CIS 4930-001: Introduction to Augmented and Virtual Reality

Display Technologies

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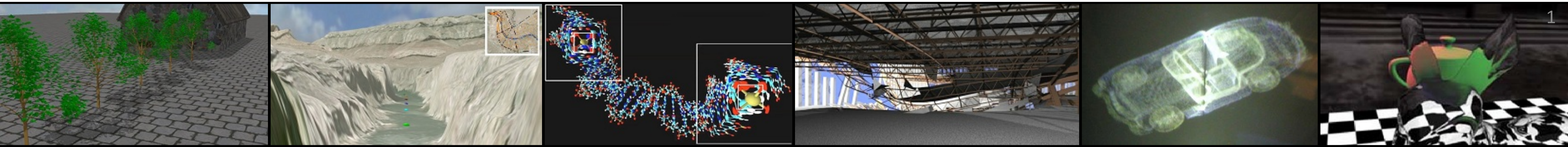
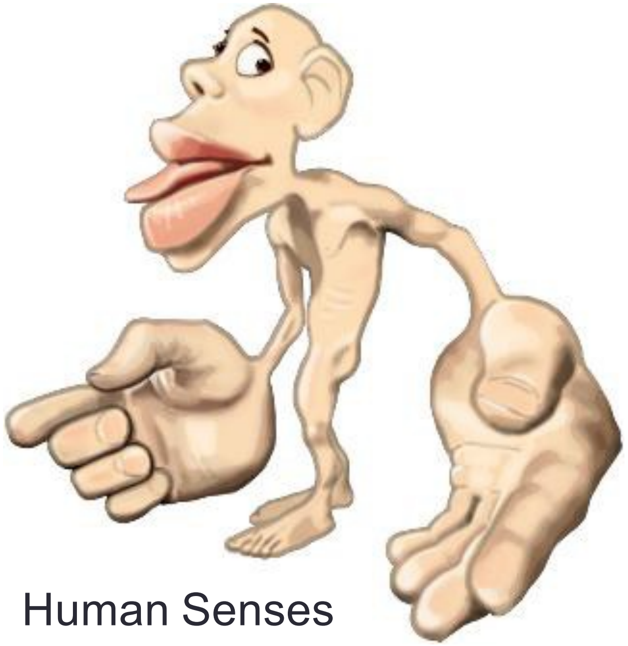


Motivation

VR Hardware



Human Senses

Understand: In order to create a strong sense of Presence we need to understand the Human Perception system

Stimulate: We need to be able to use technology to provide real world sensory inputs, and create the VR illusion

Senses

How an organism obtains information for perception:

- Sensation part of Somatic Division of Peripheral Nervous System
- Integration and perception requires the Central Nervous System

Five major senses:

- Sight (Opthalamoception)
- Hearing (Audioception)
- Taste (Gustaoception)
- Smell (Olfacaoception)
- Touch (Tactioception)

USING TECHNOLOGY TO STIMULATE SENSES

Simulate output

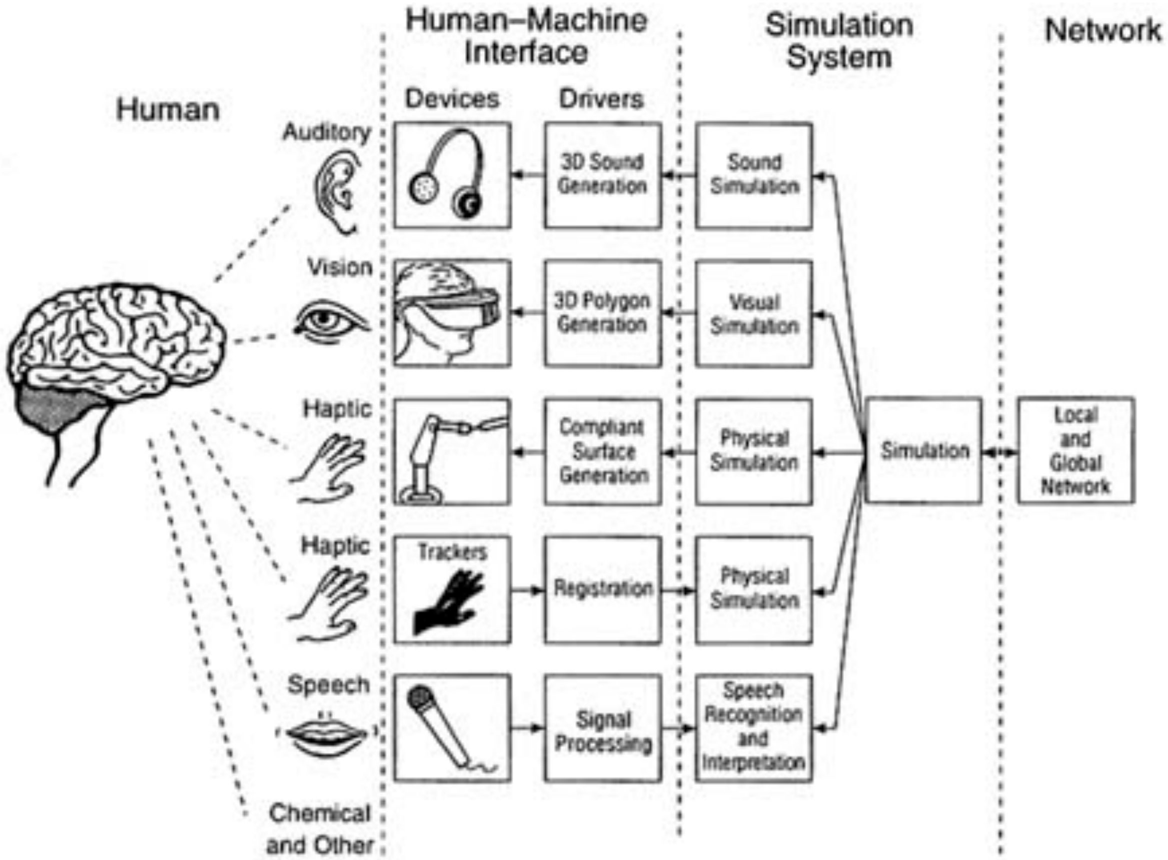
- E.g. simulate real scene

Map output to devices

- Graphics to HMD

Use devices to stimulate the senses

- HMD stimulates eyes



KEY TECHNOLOGIES FOR VR SYSTEM

Visual Display (this lecture)
- Stimulate visual sense

Audio/Tactile/Other (later on)
- Stimulate hearing/touch

Tracking (later on)
- Changing viewpoint
- User input

Input Devices (later on)
- Supporting user interaction

Properties of the Human Visual System

visual acuity: 20/20 is ~1 arc min

field of view: ~200° monocular, ~120° binocular, ~135° vertical

resolution of eye: ~576 megapixels

temporal resolution: ~60 Hz (depends on contrast, luminance)

dynamic range: instantaneous 6.5 f-stops, adapt to 46.5 f-stops

color: everything in CIE diagram

accommodation range: ~8cm to ∞, degrades with age

Creating an Immersive Experience

Head Mounted Display (HMD)

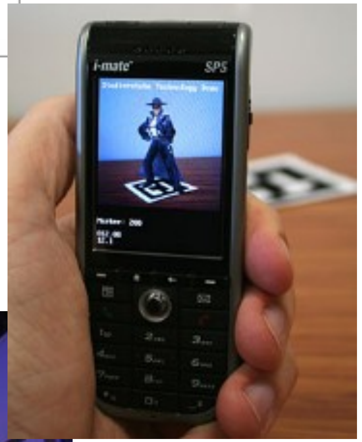
- Immerse the eyes

Handheld

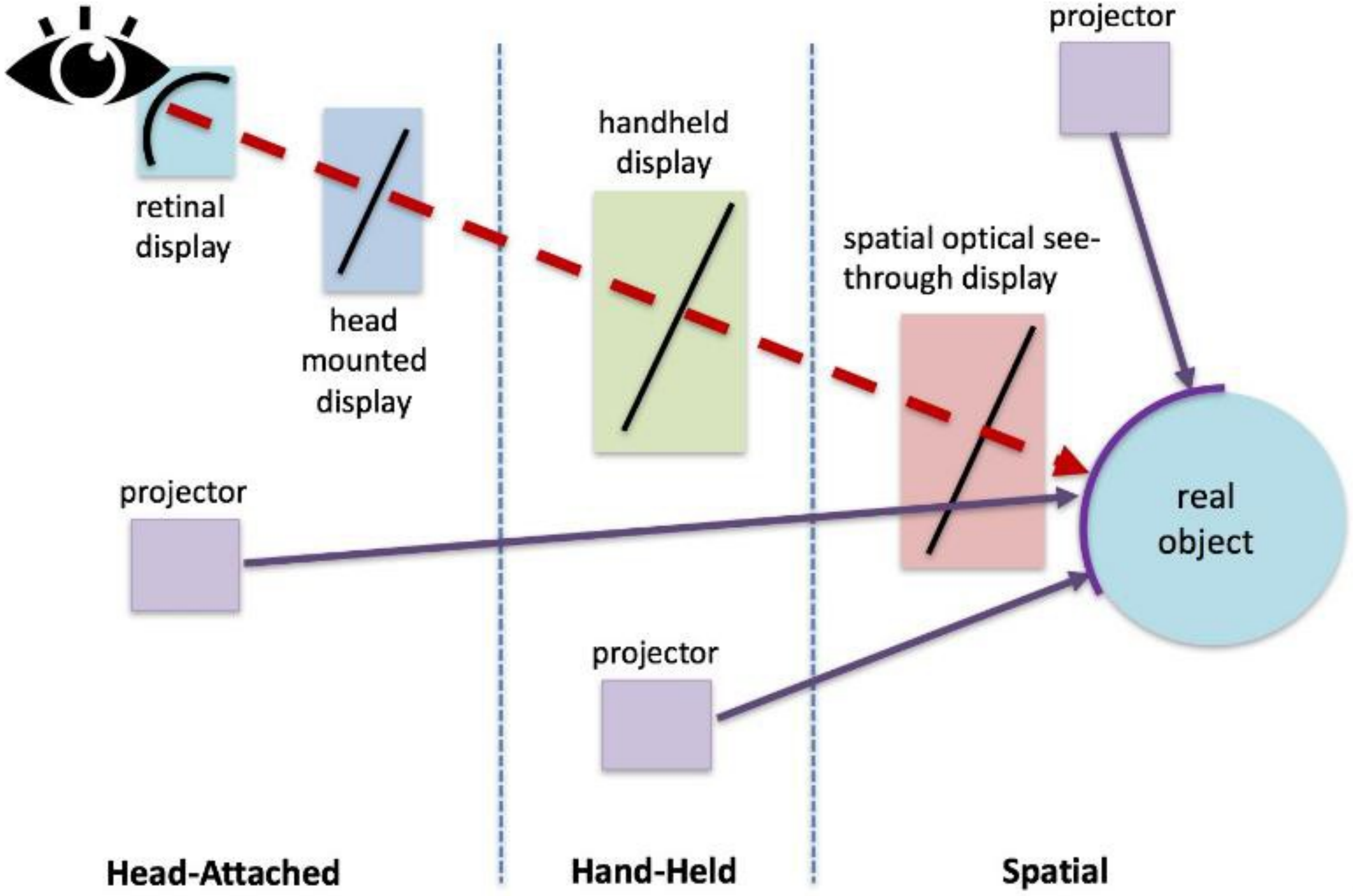
- Lightweight, dynamic, and interactive

Projection/Large Screen

- Immerse the body
- Modify the space



DISPLAY TAXONOMY



BIMBER, O., & RASKAR, R. (2005). SPATIAL AUGMENTED REALITY: MERGING REAL AND VIRTUAL WORLDS. CRC PRESS.

KEY PROPERTIES OF HMDs

Lens

- Focal length, Field of View
- Occularity, Interpupillary distance
- Eye relief, Eye box

Display

- Resolution, contrast
- Power, brightness
- Refresh rate

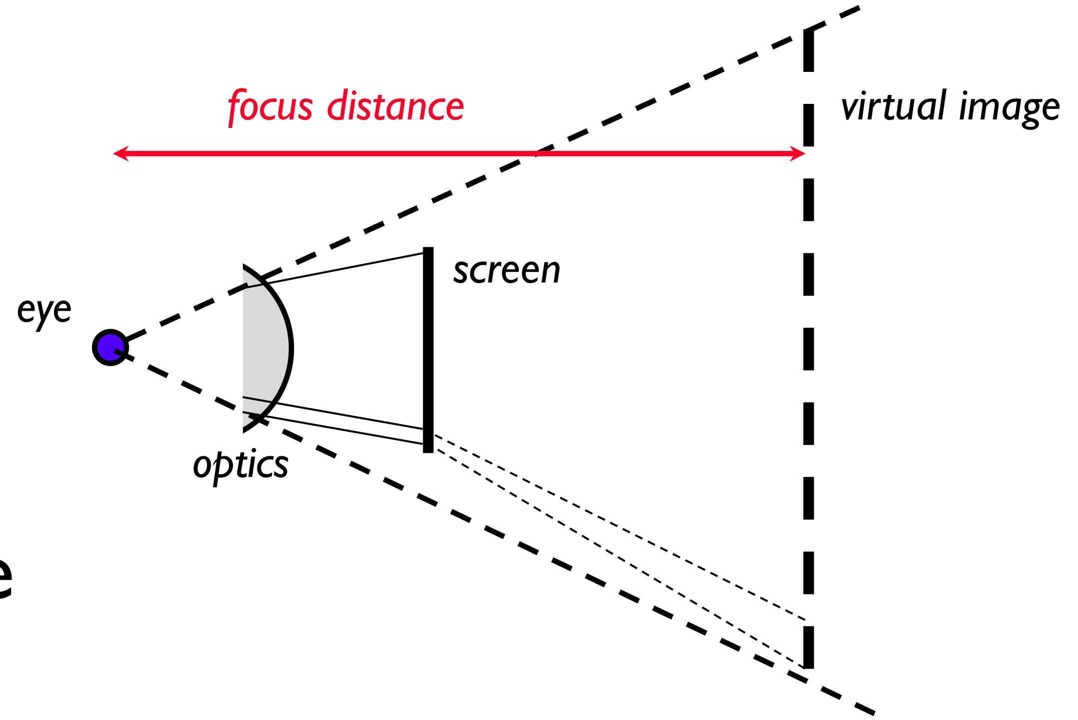
Ergonomics

- Size, weight, wearability

Focal Distance

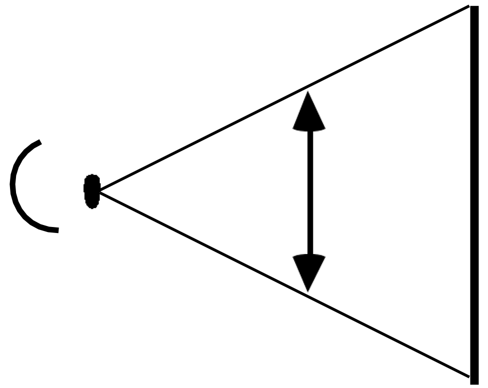
Optics between the image plane and the user's eye produce a virtual image farther away from the eye

- Reduces accommodative effort
- Ideally out a few meters to help cancel convergence/accommodative rivalry
- Optics magnify pixel granularity!



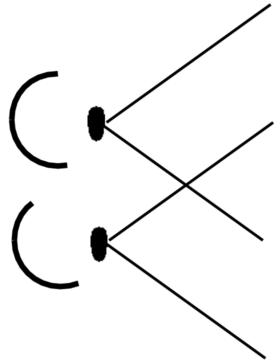
FIELD OF VIEW

Monocular FOV is the angular subtense (usually expressed in degrees) of the displayed image as measured from the pupil of one eye.



Total FOV is the total angular size of the displayed image visible to both eyes.

Binocular (or stereoscopic) FOV refers to the part of the displayed image visible to both eyes.



FOV may be measured horizontally, vertically or diagonally.

OCULARITY

Monocular - HMD image to only one eye.

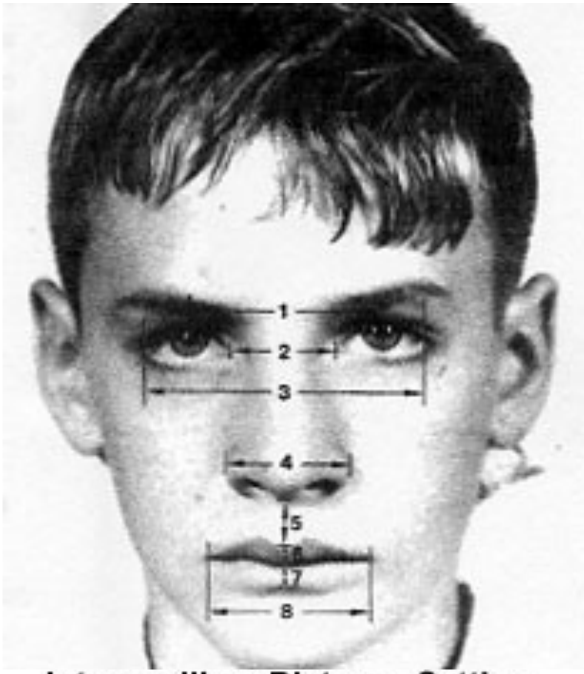
Bioccular - Same HMD image to both eyes.

Binocular (stereoscopic) - Different but matched images to each eye.

Interpupillary Distance (IPD)

IPD is the horizontal distance between a user's eyes.

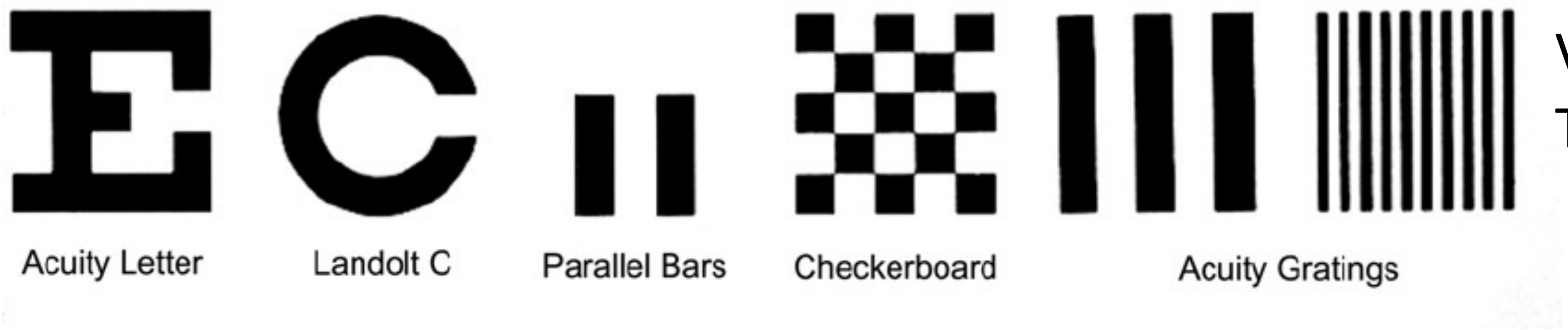
IPD is the distance between the two optical axes in a binocular view system.



Interpupillary Distance Setting

Figure 5

<u>VISUAL ACUITY</u>



Visual Acuity
Test Targets

Ability to resolve details

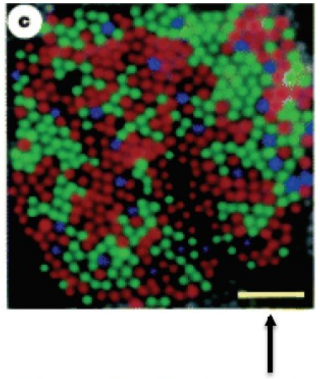
Several types of visual acuity

- detection, separation, etc.

Normal eyesight can see a US quarter at 275 ft

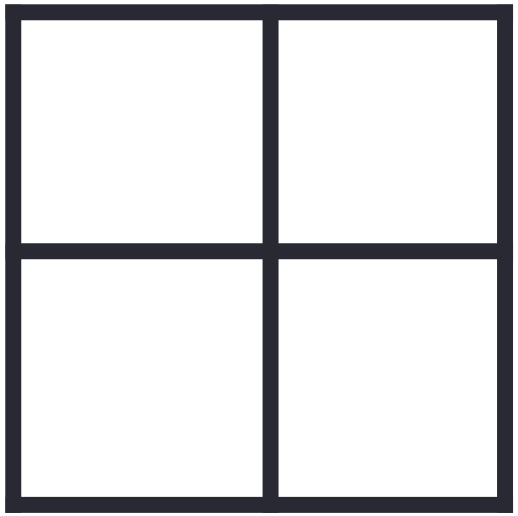
- Corresponds to 1 arc min (1/60th of a degree)
- Max acuity = 0.4 arc min

each photorecepter
~ <u>1 arc min</u> (1/60 of a degree)

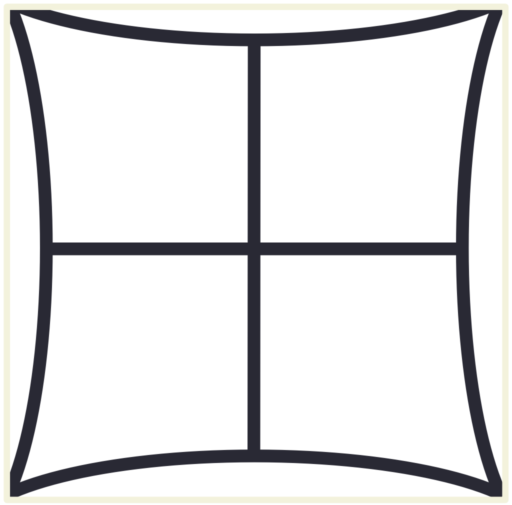


5 arcmin visual angle

DISTORTION IN LENS OPTICS



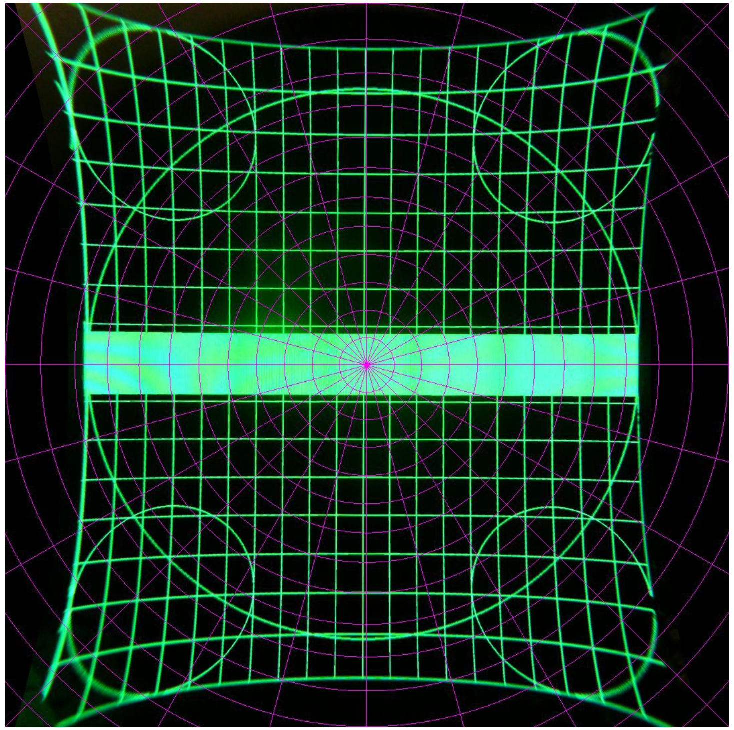
A rectangle



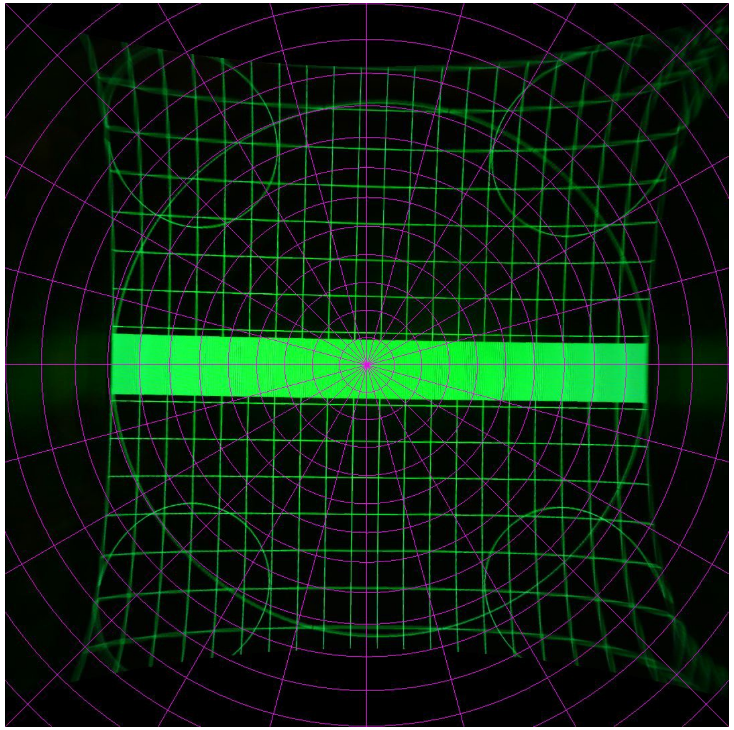
Maps to this

HMD optics distort images shown in them

Example Distortion



Oculus Rift DK2



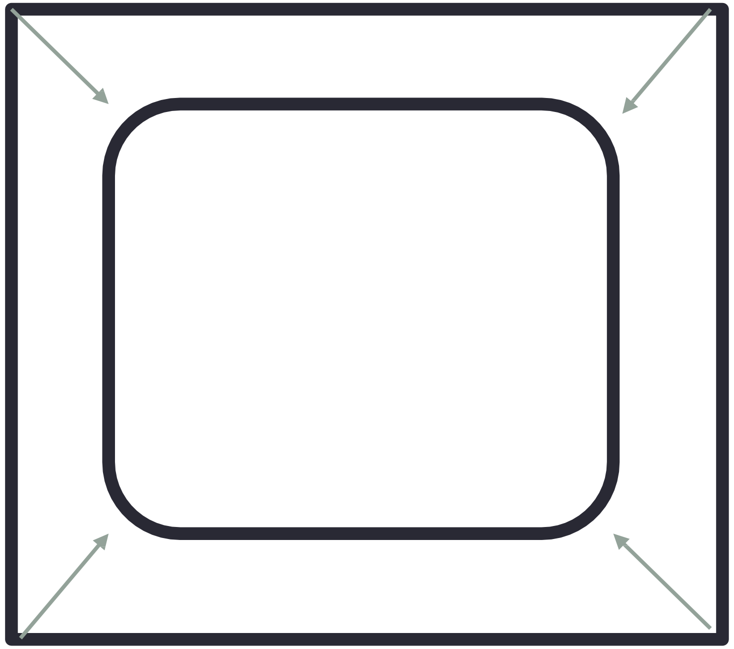
HTC Vive

To Correct for Distortion

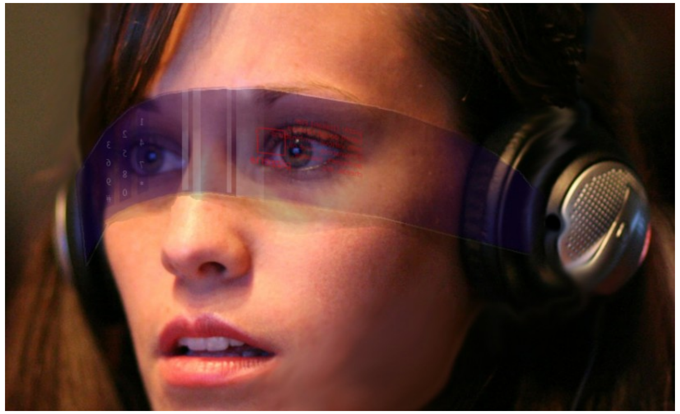
Must pre-distort image

This is a pixel-based distortion

Use shader programming



HMD DESIGN TRADE-OFFS



vs.

Resolution vs. field of view

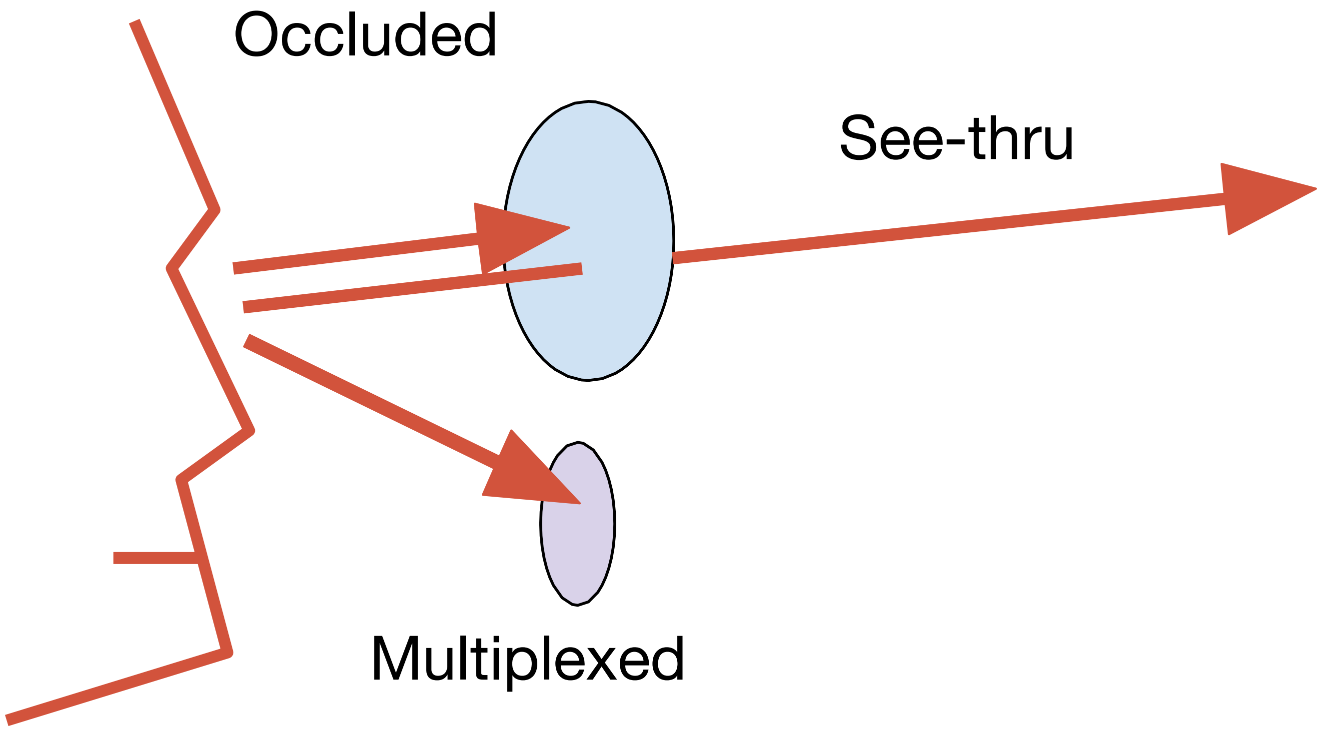
- As FOV increases, resolution decreases for fixed pixels

Eye box vs. field of view

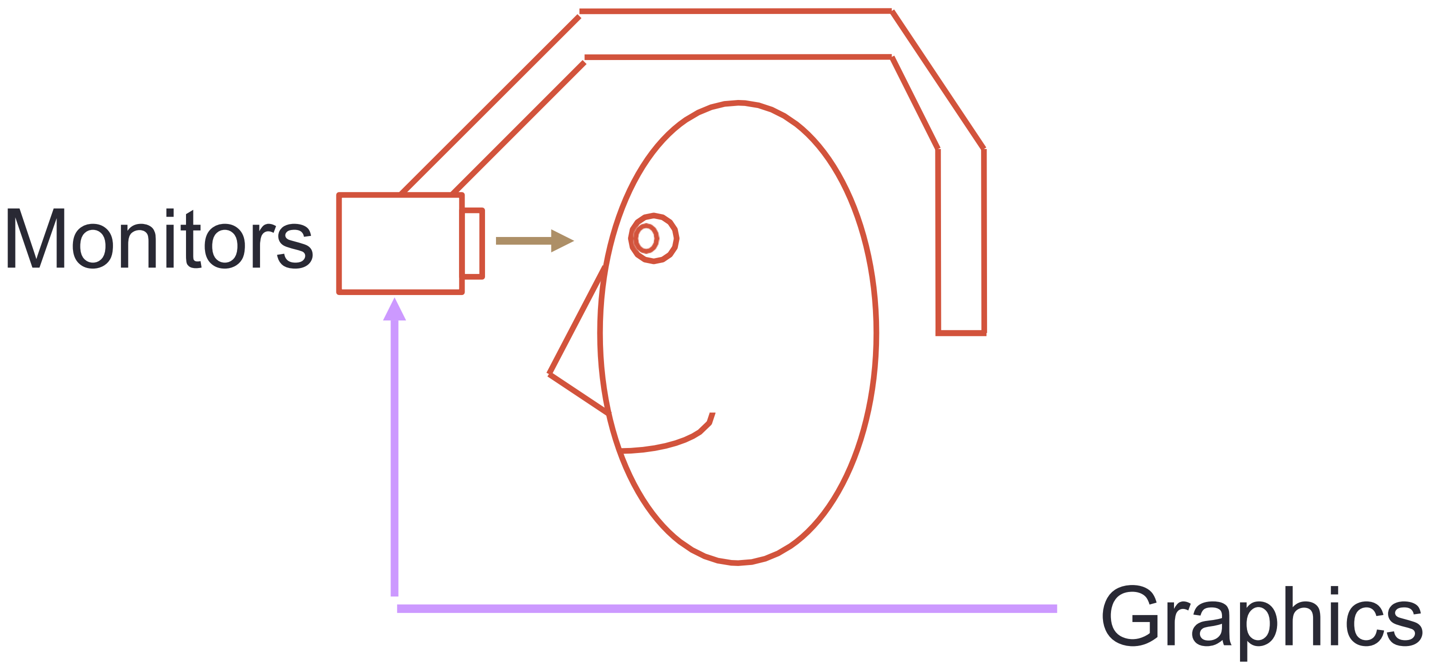
- Larger eye box limits field of view

Size, Weight, and Power vs. everything else

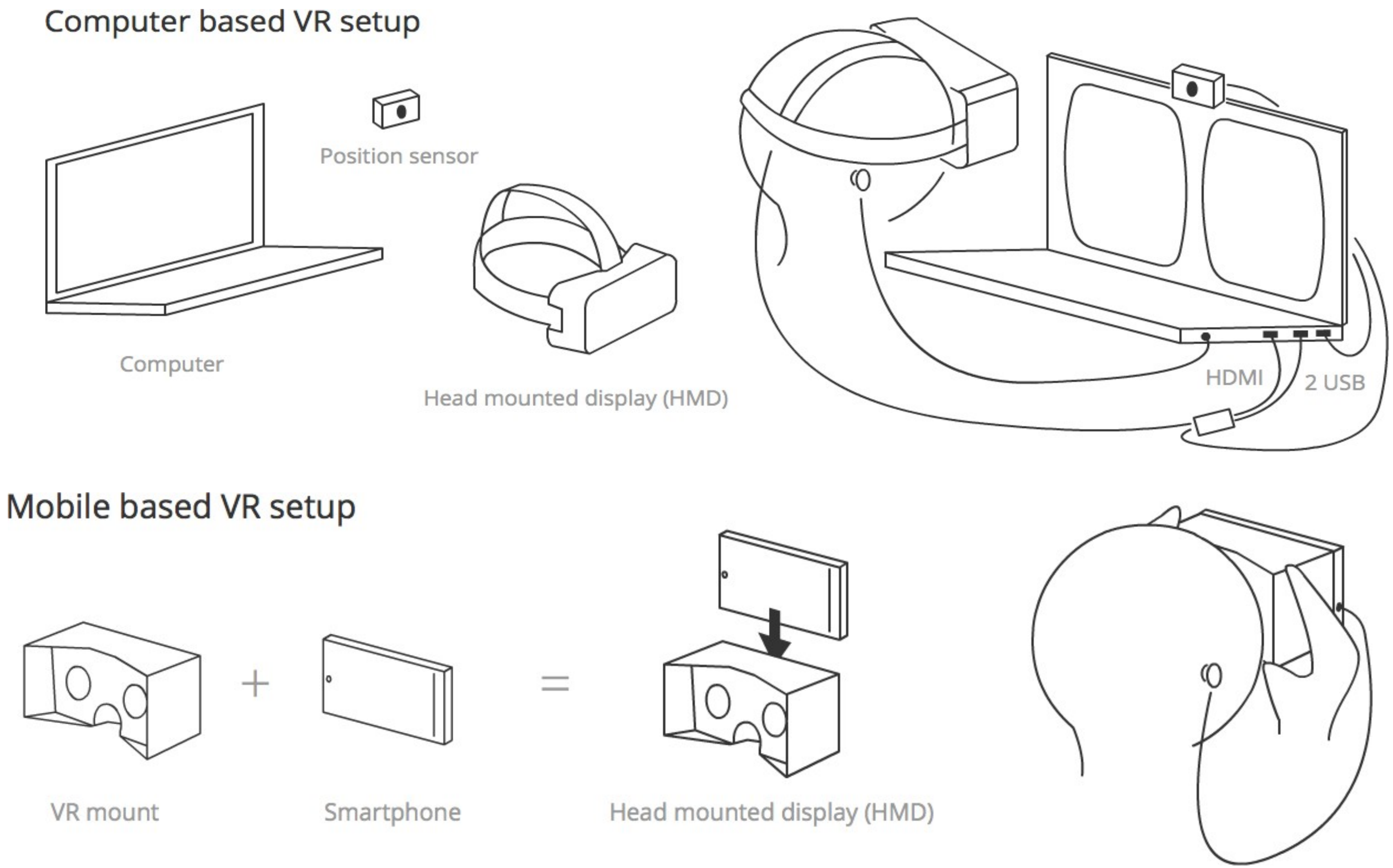
3 Types of Head Mounted Displays



VR ONLY HMD



Computer Based vs. Mobile VR Displays



Good Ol' Days: CRT-based HMD

Datavisor HiRes: 1280x1024, 1.9'/pixel, 42° fov (100% overlap), about 4lbs, uses monochrome CRT w/ color filter shutters

Datavisor 80: 1280x1024, 3'/pixel, accommodation at infinity, 80° diagonal fov, 120° with 20% overlap, about 5lbs

Oculus Rift

Cost: $399 USD

FOV: 110o Horizontal

Refresh rate: 90 Hz

Resolution 1080x1200/eye

3 DOF orientation tracking

3 axis positional tracking

Inside an Oculus Rift

Oculus DK2 Teardown

- Samsung 5.7” AMOLED: 1920x1080px, 75Hz
- 2 sets of lenses (for different prescriptions)
- InvenSense 6-axis IMU
- ARM Cortex-M3 MCU
- …

https://www.ifixit.com/Teardown/Oculus+Rift+Development+Kit+2+Teardown/27613

Comparison Between HMDs

					
Name	**Oculus Rift**	**HTC Vive**	**PlayStation VR**	**StarVR**	**OSVR HDK**
Manufacturer	Oculus VR	HTC, Valve	Sony	Starbreeze	Razer, Sensics
Display	2x OLED	2x OLED	OLED	2x LCD	LCD
Resolution	2160x1200px	2160x1200px	1920x1080px	5120x1440px	1920x1080px
Framerate	90fps	90fps	120fps	60fps	60fps
Field of view	>110°	>110°	100°	210°	100°
Positional tracking	6DOF	6DOF Valve Lighthouse	6DOF	6DOF	6DOF
Controller	Xbox One controller/Oculus Touch	two SteamVR controllers, one for each hand	Playstation Move/DualShock 4	-	-

Mobile VR: Google Cardboard

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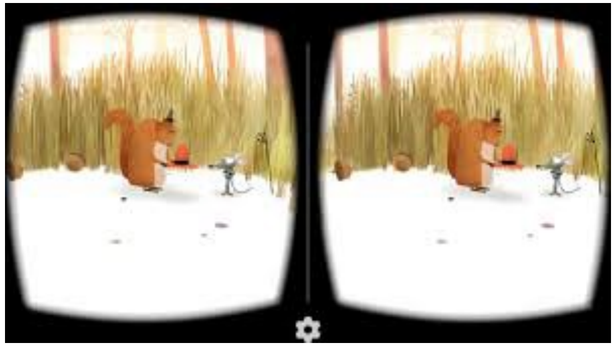


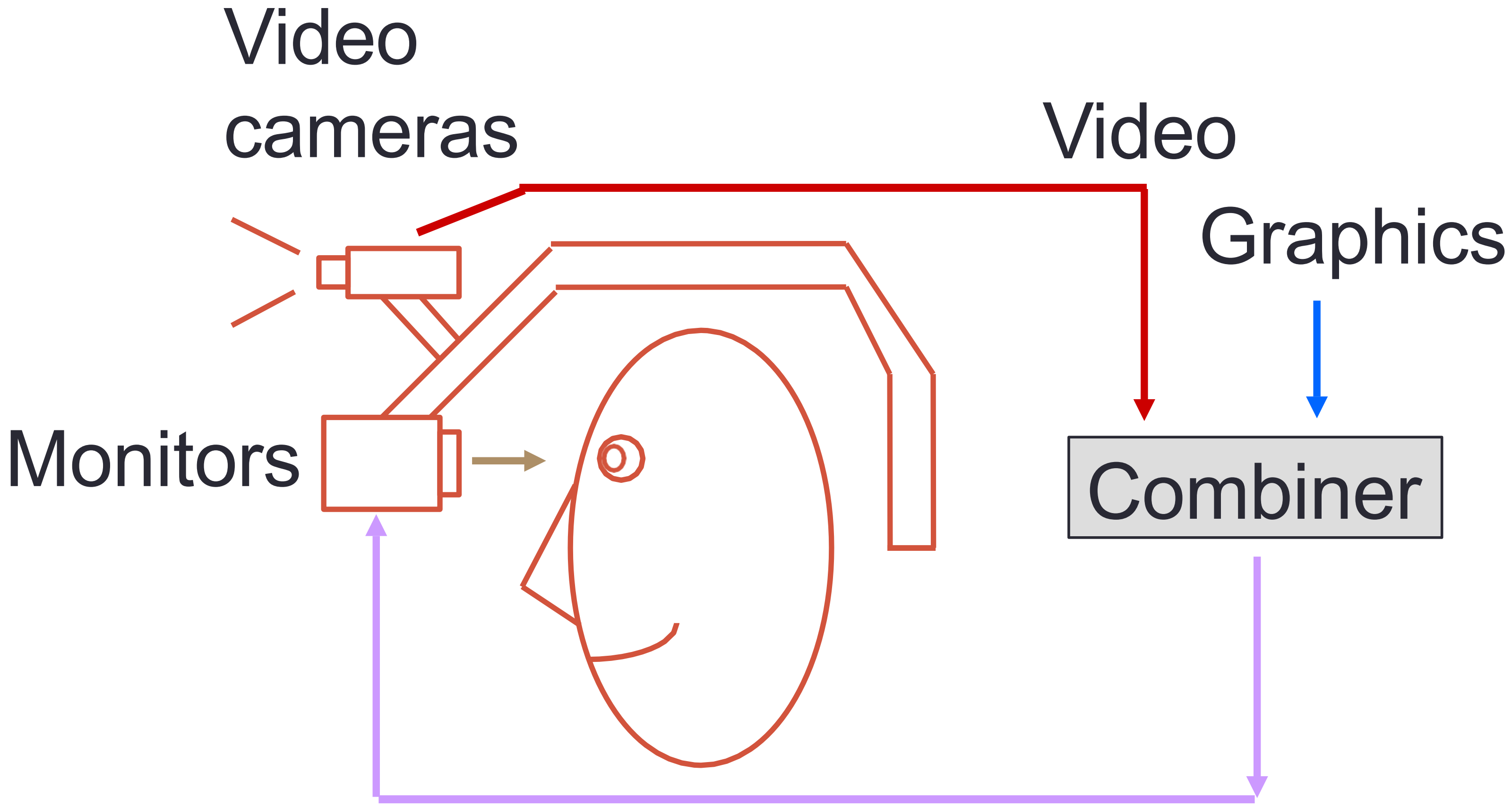
Released 2014 (Google 20% project)

>5 million shipped/given away

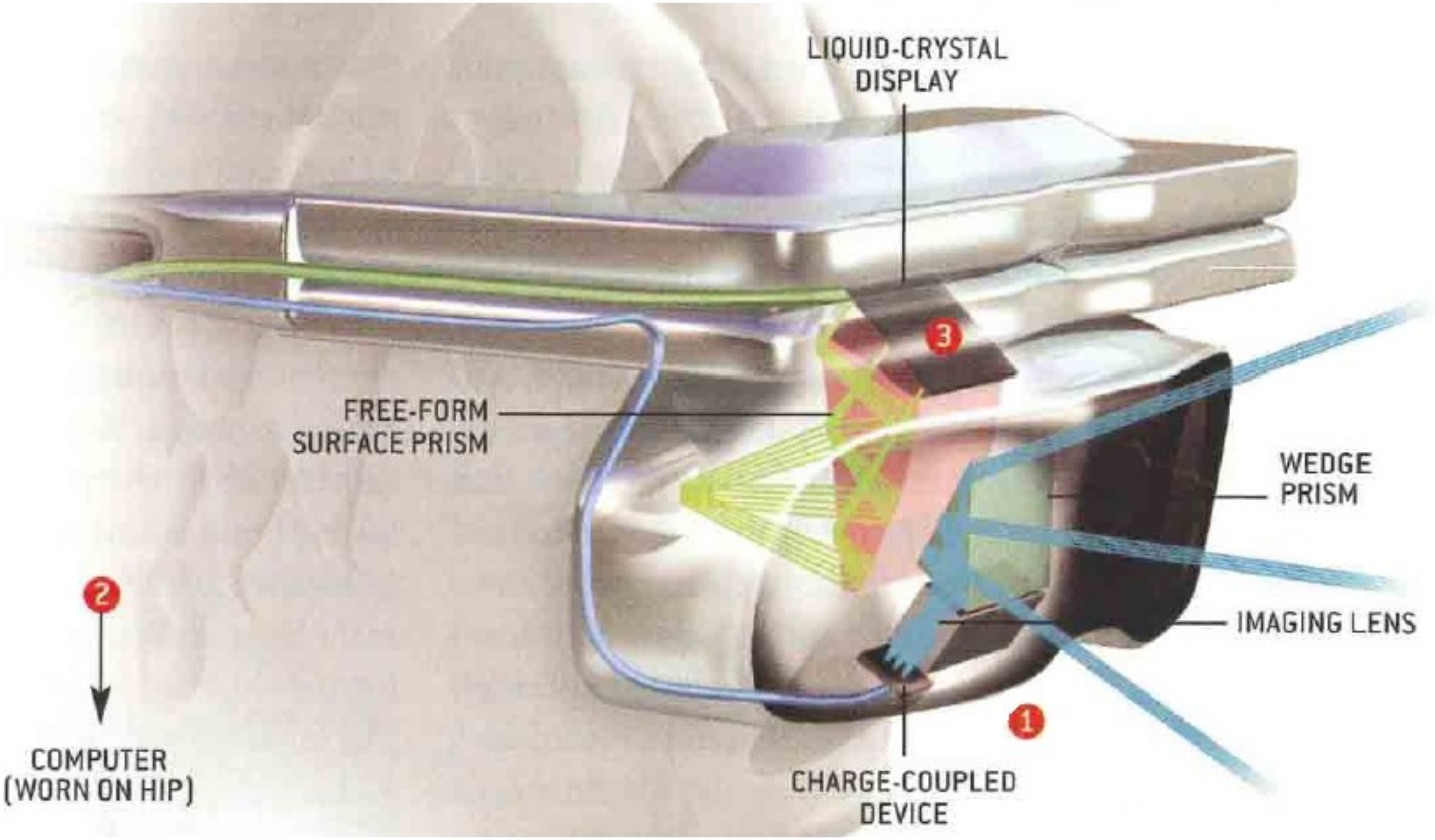
Easy to use developer tools

Multiple Mobile VR Viewers Available

VIDEO SEE-THROUGH HMD



Video See-Through HMD



EXAMPLE: VIVE PRO

Resolution: 1440x1600 pixels per eye

- 2880x1600 pixels combined

Refresh rate: 90 Hz

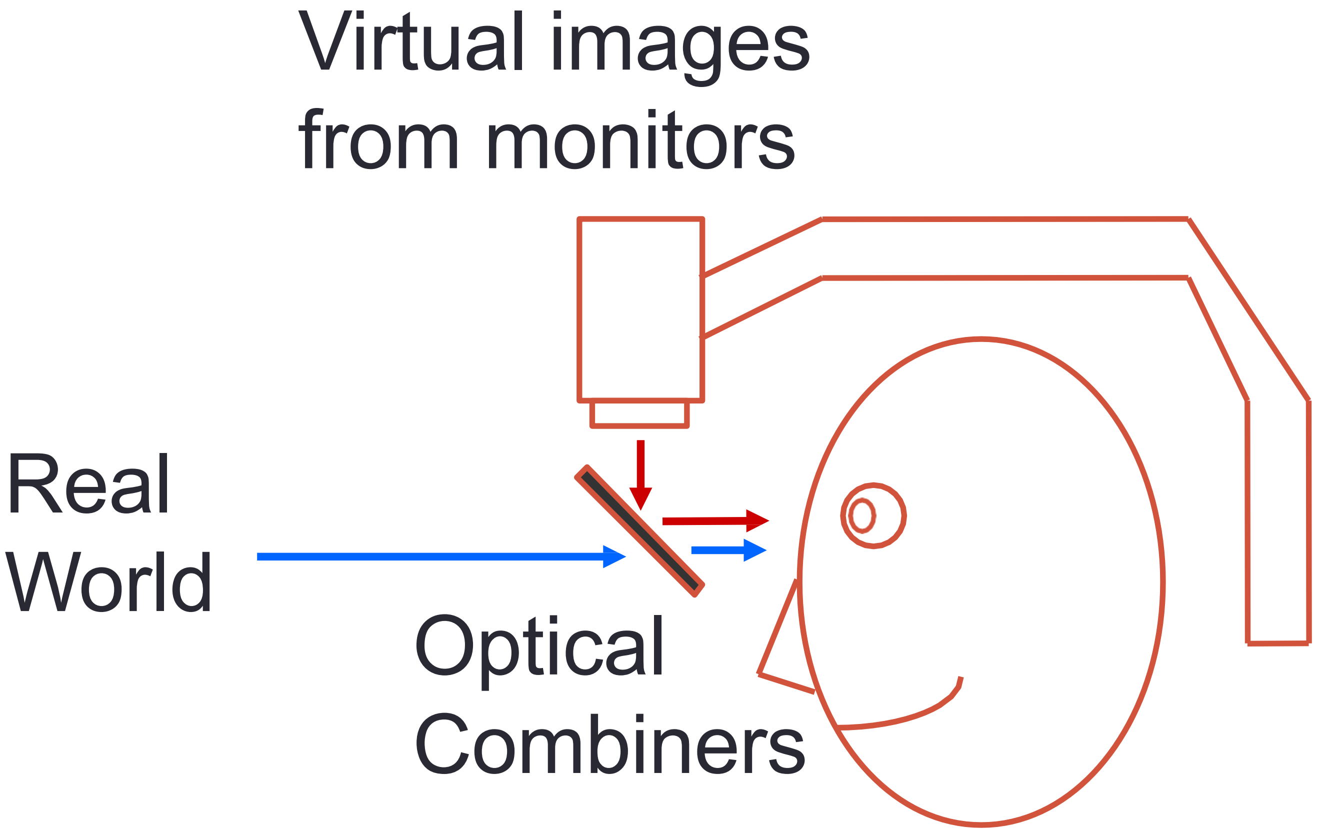
Field of view: 110 degrees

https://www.vive.com/us/product/vive-pro/

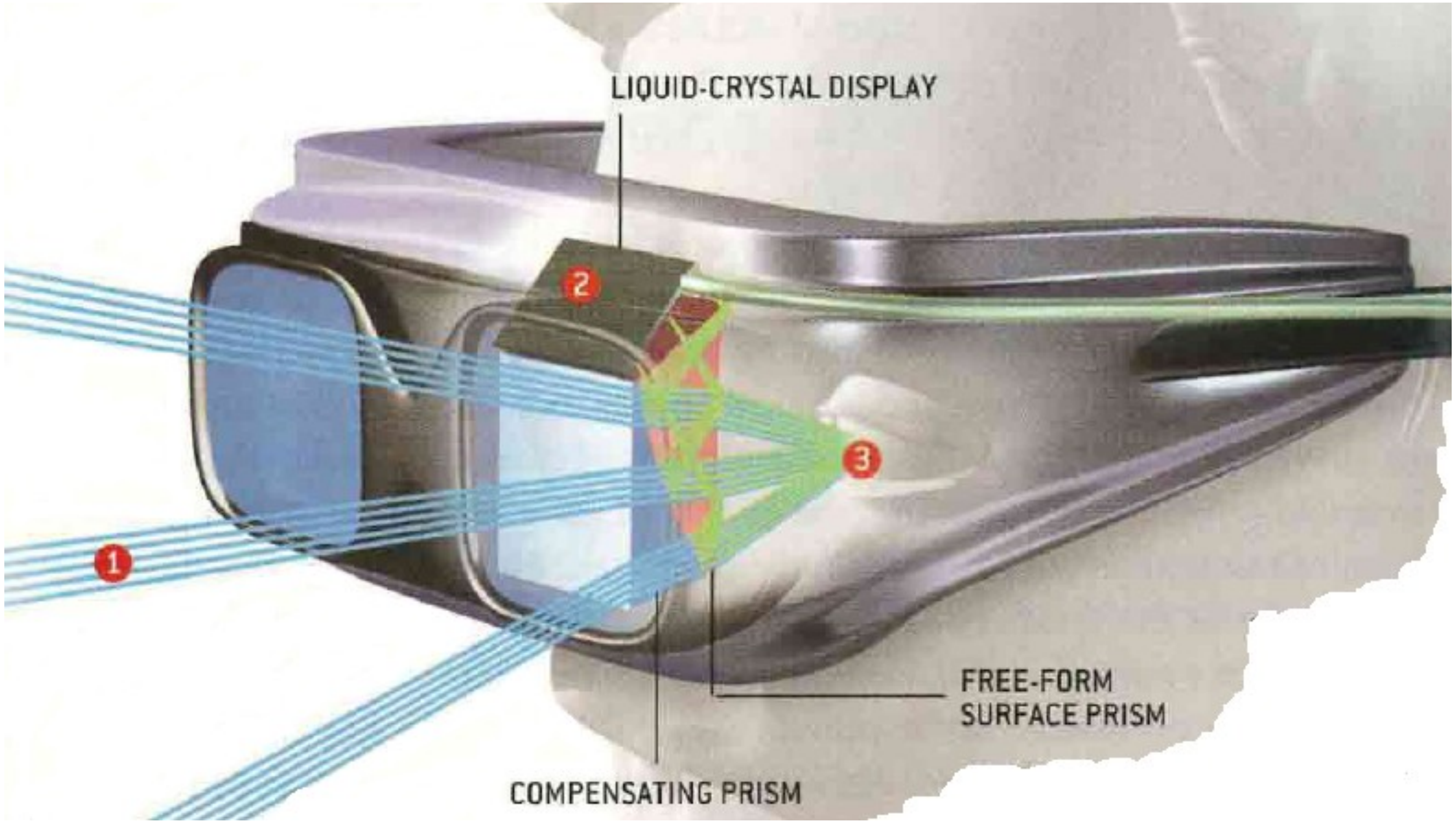
Vive Pro Video-Through Demo

https://youtu.be/yl44JFtDo0E

Optical see-through Head-Mounted Display



Optical See-Through HMD



Strengths of Video See-Through AR

True occlusion

- AR pixels block video pixels

Digitized image of real world

- Flexibility in composition
- Matchable time delays
- More registration, calibration strategies

Wide FOV is easier to support

Optical See-Through Displays

Epson Moverio BT-300 - $700

- 1280 RGB x 720 pixels, 23 degree FOV, 30Hz, 69g
- Android Powered, separate controller
- VGA camera, GPS, gyro, accelerometer
- https://epson.com/moverio-augmented-reality-smart-glasses-for-drone-flying

Microsoft HoloLens - $3,000 USD

- Wearable computer
- Waveguide displays
- https://www.microsoft.com/hololens

Meta Meta2 - $1,500 USD

- Wide field of view (90 degrees)
- Tethered display
- https://www.metavision.com/

Mira Prism - $100 USD

- Smart phone based
- Wide field of view
- https://www.mirareality.com/

Example: Meta2

https://youtu.be/e1W29w63W4g

STRENGTHS OF OPTICAL SEE-THROUGH AR

Simpler (cheaper)

Direct view of real world

- Full resolution, no time delay (for real world)
- Safety
- Lower distortion

No eye displacement

- but some video see-through displays avoid this

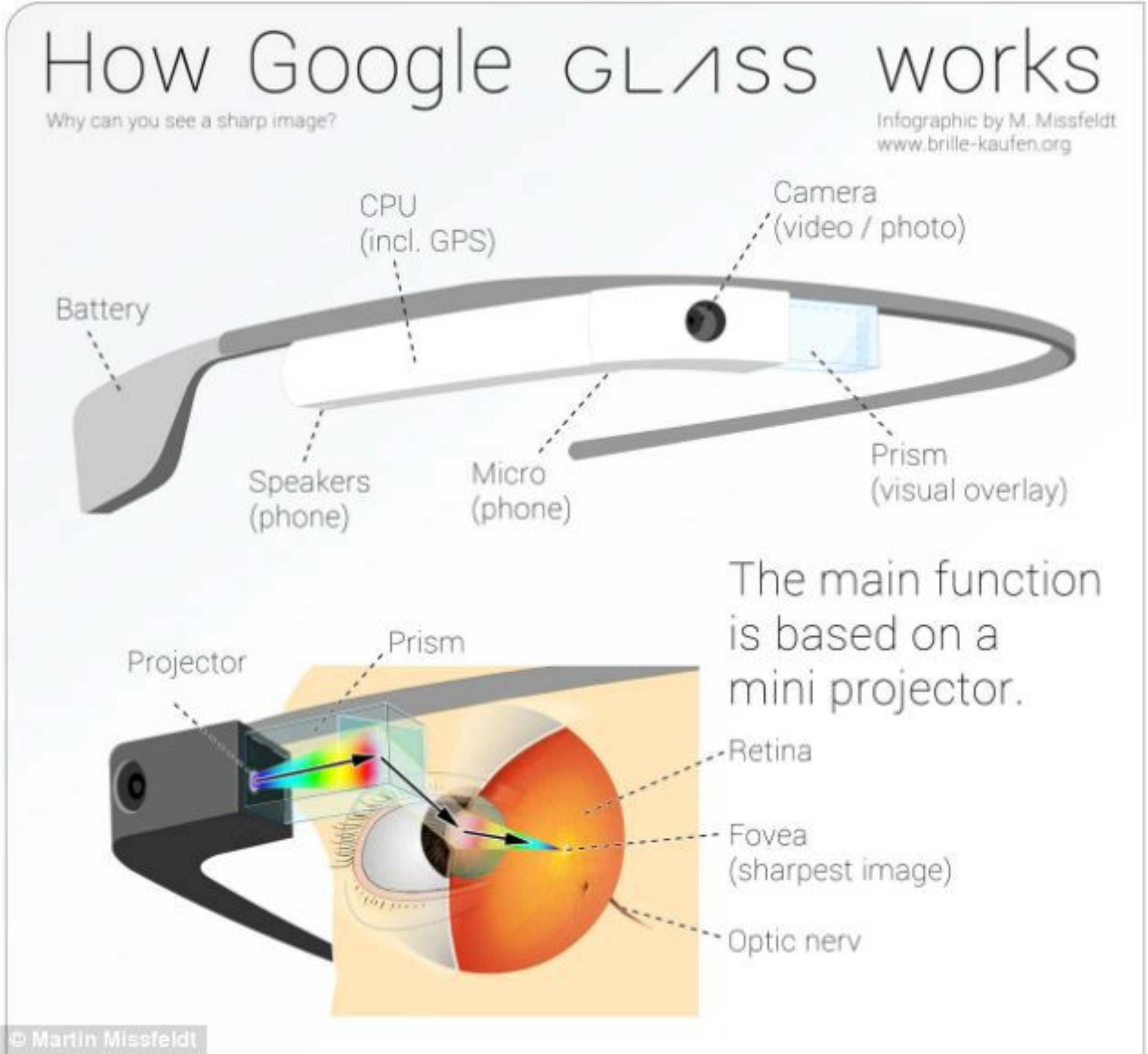
HUD-Type See-Through AR

Devices for monocular or bioccular display of information

EXAMPLE: GOOGLE GLASS

View Through Google Glass

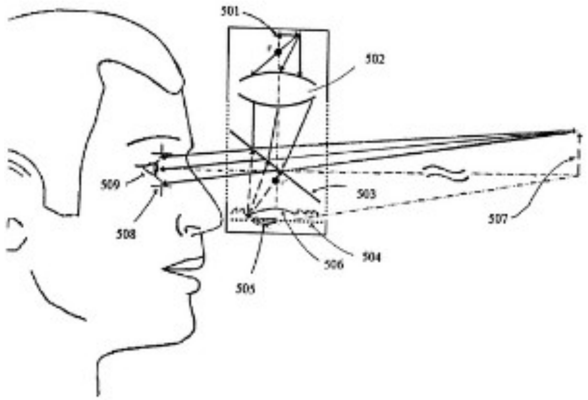
HTTPS://YOUTU.BE/ZKNV505SYAM


How Google GLΛSS works
Why can you see a sharp image?
Infographic by M. Missfeldt
www.brille-kaufen.org
CPU
(incl. GPS)
Camera
(video / photo)
Battery
Speakers
(phone)
Micro
(phone)
Prism
(visual overlay)
The main function
is based on a
mini projector.
Projector
Prism
Retina
Fovea
(sharpest image)
Optic nerv
© Martin Missfeldt

DISPLAY TECHNOLOGY

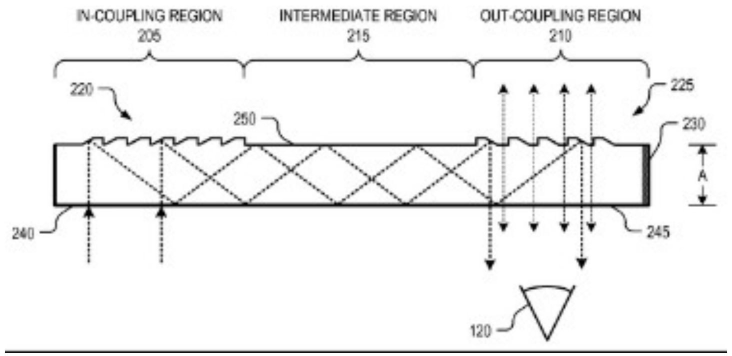
Curved Mirror

- off-axis projection
- curved mirrors in front of eye
- high distortion, small eye-box

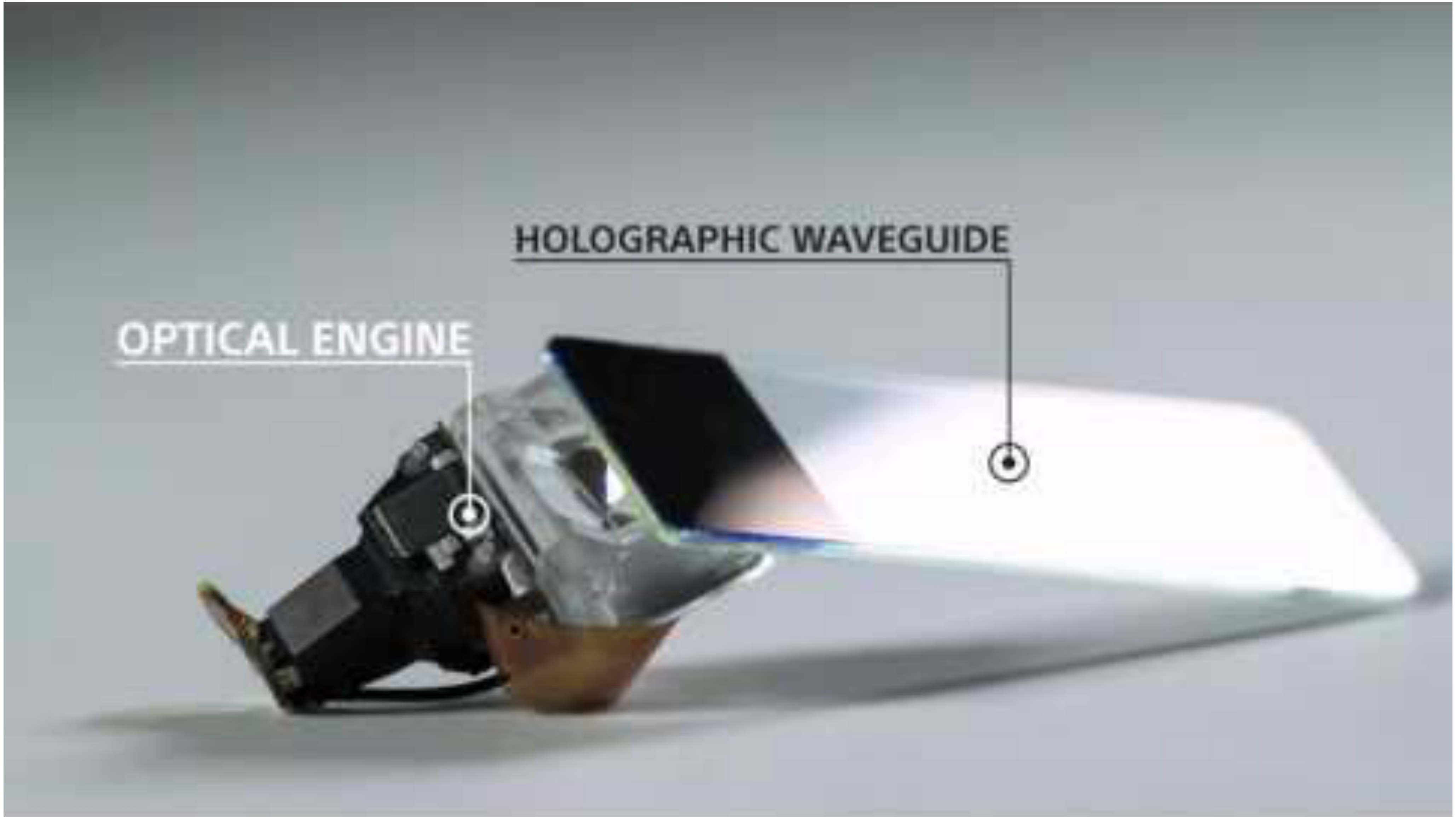


Waveguide

- use internal reflection
- unobstructed view of world
- large eye-box



Example: Sony Waveguide Display



https://youtu.be/G2MtI7asLcA

SEE-THROUGH THIN DISPLAYS (WAVEGUIDE)

Opinvent Ora

Lumus DK40

Waveguide techniques for thin see-through displays

- Wider FOV, enable AR applications

EXAMPLE: SONY SMART EYEGLASSES

HTTPS://YOUTU.BE/KYPWAMSARSS

Head Mounted Displays (HMD)

Positives

- Display and Optics mounted on Head
- Can be fully immersive
- See-through HMDs can be used for AR
- May or may not fully occlude real world
- Provide full-color images

Negatives

- Cumbersome to wear—bulky, heavy, obtrusive
- Brightness
- Tethering to computer or require low power consumption
- Resolution limited—mismatch between accommodation/convergence; distortion at edges
- Social acceptance?
- Cost is high?
- Adjustments: IPD, eye relief?
- Eye glasses?






Comparison between Eyes and HMD

	Human Eyes	HTC Vive
FOV	200° x 135°	110° x 110°
Stereo Overlap	120°	110°
Resolution	30,000 x 20,000	2,160 x 1,200
Pixels/inch	>2190 (100mm to screen)	456
Update	60 Hz	90 Hz

HTTP://DOC-OK.ORG/?P=1414
HTTP://WWW.CLARKVISION.COM/ARTICLES/EYE-RESOLUTION.HTML
HTTP://WOLFCROW.COM/BLOG/NOTES-BY-DR-OPTOGLASS-THE-RESOLUTION-OF-THE-HUMAN-EYE/

PROJECTION/LARGE DISPLAY TECHNOLOGIES

Conventional Projection

Room Scale Projection

- CAVE, multi-wall environment, spherical display

Vehicle Simulator

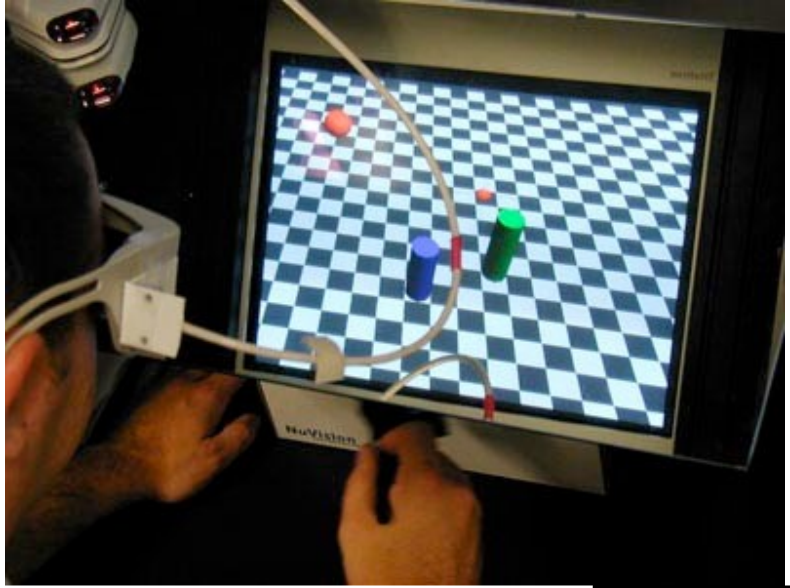
Spatial Augmentation

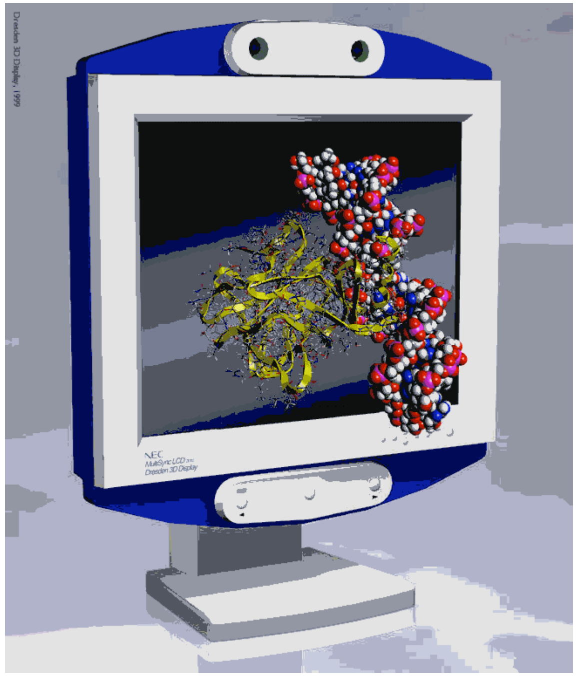
DESKTOP VR

Also known as "fishtank" VR

Use computer monitor

- Track head
- Stereo from shutter glasses

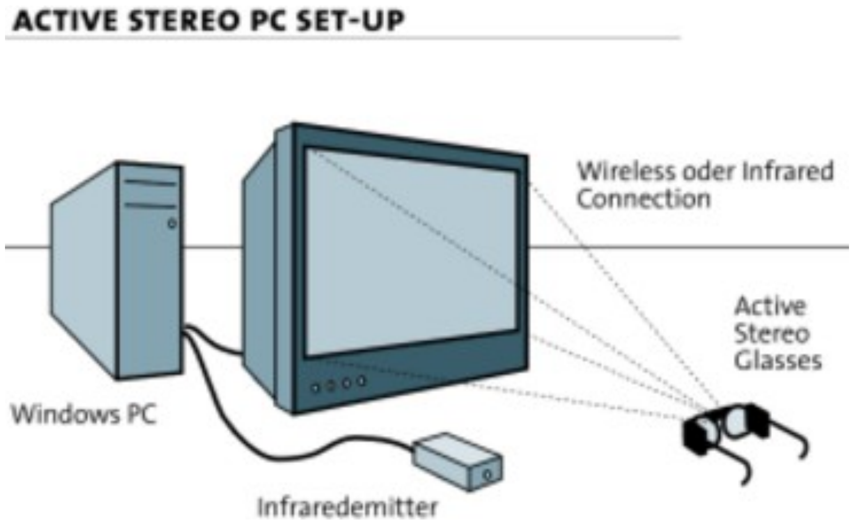


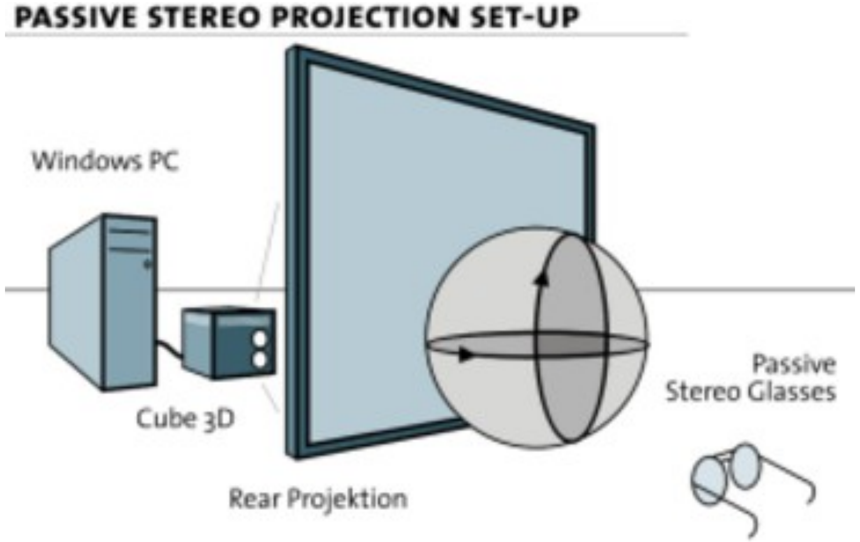


STEREO PROJECTION

Active Stereo
- Active shutter glasses
- Time synced signal
- Brighter images
- More expensive

Passive Stereo
- Polarized images
- Two projectors (one/eye)
- Cheap glasses (powerless)
- Lower resolution/dimmer
- Less expensive





Displaying stereo

Passive/Polarization

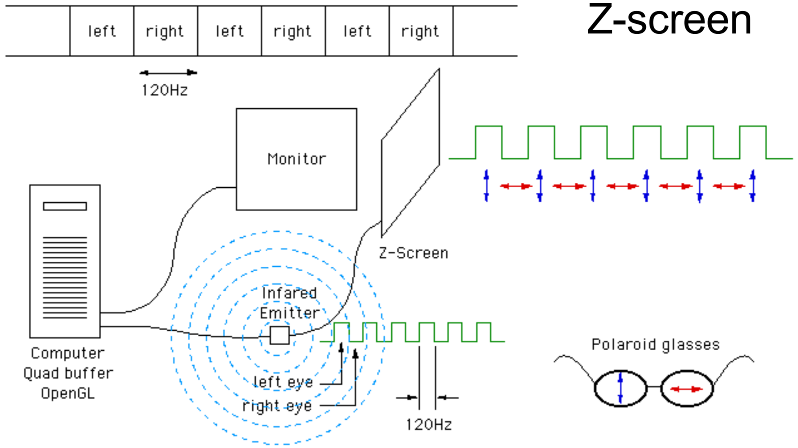
Active/Shutter glasses

DISPLAY TECHNIQUES FOR STEREO VIEWING

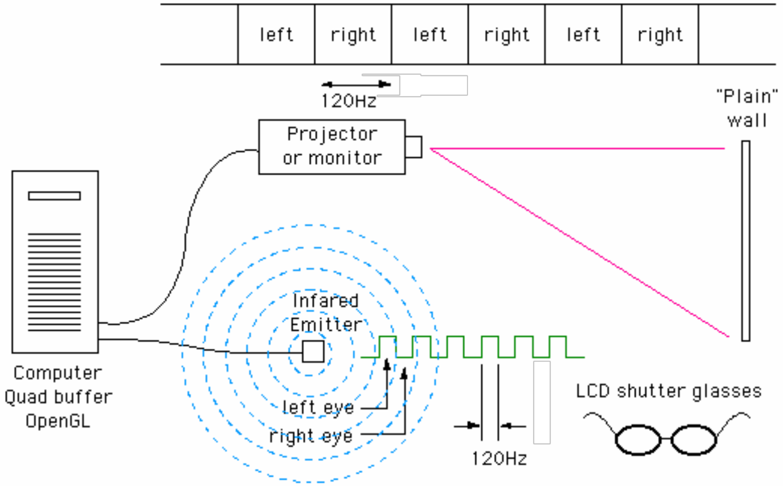
But how do we present stereo images to the viewer?

Right eye should see right image only, same for left.

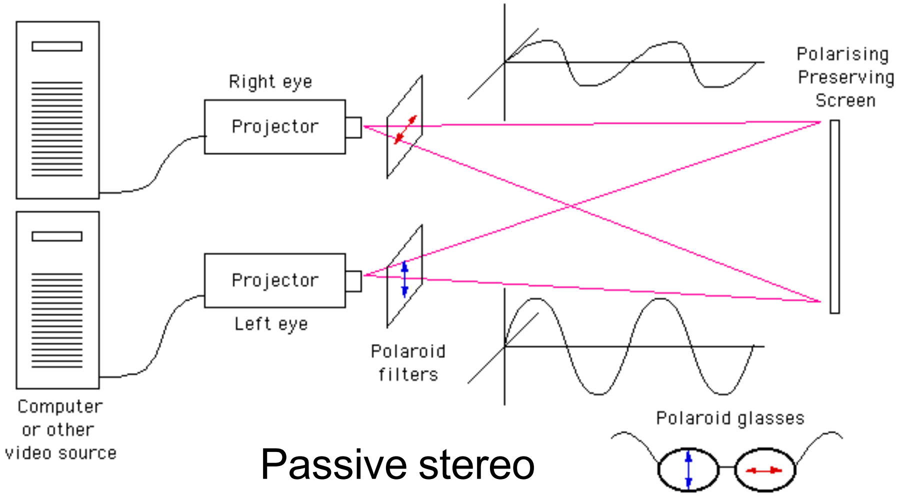
Otherwise ghosting (crosstalk) can appear.



Z-screen

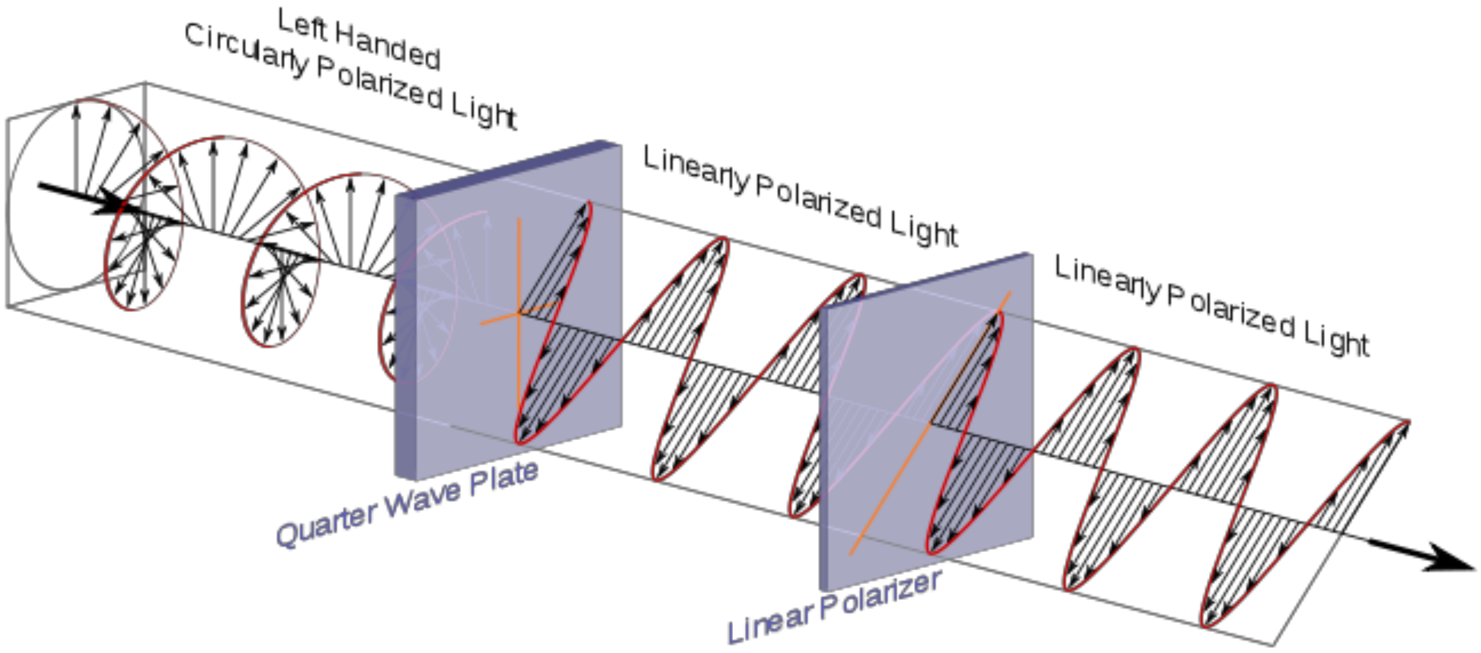


Active stereo

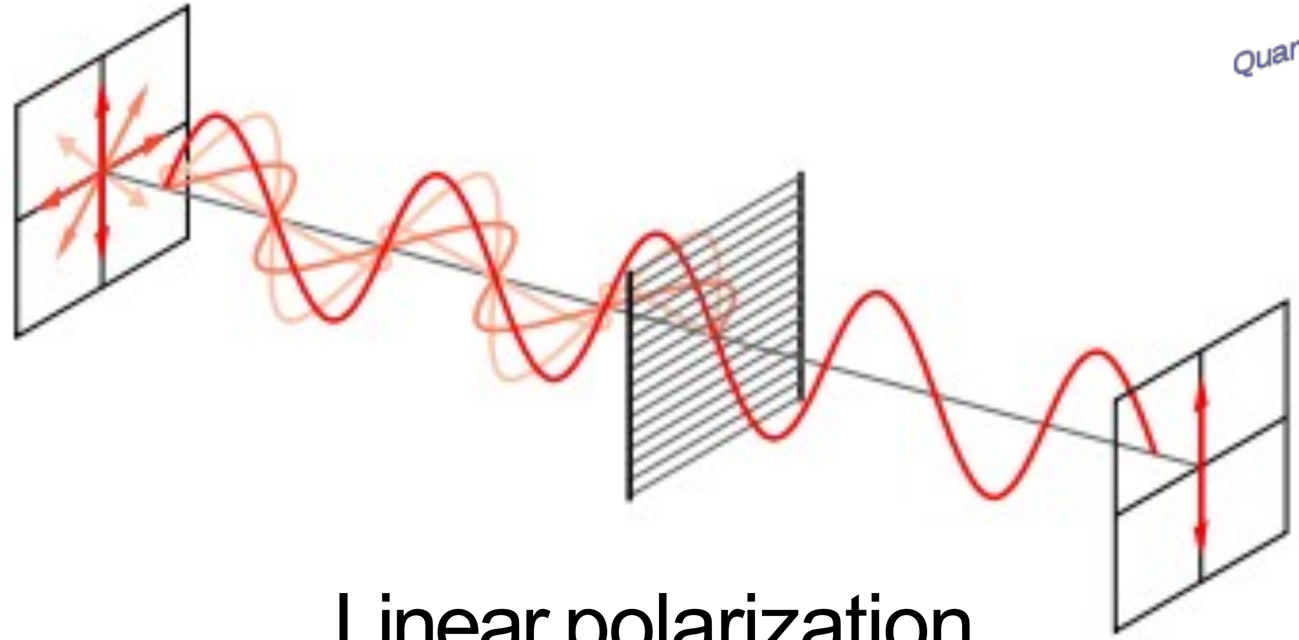


Passive stereo

POLARIZED LIGHT



Circular polarization



Linear polarization

Passive systems

Pros

- Cheap glasses, many viewers
- Usually bright images (not much light is dropped, Max 60% left)

Cons

- Not possible to rotate head when using linear polarization (solved with circular polarization)
- Expensive projection surfaces (should not remove polarization)
- bright projectors are required due to issue with light efficiency

Active systems

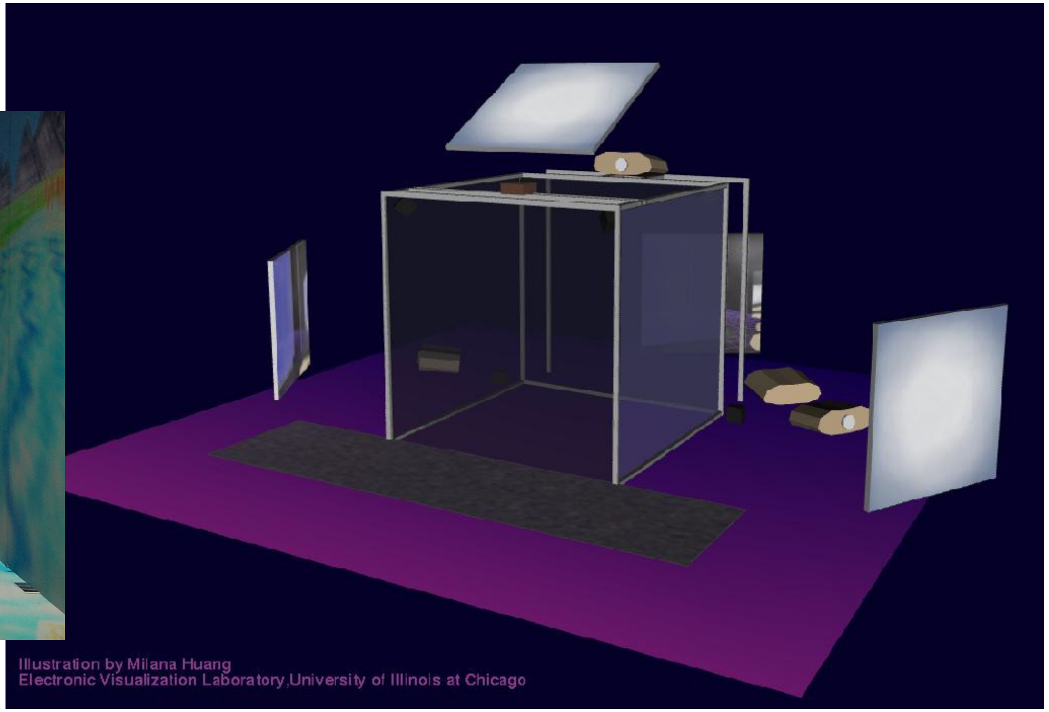
Pros

- Usually better separation between eyes

Cons

- Expensive glasses (does not scale to a large crowd)
- Lower intensity, due to sequential image display technique
- Generally, expensive
  - Bright projectors – about half of light is lost due to left/right switching glasses alone
  - Projectors must be capable of high refresh rates (120Hz) for active stereo

CAVE

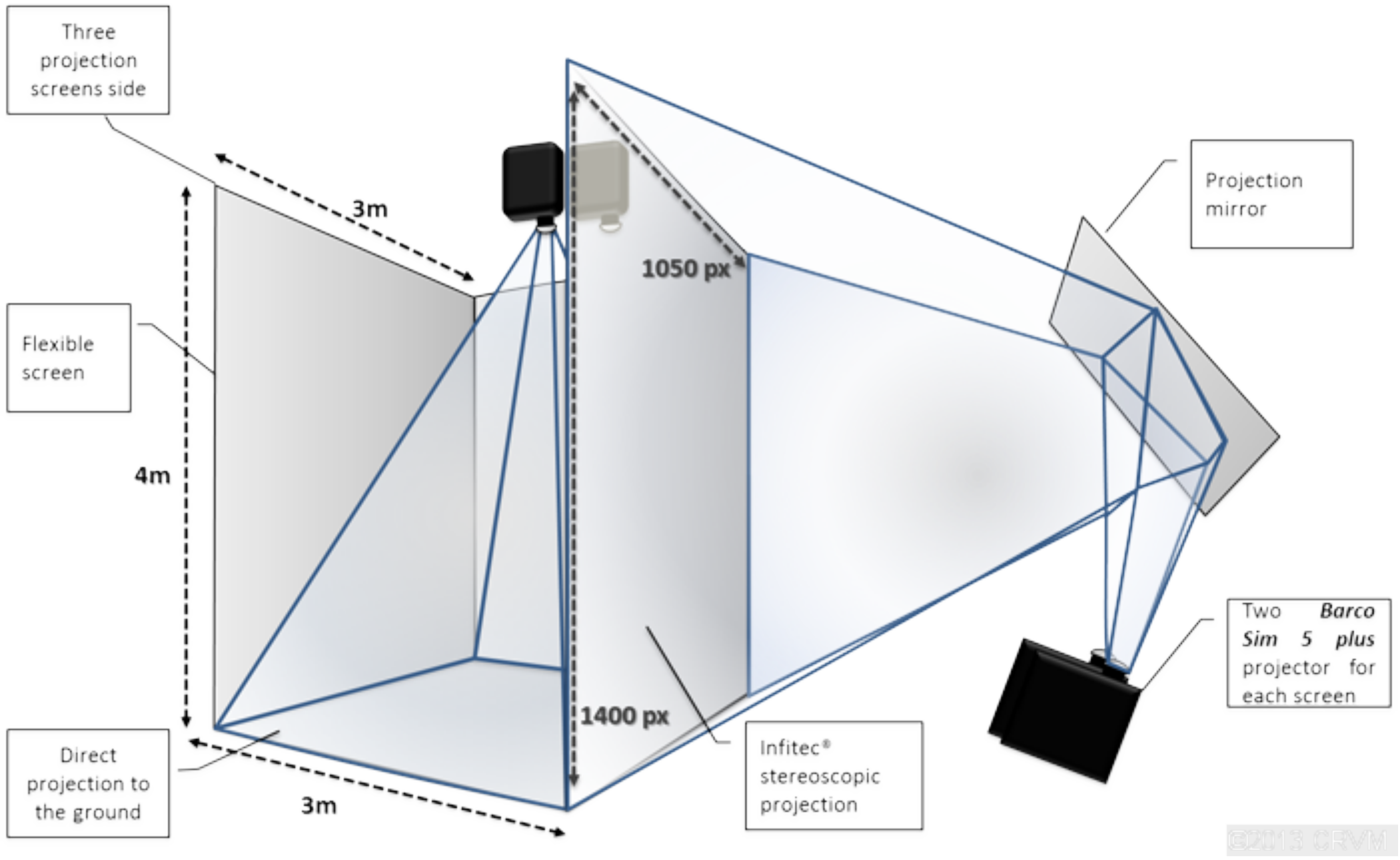


Multi-walled stereo projection environment

Head tracked active stereo

Cruz-Neira, C., Sandin, D. J., DeFanti, T. A., Kenyon, R. V., & Hart, J. C. (1992). The CAVE: audio visual experience automatic virtual environment. Communications of the ACM, 35(6), 64-73

TYPICAL CAVE SETUP

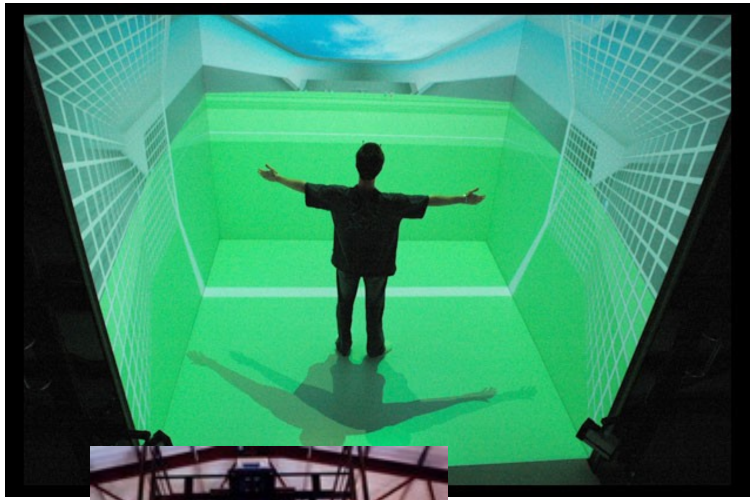


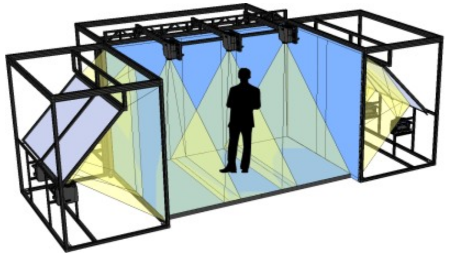
4 sides, rear projected stereo images

Demo Video – Wisconsin CAVE

https://youtu.be/mBs-OGDoPDY

CAVE VARIATIONS





Caterpillar Demo

https://youtu.be/r9N1w8PmD1E

VISION DOME AND OTHER SPHERICS

Vehicle Simulators

Combine VR displays with vehicle

- Visual displays on windows
- Motion base for haptic feedback
- Audio feedback

Physical vehicle controls

- Steering wheel, flight stick, etc

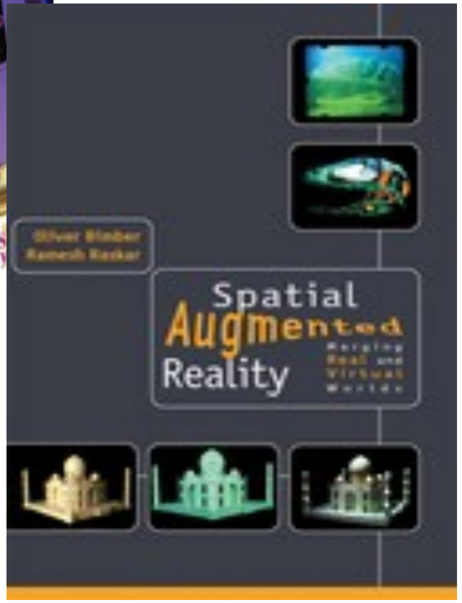
Full vehicle simulation

- Emergencies, normal operation, etc
- Weapon operation
- Training scenarios

Demo: Boeing 787 Simulator

https://youtu.be/3iah-blsw_U

<u>Spatial Augmented Reality</u>

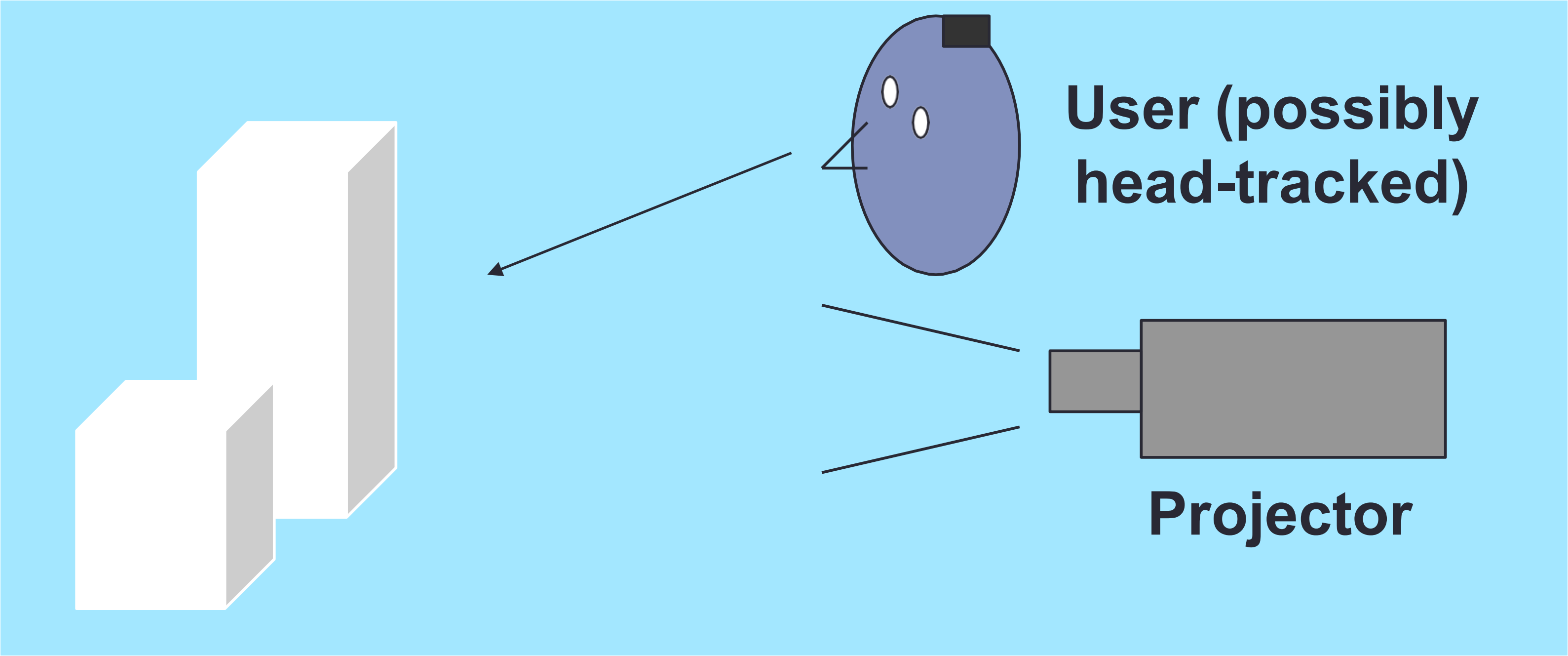


Project onto irregular surfaces

- Geometric Registration
- Projector blending, High dynamic range

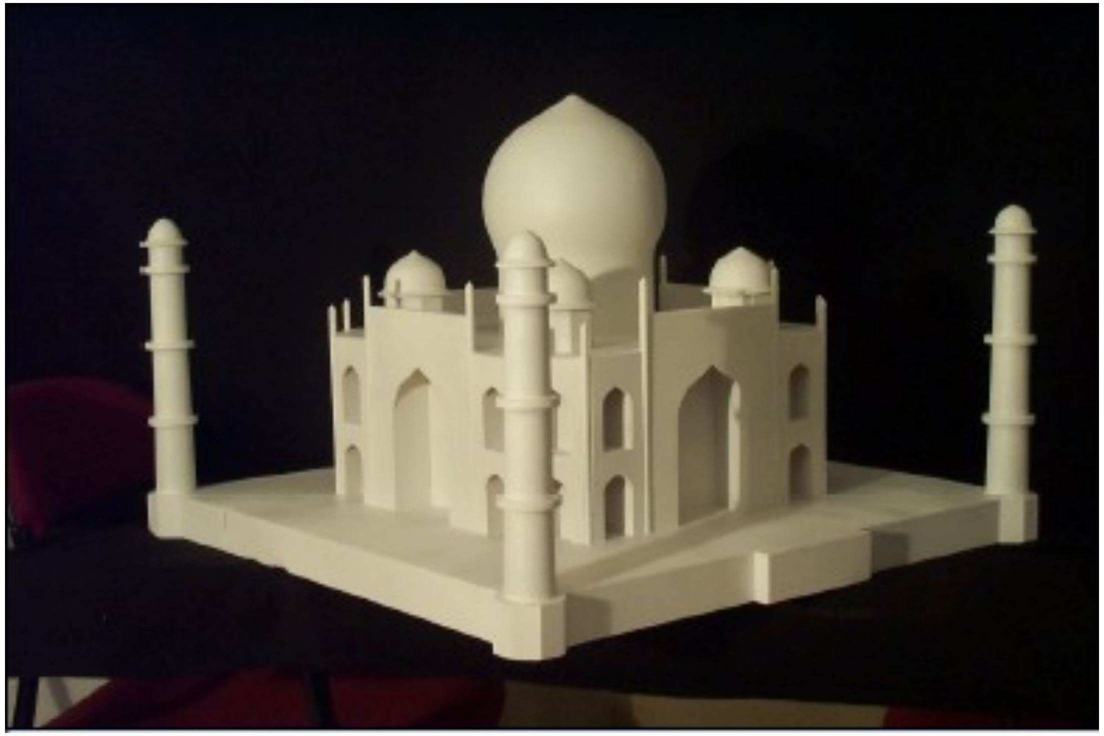
Book: Bimber, Rasker "Spatial Augmented Reality"

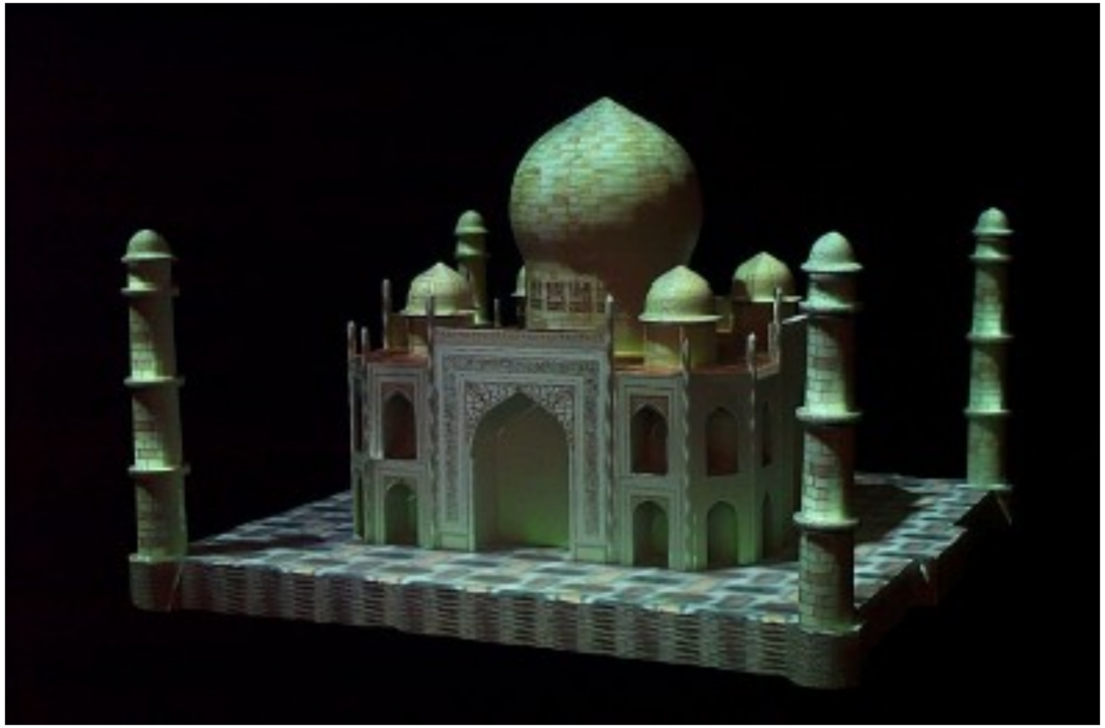
PROJECTOR-BASED AR



Real objects
with retroreflective
covering

Example of Projector-Based AR



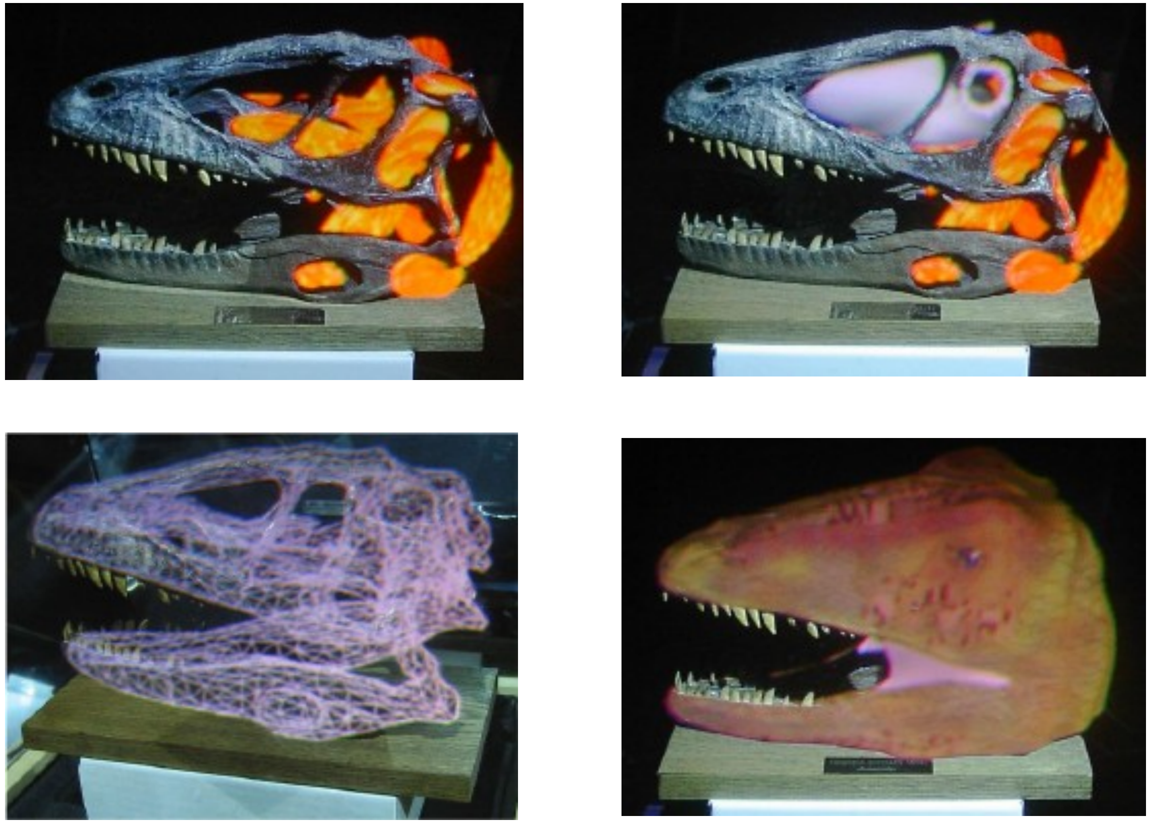


Ramesh Raskar, MIT

Example of Projector-Based AR

Ramesh Raskar, MIT

Augmented Paleontology



Bimber et. al. IEEE Computer Sept. 2002

CastAR (now defunct)

Stereo head worn projectors

Interactive wand

Rollable retro-reflective sheet

DEMO: CASTAR

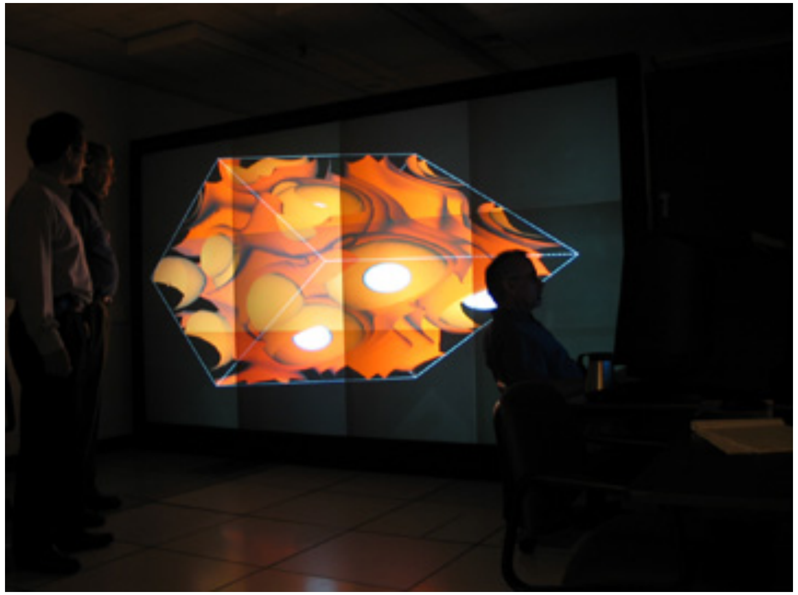
HTTPS://YOUTU.BE/AOI5UW9KHOQ?T=47

WORKBENCH / MR TABLETOPS

Pain points with projection VR

Alignment matters

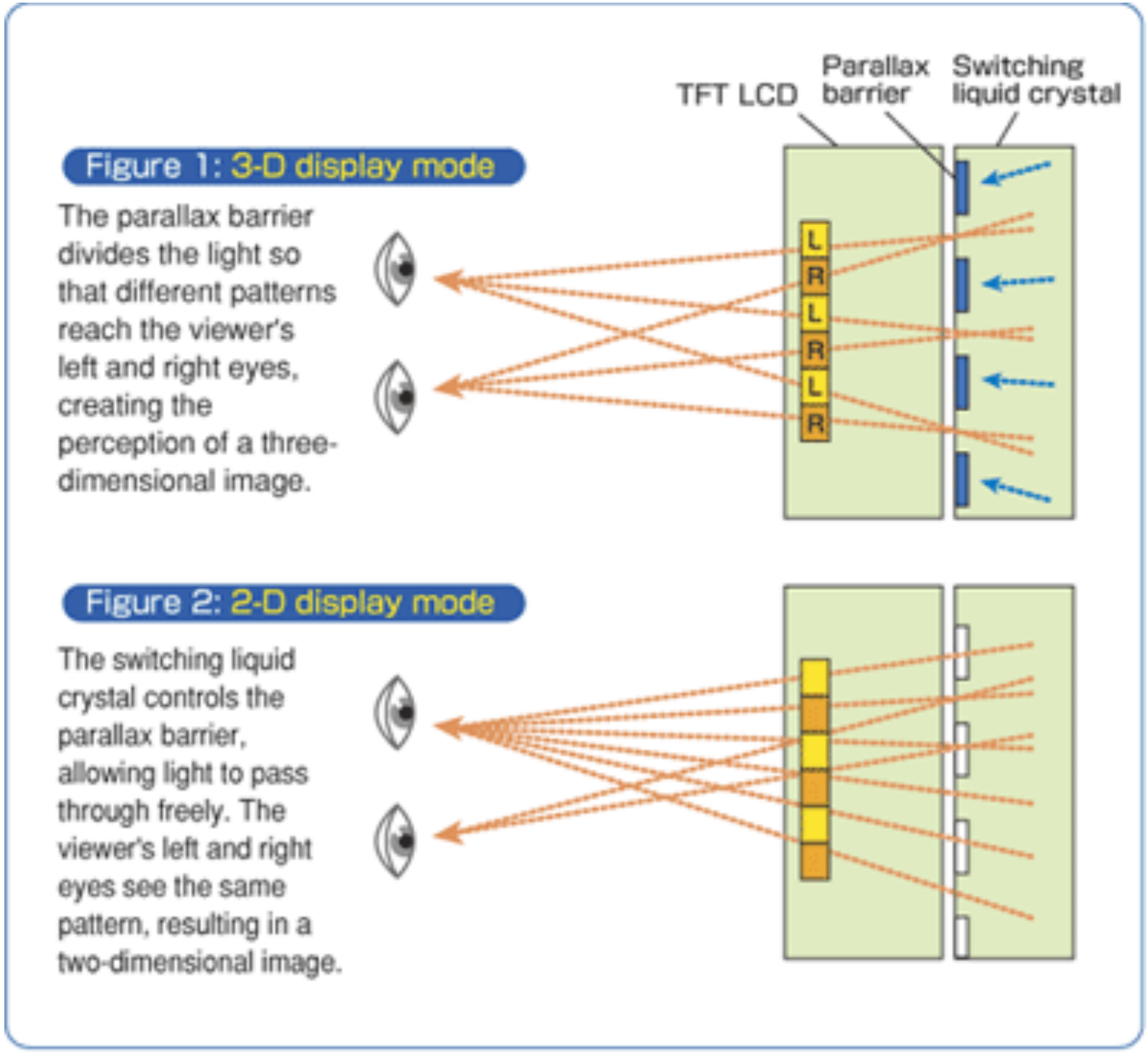
- for stereo setups, especially passive stereo, alignment is crucial
- for tile-able displays with high resolution
  - images must overlap and blend



Actually, should be able to project on any surface

- large set of research devoted to
  - automatic alignment
  - image blending, color matching
  - projection onto arbitrary surfaces (not just flat walls)

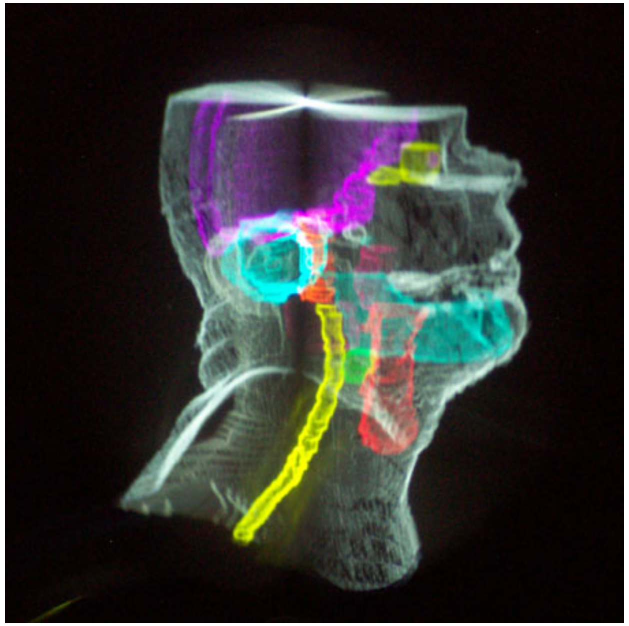
AUTOSTEREOSCOPIC DISPLAYS



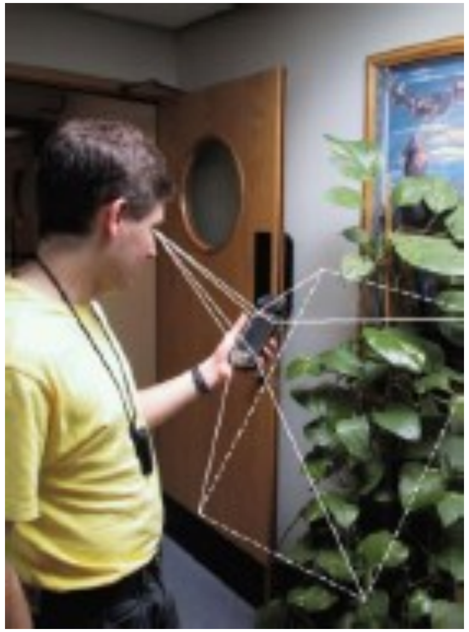
<u>Volumetric displays</u>

Perspecta by Actuality Systems

Used rotating screen



"HANDHELD" DISPLAYS



Tablet Laptop Mobile Phone

Phones and Tablets

Largest segment of the available devices

Contain "everything" you need—display, camera, microphone, speaker, tracking

Device variation makes product consistency difficult (requires calibration and special accommodations)

WHICH VISUAL DISPLAY TO USE?

Consider lists of pros and cons

Consider depth cues supported

Consider level of visual immersion

But this is a very hard question to answer empirically

Instead of comparing actual displays, compare levels of immersion