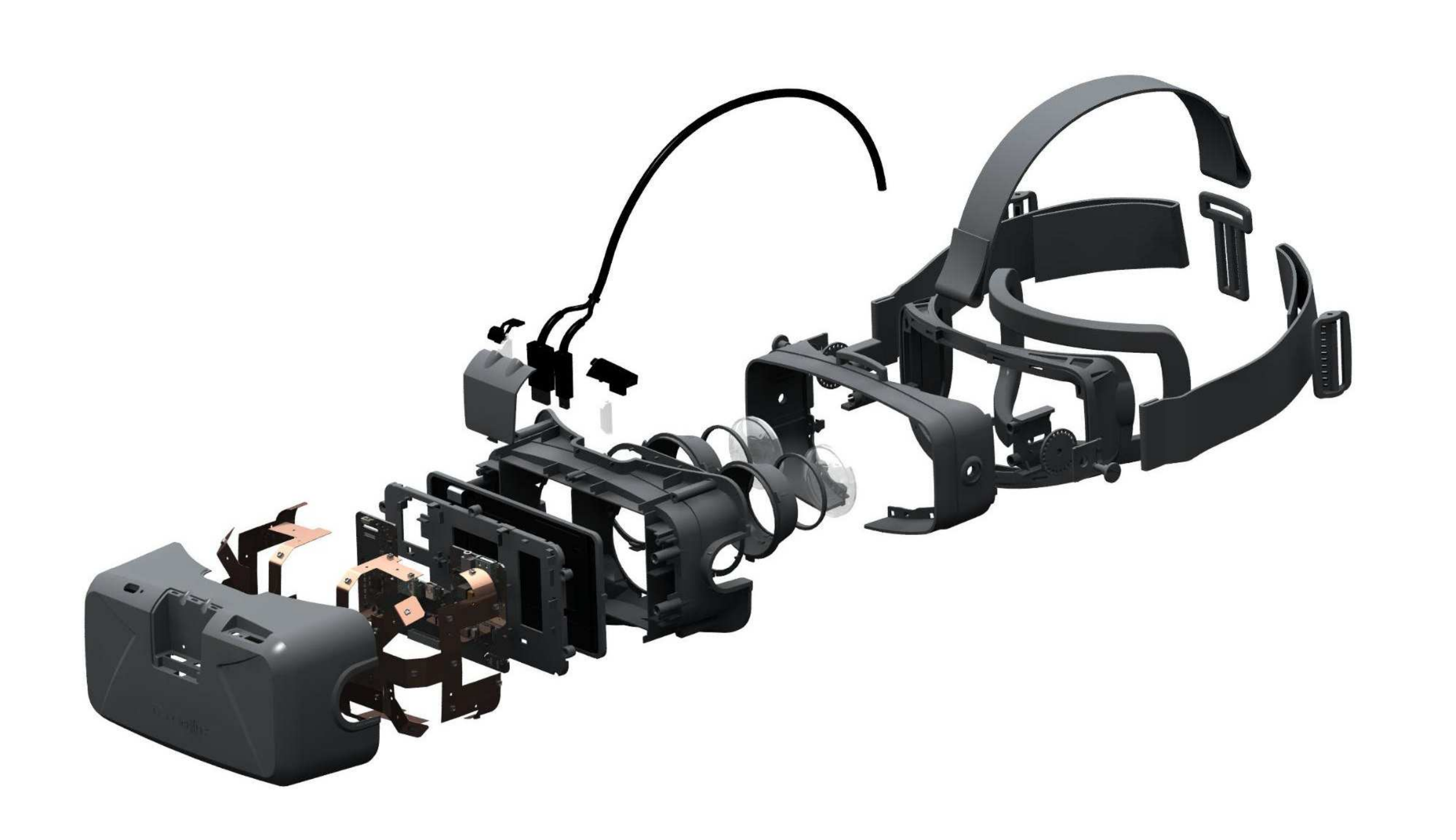
Two Main Ways of Doing Virtual Reality

- Near Eye Displays (head-mounted displays)
  - Display near head (screen(s), projectors, etc.)

- Immersive projection technology (CAVE-like)
  - Display in the world (screens, projectors, etc.)

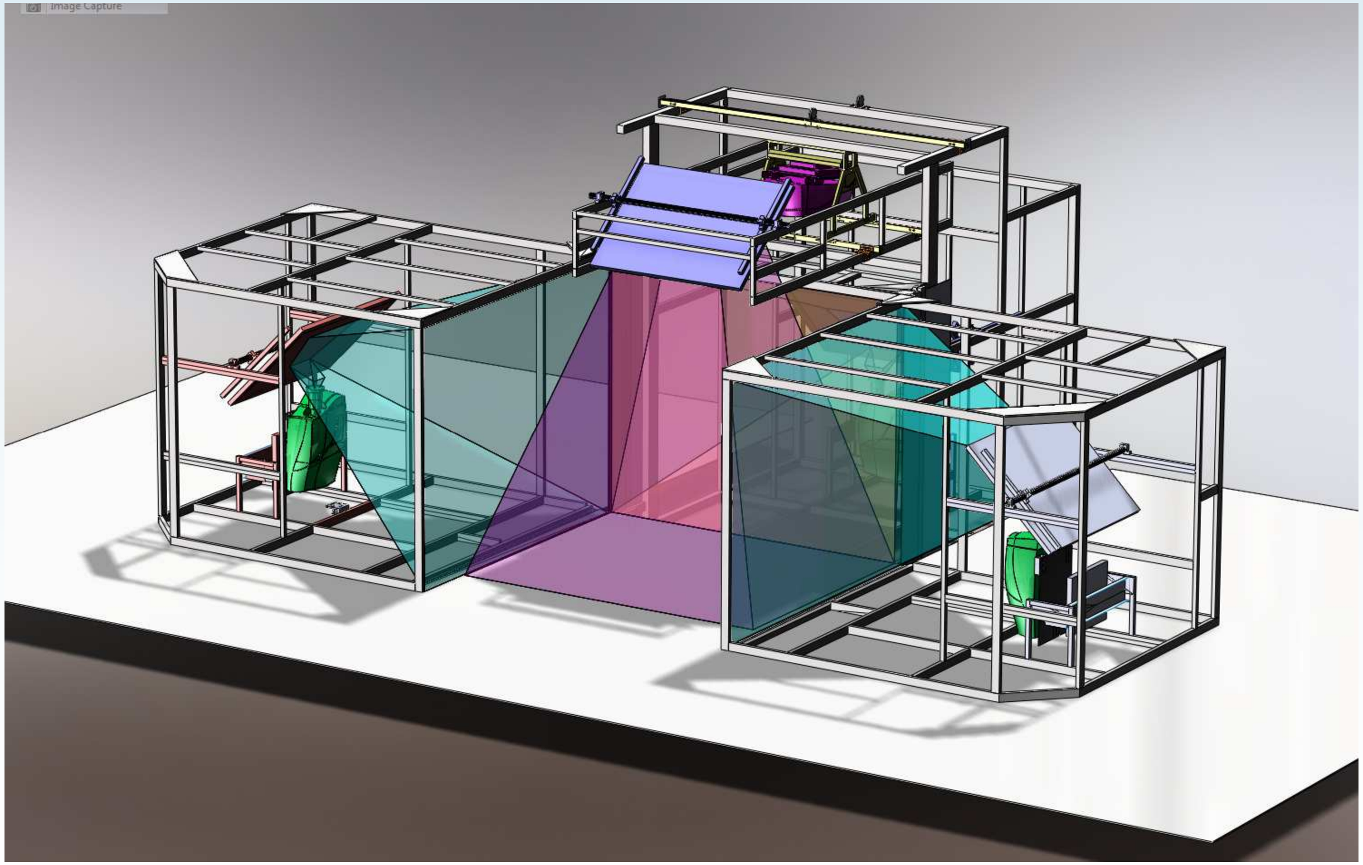
- Both require
  - Rendering for 1st person view
  - Issues with display types
- 100s of examples of each

HMD



https://developer.oculus.com/blog/open-source-release-of-rift-dk2/

EVL CAVE (1991)

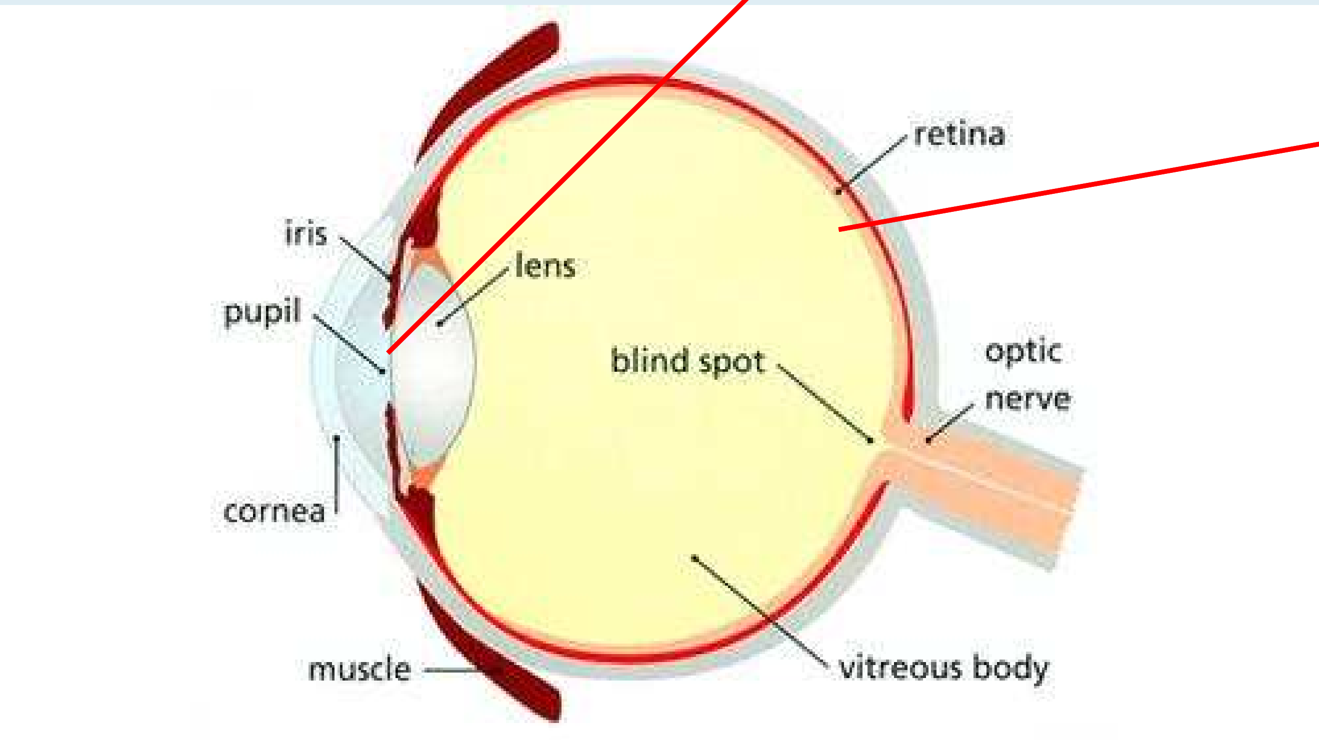


https://vrtifacts.com/cave%C2%AE-a-virtual-reality-theater-1993/

The eye…

ANTERIOR: Pupil, iris & lens modelled as camera optics…

POSTERIOR: Retina modelled as distribution of photoreceptors…

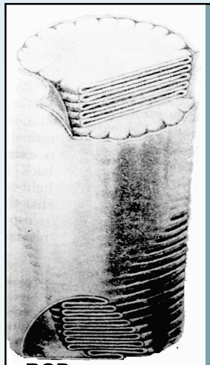


https://www.moorfields.nhs.uk/content/anatomy-eye

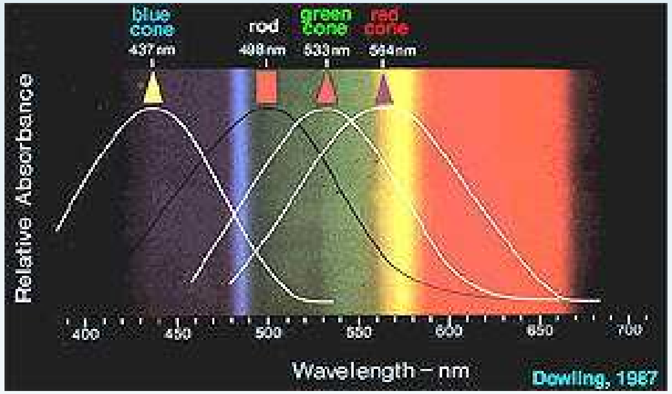
UCL

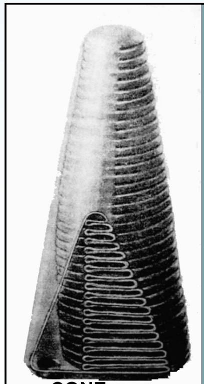
Photoreceptors in the Retina: Rods & Cones

视杆细胞 无色(黑白)


ROD

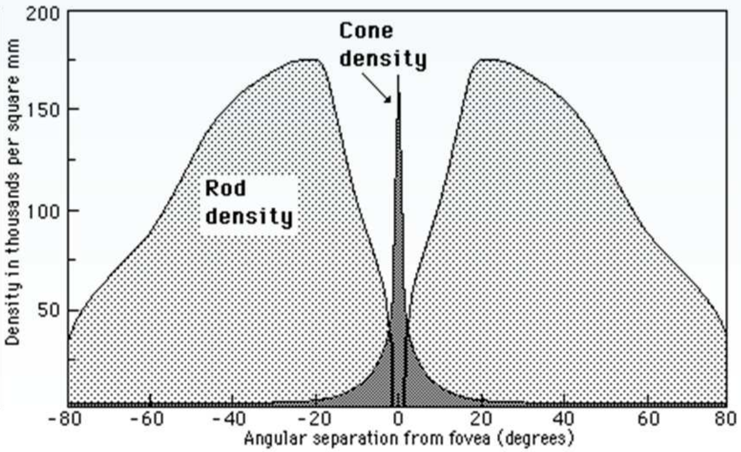
- Extremely sensitive to light
- Provide achromatic vision
- Work at low level (scotopic) illumination
- Large receptive fields 更大视野
- Peak absorbance (sensitivity) at ~500nm




CONE

- Less sensitive to light
- Provide colour vision
- Work at high level (photopic) illumination
- Three types:
  'B' peak at 437nm, 'G' peak at 533nm, 'R' peak: 564nm

Much smaller receptive fields



视锥细胞

Some Immersive Characteristics of Displays

- Recall that immersion is a means of quantifying the properties of the systems
- For visual display systems, many characteristics can be looked at:
  - Resolution
  - Refresh rate
  - Frame rate
  - Colour gamut
  - Field of view

	Oculus Rift S	1280 × 1440	80	110
	OSVR	1080 × 1200	90	110
	PIMAX 4K	1920 × 2160	60	110
	PIMAX 8K	3840 × 2160	120	200
	Samsung Gear VR	1280 × 1440	60	101
	Samsung HDM Odyssey Windows Mixed Reality	1440 × 1600	90	110
	Sony PlayStation VR	960 × 1080	120	100
	StarVR	2560 × 1440	90	210

https://benchmarks.ul.com/compare/best-vr-headsets

The Refresh Rate

- This is the number of times the display hardware *draws the image* per second
- It has to be sufficiently fast that the display intensity appears steady

From http://en.wikipedia.org/wiki/Refresh_rate

Device Refresh Rates

- Normal screens
  - Standard OLED/LCD panels up to 75Hz, for gaming tend to 144Hz
  - September 2020, NVidia launches 360Hz eSports displays
- Projectors
  - DLP can now match this (digital cinema rear projection)
- HMD screens
  - 72Hz OLED in Oculus Quest
  - 120/144Hz for Valve Index

Low Persistence Displays

- There is a very important problem on HMDs *hold-type blur*
- That is, if a pixel is turned on as your head moves, it creates the illusion of a spread of light in space

Flicker Fusion Threshold

- This varies across the eye
  - Foveal vision is least sensitive
  - Peripheral vision is most sensitive

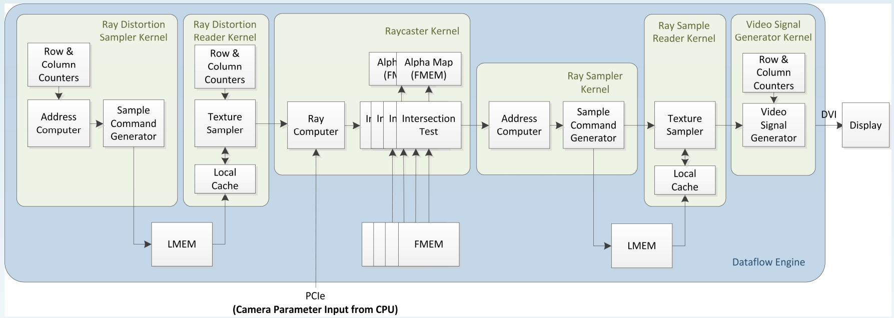
- The consequences of this can be seen when you look at the refresh rate for different types of devices

The Frame Rate

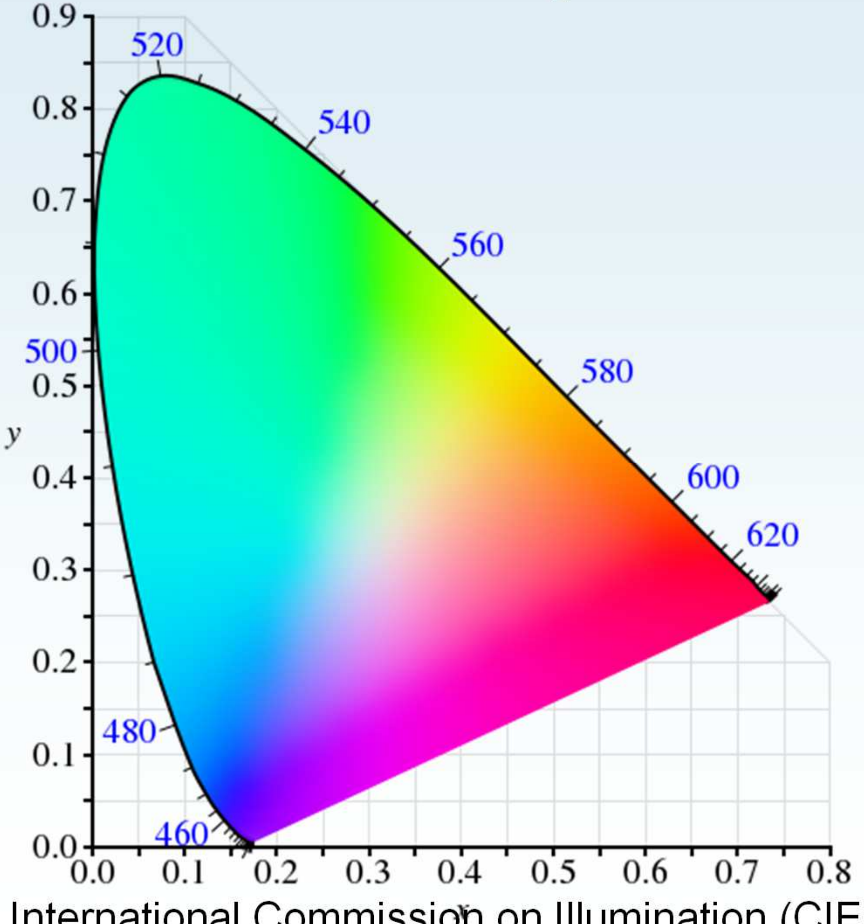
- This is the number of times the hardware produces a *unique image* per second
- Dictated by the power of the graphics card
- Ideally, for VR, at the display rate
- If not, modern HMD drivers use *frame-reprojection techniques* to “extrapolate” frames

Frame Rate and Latency

- Later we will see that latency is key to performance (and preventing sickness)
- Higher display rates support lower latency
- In extreme, can "race the beam" that is, calculate pixels just before display needs them
  - (See Sebastian Friston's work)



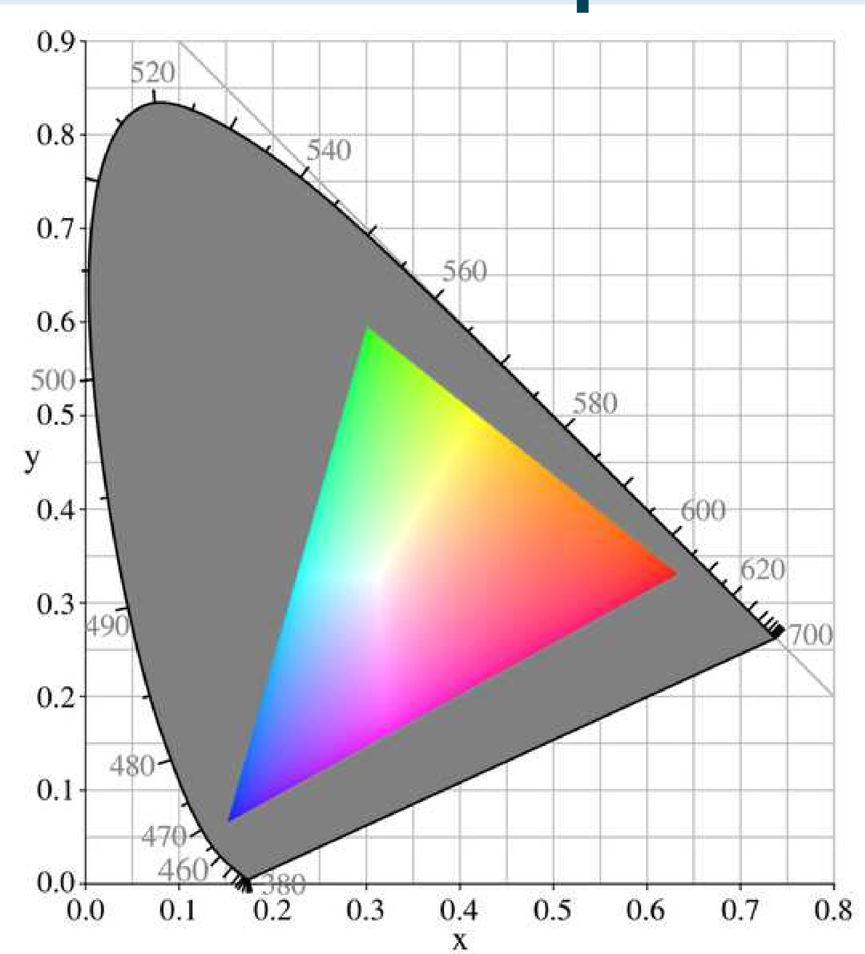
Human-Perceptible Colour Gamut



International Commission on Illumination (CIE) Chromaticity Diagram (1931)

- Colour is the perceptible proportion of the electromagnetic spectrum
- International Commission on Illumination (CIE) Chromaticity Diagram (1931). Describes 'average' properties of human eye.
- Curve is monochromatic (single-wavelength, nm) light

Standard Computer Display Gamut



- Only a portion of the human colour gamut is reproduced by typical computer displays.
- Image shows typical CRT/LCD display. Different devices have different gamuts: type (printer, projector, HDR display...), manufacturer, model.
- Image on previous slide describes colours outside the sRGB gamut, so depending on the display calibration, they may not be displayed properly!

Brightness & Contrast

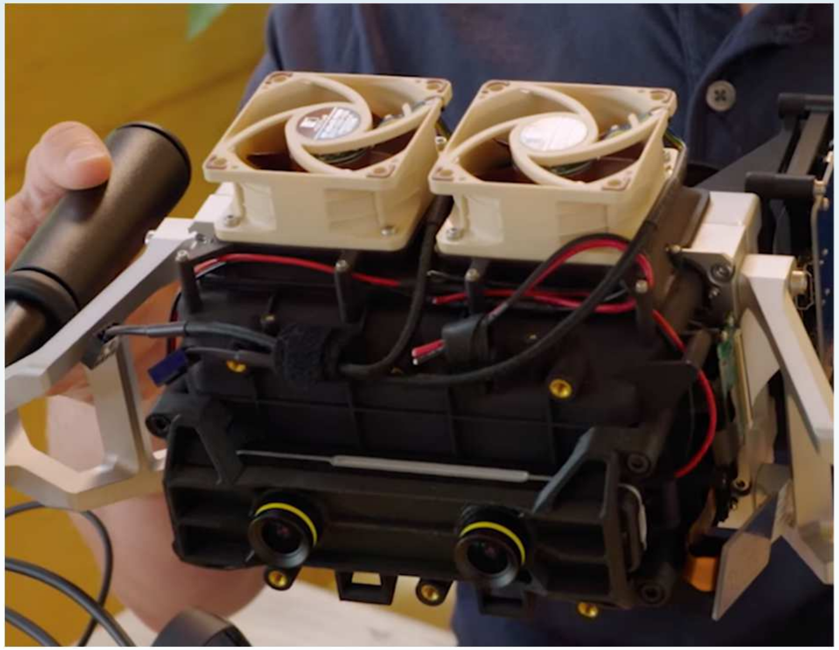
- Brightness
  - Projectors 2000 lumen
  - Screen 500 nits (1 Nit = 3.426 Lumens)
  - Luminance may be different for different colours
- Contrast Ratio

对比度：不同区域之间的亮度差异

  - Ratio between black level and white
  - 1000:1 is good
  - Very difficult to measure accurately
  - Also depends on response time (time to change between any two levels). Static vs Dynamic ratio.

High Dynamic Range

- Contrast ratio is determined by the lowest black level of the display (0,0,0 does not equal no light on most displays)
- Prototype HDR HMDs have been built
  - Meta's Starburst HMD, 20,000 nits
  - Note that brightness is dangerous



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2. **Stereo Rendering**

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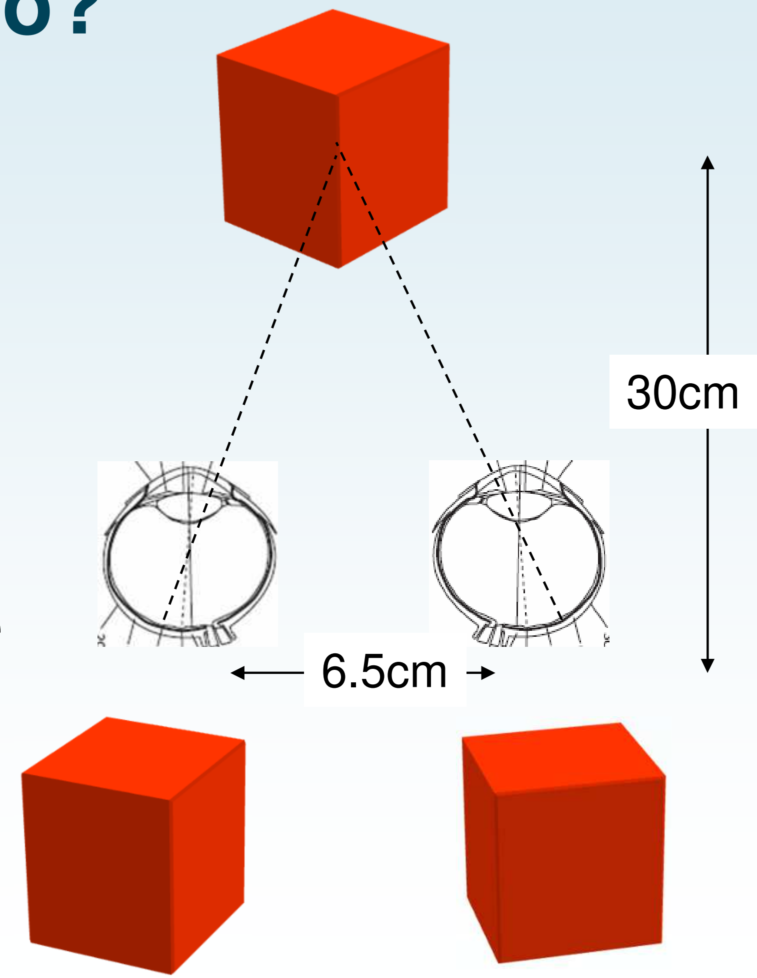
Virtualisation and How to Achieve It

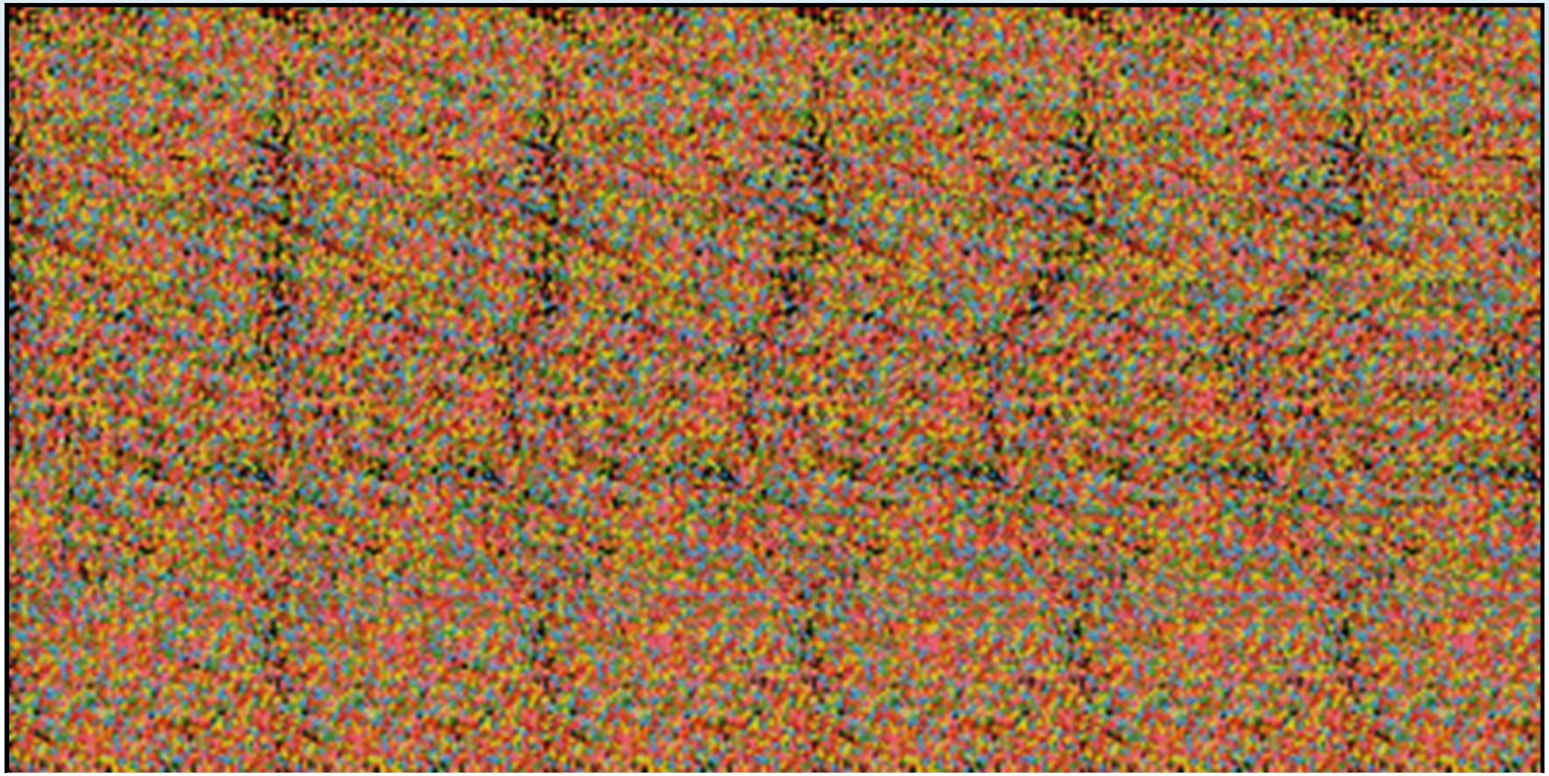
Level of virtualization	Definition	Cues	Technology
Virtual Space	3D objects inscribed on a flat sheet	ALL PSYCHOLOGICAL CUES: Linear persp., Shading, Shadows, Aerial persp., Occlusion, Texture cues	Pen & Paper + Perspective… ??
Virtual Image	Perception of objects with depth	PHYSIOLOGICAL CUES Stereoscopic disparity, Accomodation* Convergence*	“Stereoscope” 1830s Charles Wheatstone Stereo screens…
Virtual Environment	Objects slaved motion parallax	All cues consistent with observer motion	Cave, HMDs… ~1980s - ‘90s

How do we see in stereo?

- Inter-Pupilary Distance (IPD) or binocular disparity ~ 65mm
- Each eye has different view of same object
- Perceptual fusion of two views (cyclopean union), subsequent perception of depth
- Inputs from 2 eyes converge on the same cortical neurons in visual cortex (V1)



Autostereograms



Override vergence by forcing your eyes parallel

Presenting 3D images: Ideals

- Congruence

  L & R images should be same (except as caused by the horizontal parallax)

  Especially colour & brightness same for homologous points

- Vertical parallax = Zero

  If>0, uncomfortable to fuse images

- Parallax (view separation) trade off…

  Wide parallax: good depth, but too wide leads to discomfort.

  Parallax should be less <= IPD

  Closer the homologous points…less disparity between convergence & accommodation

  To provide maximum depth but lowest parallax, place principal objects so that ~½ parallax values are +ve, ½ -ve

Presenting Stereo

- In a HMD each eye sees a separate screen or part of one screen
- In CAVE-like VR, both eyes see the same screen
- Various methods for separating stereo views (similar to 3D cinema)
  - Active Stereo (shutter glasses)
  - Passive Stereo (e.g. polarising glasses)

- There are other methods that we will not cover
  - Wavelength separation
  - Autostereo displays

Active Stereo

- LCD alternates between transparent, and opaque when voltage is applied.
- Alternate-frame synchronising with display refresh using transmitter (IR in the CAVE).

Advantages:

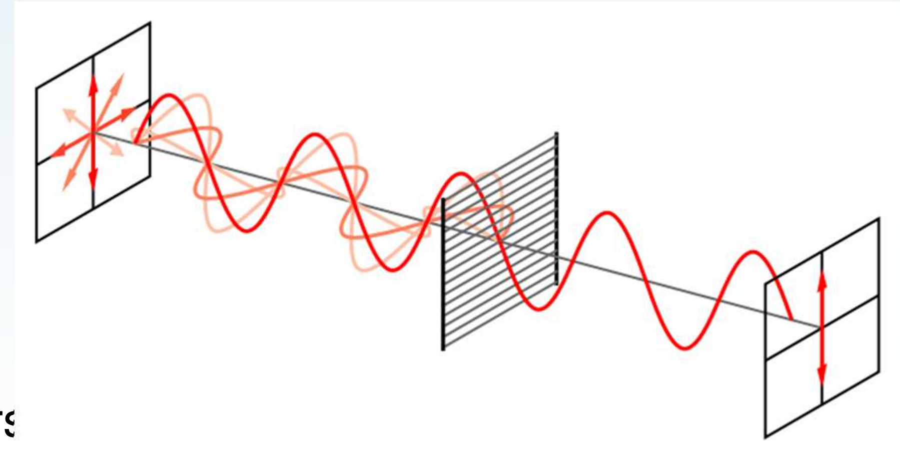
- No ghosting
- Copes with head-tilting well

Disadvantages:

- Need high-refresh monitor to avoid flickering
- Dark, as they shut out light (sunglasses)
- Bespoke and expensive

Passive Stereo

- Exploits polarisation of light. Left and right images are projected through different polarising filters. Left and right lenses of glasses pass similarly polarised light and block oppositely polarised light.
- Linear or circular polarisation. Circular supports head-tilting.



Advantages:

- Cheaper than active stereo
- Lightweight glasses

Disadvantages:

- Requires fitting projector filters
- Less flexibility with displays

HMD Optics

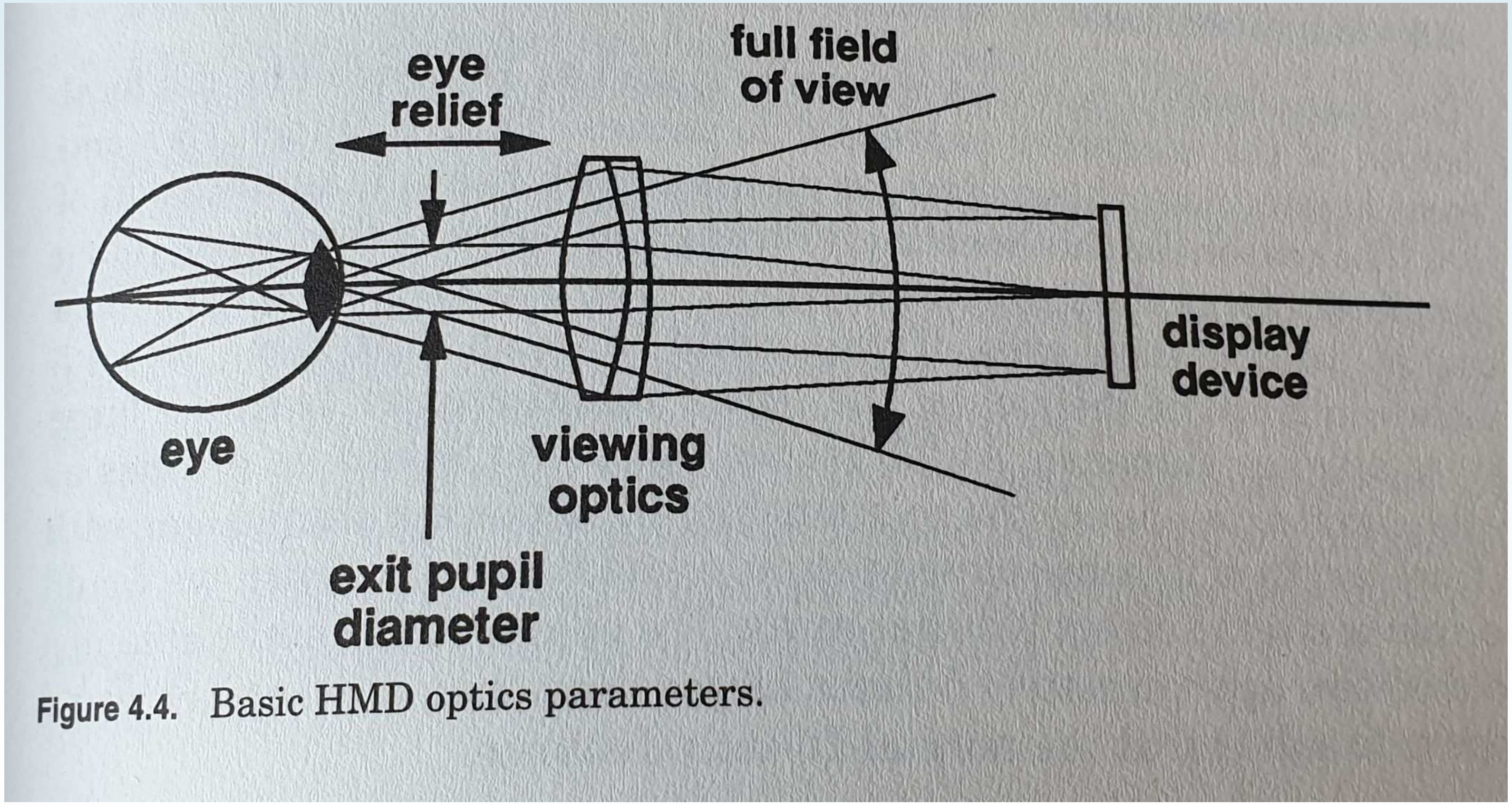
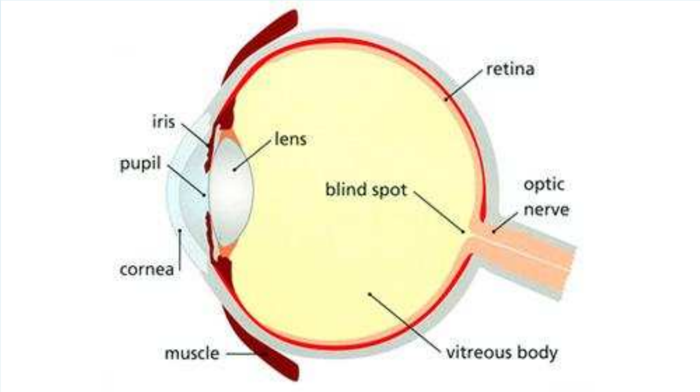


Figure 4.4. Basic HMD optics parameters.

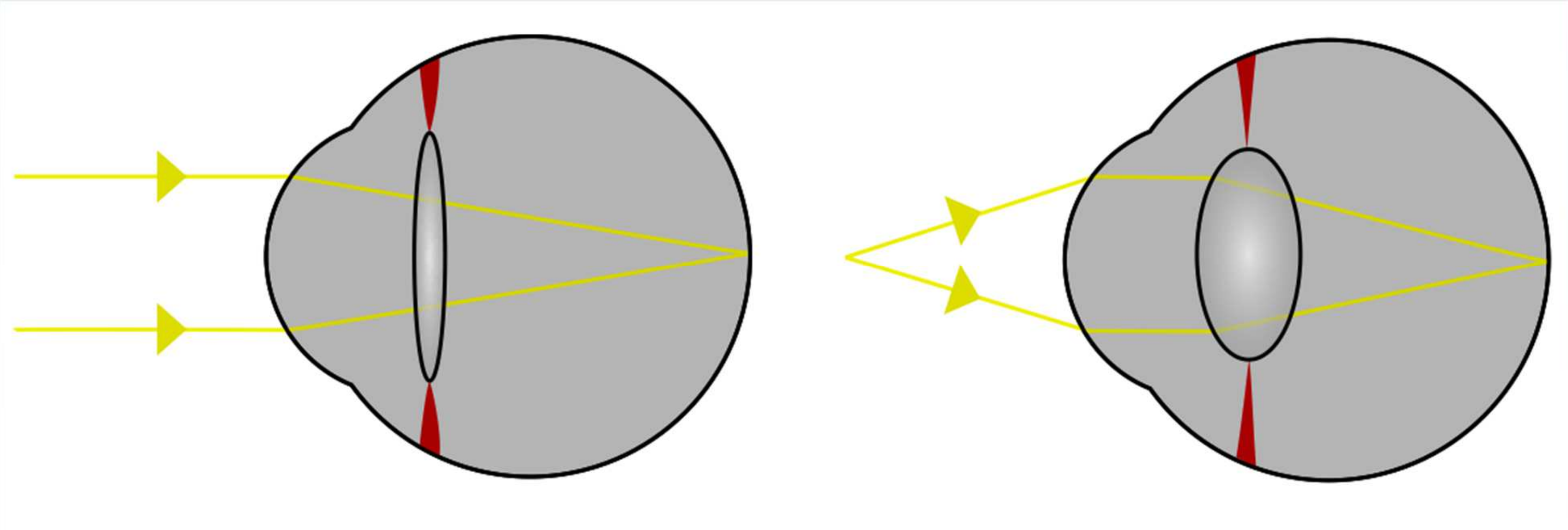
Head Mounted Displays, Melzer & Moffitt, 1997

HMD Optical Trade-Offs

- The screen is close to the eyes, so we need to relax the focus
- Screen size and pixel density is traded with optics and field of view
- Need to consider accommodation and vergence
- Optics is expensive or bulky
- Not a trade off, but no current commercial system is variable focus (with a minor exception for an AR display

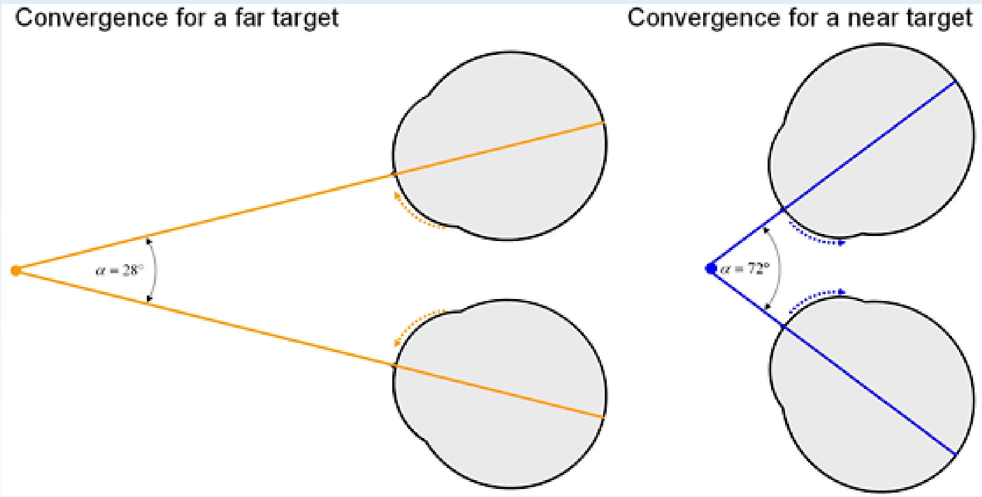


Accommodation



http://en.wikipedia.org/wiki/Accommodation_%28eye%29

Convergence



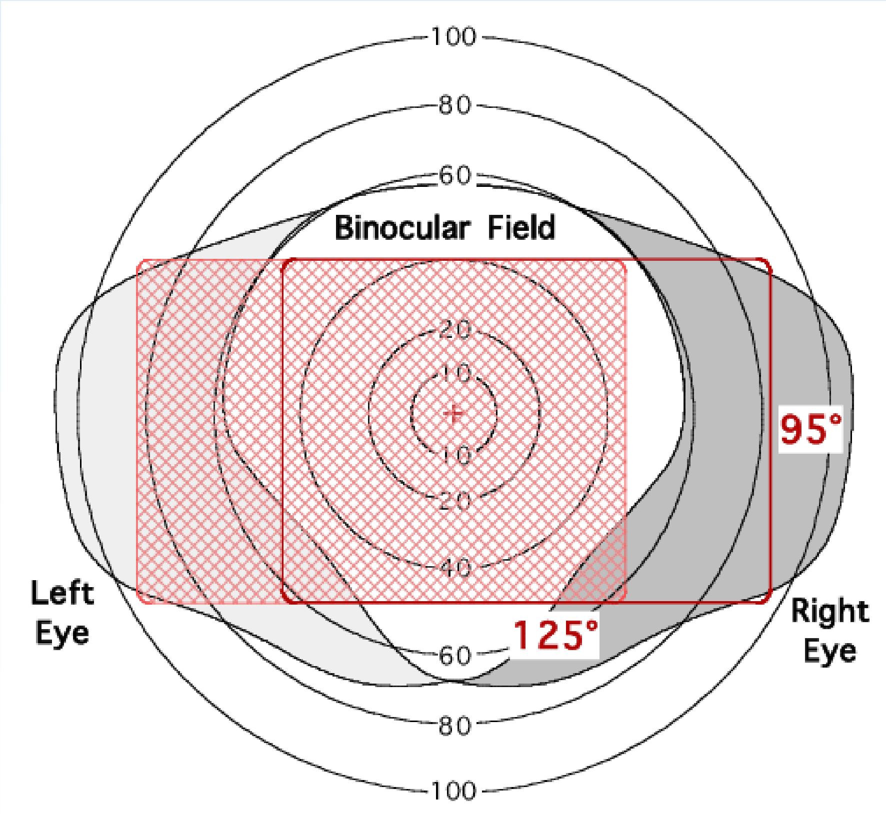
for depth
perception

http://www.sapdesignguild.org/editions/edition9/vision_physiology.asp

Accommodation and Convergence

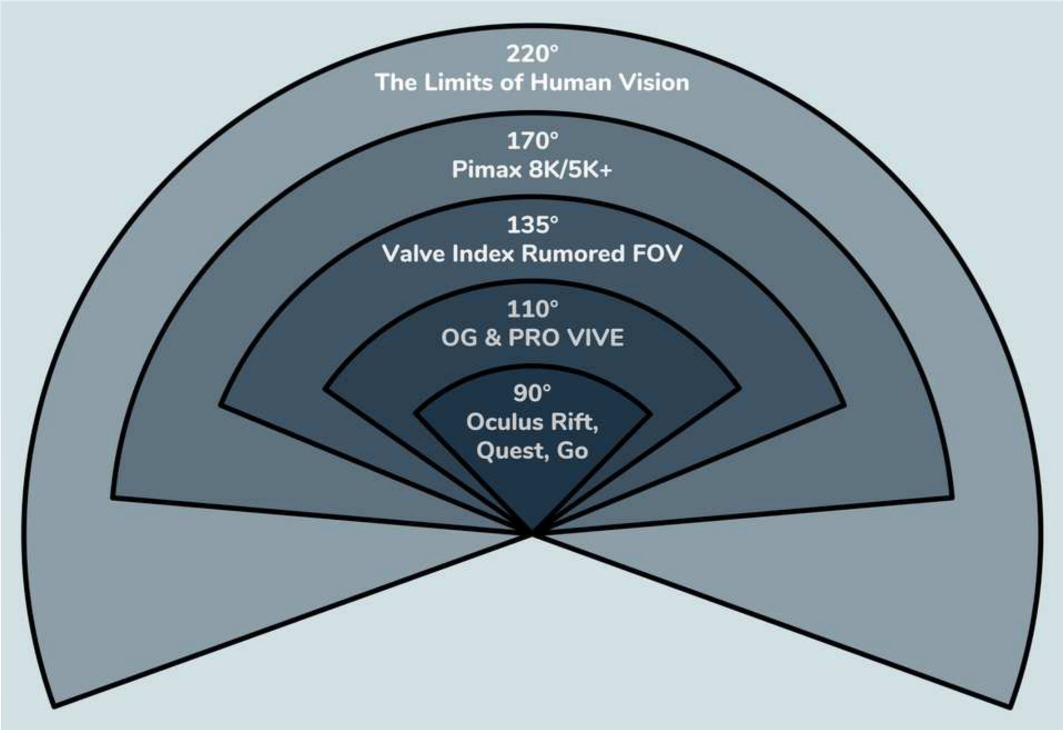
- Usually work in conjunction with each other
- This correspondence is not physiologically determined
- Learned by experience
- Can be broken by e.g. looking at screen based stereo views

Field of View



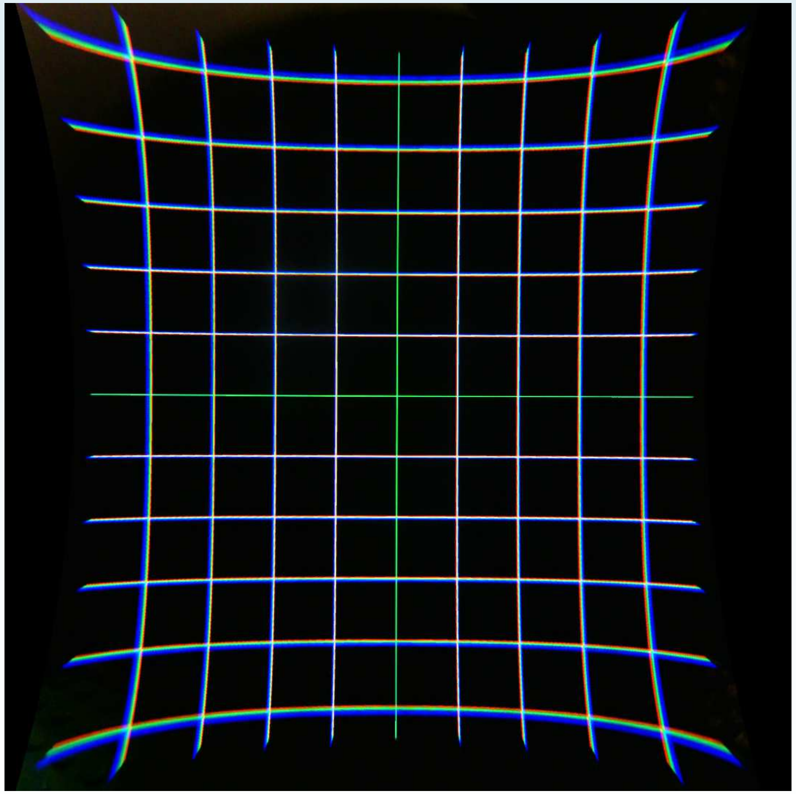
Templeman, James & Sibert, Linda & Page, Robert & Denbrook, Patricia. (2009). Comparing Two Different Forms of Dismounted Infantry Simulators.

Comparison of Current HMDs



https://www.reddit.com/r/ValveIndex/comments/b9lp7t/comparison_of_the_horizontal_fov_of_different/

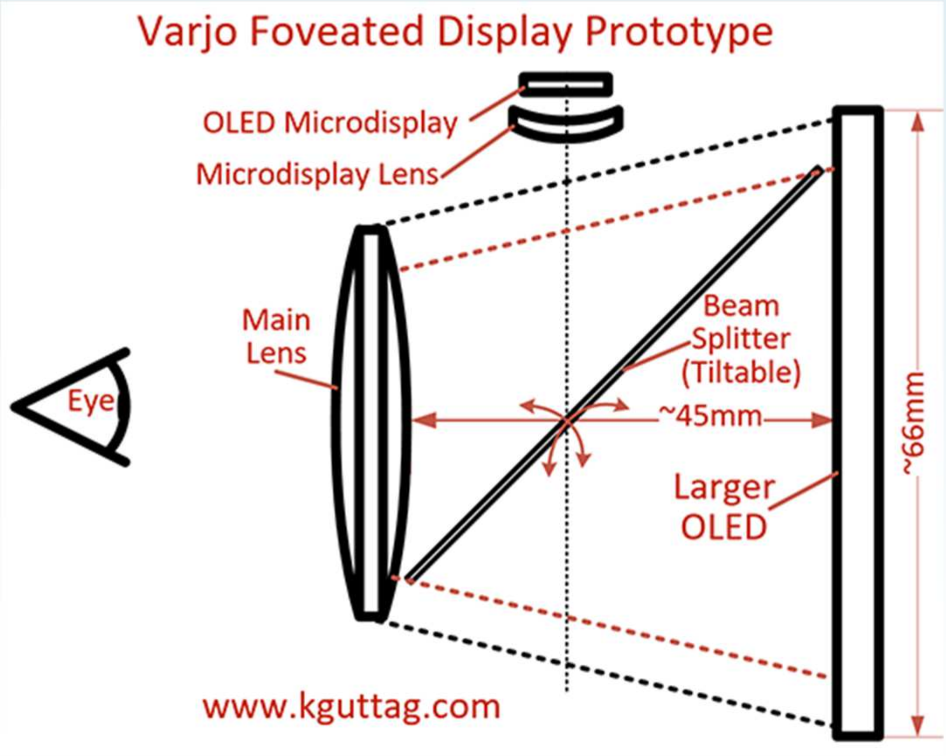
Aberration



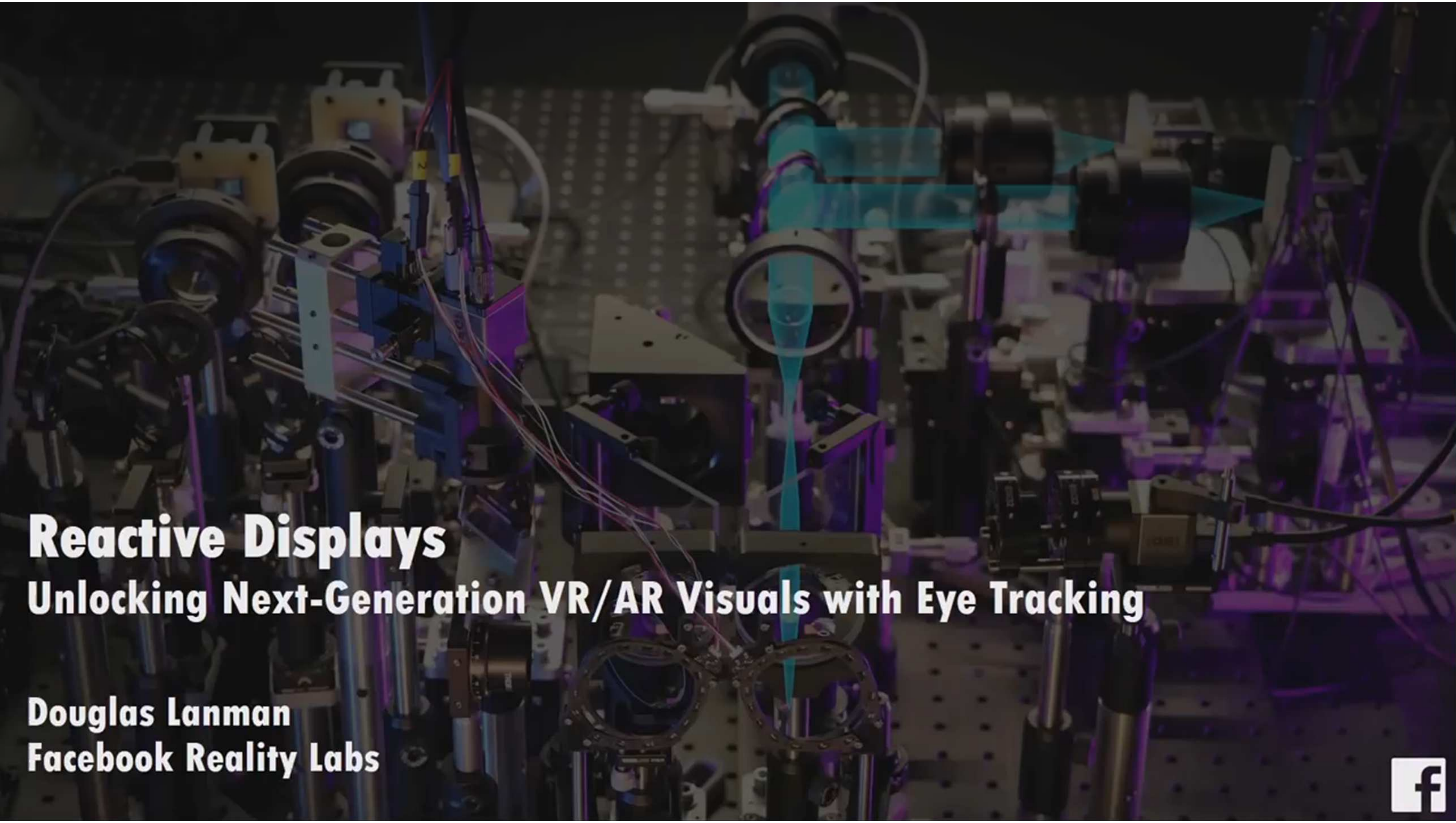
http://doc-ok.org/?p=1414

- Correct in software (or better optics)

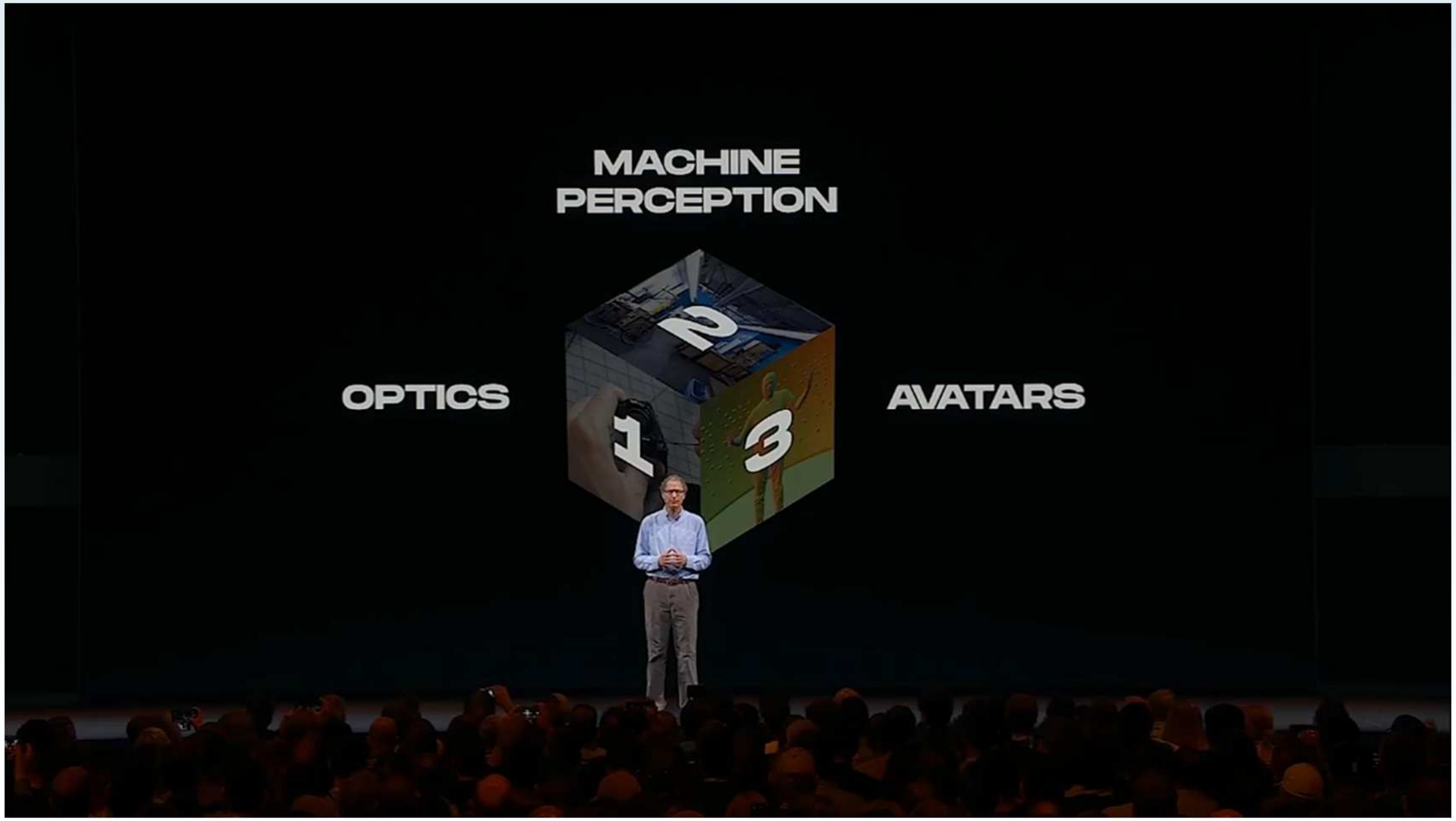
Varjo Foveated Display



https://www.kguttag.com/2017/06/26/varjo-foveated-display-part-1/


Reactive Displays
Unlocking Next-Generation VR/AR Visuals with Eye Tracking
Douglas Lanman
Facebook Reality Labs

Half-Dome 3



OC6 Facebook's Michael Abrash Talks New Half Dome Prototypes

Butterscotch Varifocal

https://www.meta.com/en-gb/blog/quest/reality-labs-research-display-systems-siggraph-2023-butterscotch-varifocal-flamera/

Summary

- Design of displays is a tradeoff of immersive characteristics
- Consumer VR systems follow a long tradition of similar HMDs back to the 1980s but change (e.g. varifocal) is coming
- While developments in consumer HMDs 2010-2015 was driven by smartphone screens, more recent HMDs have needed better screen technology