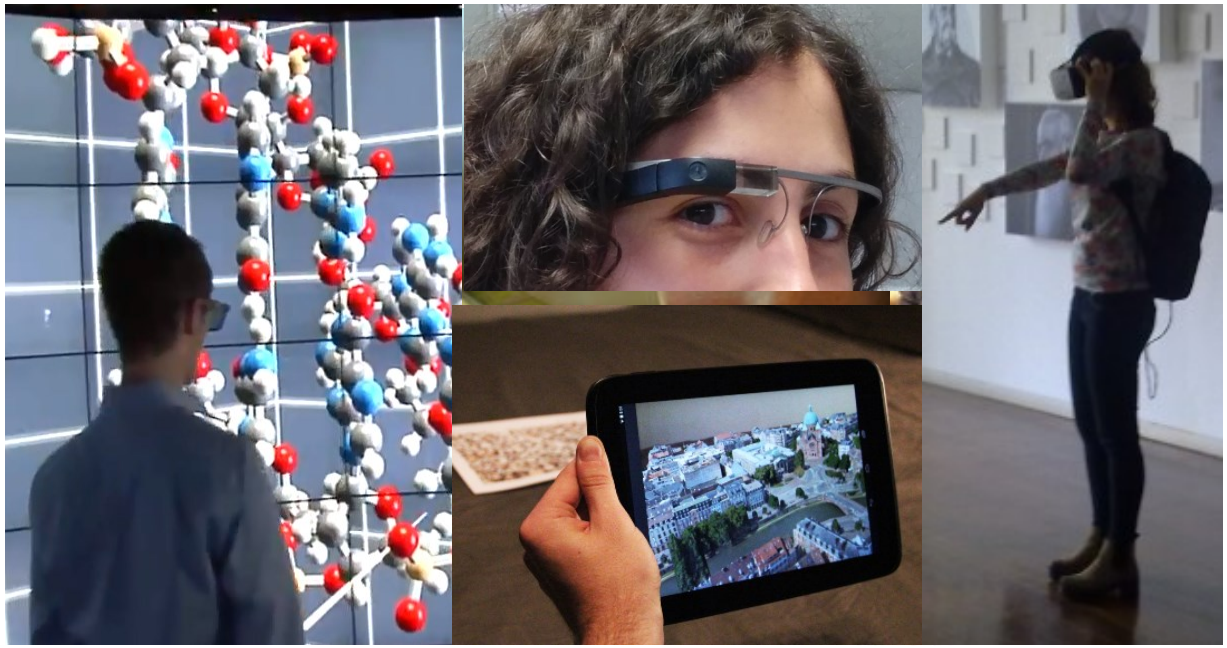
Universidade de Aveiro
Departamento de Electrónica,
Telecomunicações e Informática

Output Devices - I



What is Virtual Reality?

"A high-end user interface that involves real-time simulation and ***interaction*** through **multiple *sensorial channels***." (**vision, sound, touch, …**) (Burdea and Coiffet., 2003)

The human senses need specialized interfaces

- **Graphics displays for visual feedback**
- 3-D audio hardware for localized sound
- Haptic interfaces for force and touch feedback

Olfactory feedback has been increasingly researched lately

Some experiments with taste feedback do exist

The ultimate display?

"The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal." (Ivan Sutherland, 1965)

Visual Displays

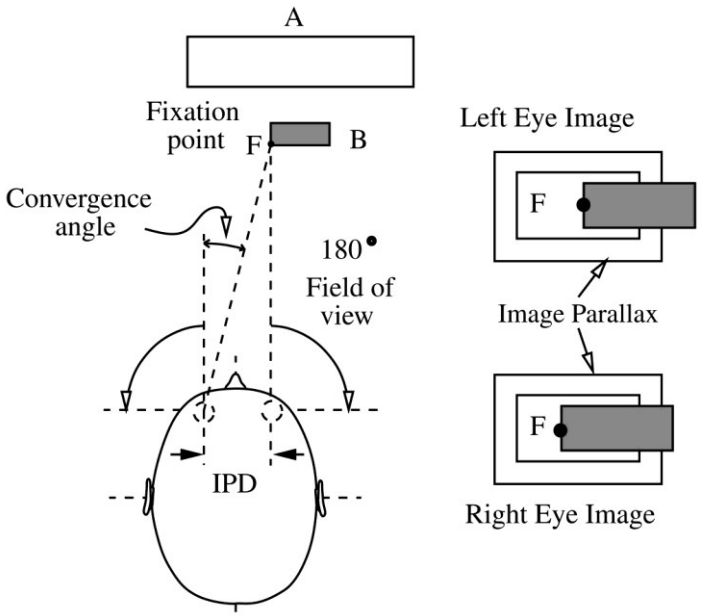
"A graphics display is a computer interface that **presents synthetic world images** to one or several users interacting with the virtual world."

(Burdea and Coiffet., 2003)

• Personal displays:	Main technologies:
- HMDs (VR/AR)	
- Binoculars	LEDs/OLEDs
- Monitor-based displays/active glasses	LCDs
- Autostereoscopic displays	lenticular/barrier
• Large volume displays:	
– Caves	projectors
– Walls, domes	

…

Human Visual System and depth perception



(Burdea and Coiffet., 2003)

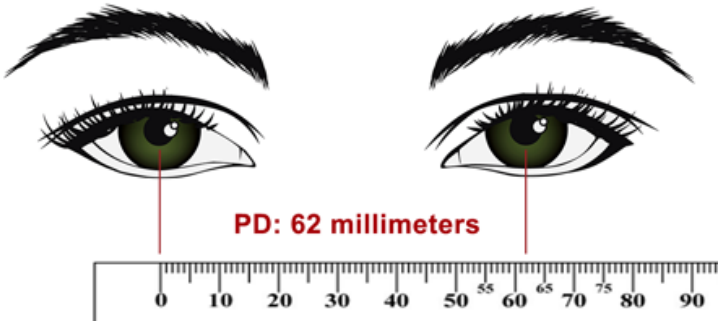
- Vision is the dominant sensorial channel

- Depth perception in mono images is based on:

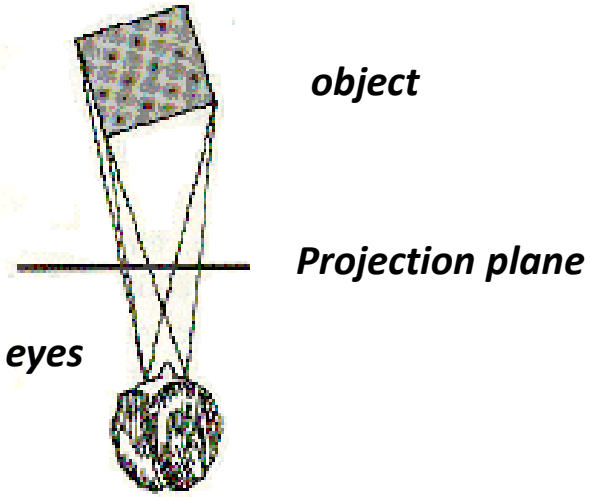
  - occlusion (one object partially covering another)
  - perspective (point of view)
  - familiar size (we know the real-world sizes of many objects)
  - shadows (casted on objects)

- Depth perception in stereo is based on stereopsis
  (when the brain registers and fuses two images)
- Image parallax means that the two eyes register different images
  (horizontal shift)
- The amount of shift depends on the “inter-pupillary distance”
  (PD) (varies for each person in the range of 53-73 mm)
- 3-5% of people are stereoblind

(Jerald., 2016)



Stereopsis



Stereo ="solid" or "three-dimensional“

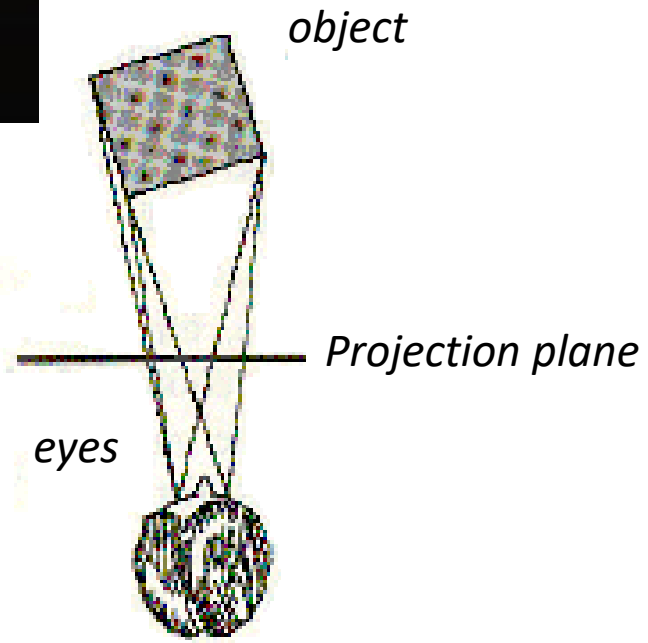
opsis = appearance or sight

'binocular vision‘ , 'binocular depth perception' , 'stereoscopic depth perception'

- Stereopsis is the impression of depth that is perceived when a scene is viewed with both eyes by someone with normal binocular vision
- **Binocular disparity is due to the different position of our two eyes**

https://en.wikipedia.org/wiki/Stereopsis

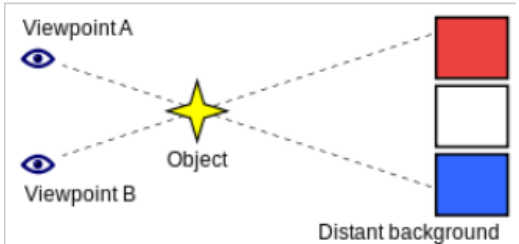
Right eye image *Left eye image*

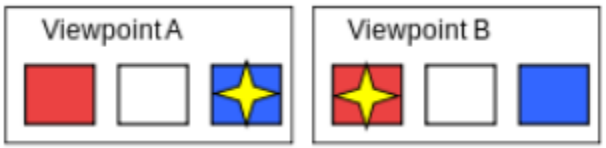


- Many of the perceptual cues we use to visualize 3D structures are available in 2D projections

- We have seen that cues include:
  - occlusion (one object partially covering another)
  - perspective (point of view)
  - familiar size (we know the real-world sizes of many objects)
  - Shadows …

- Four cues are missing from 2D media:
  - stereo parallax—seeing a different image with each eye
  - movement parallax—seeing different images when we move the head
  - accommodation—the eyes' lenses focus on the object of interest
  - convergence—both eyes converge on the object of interest

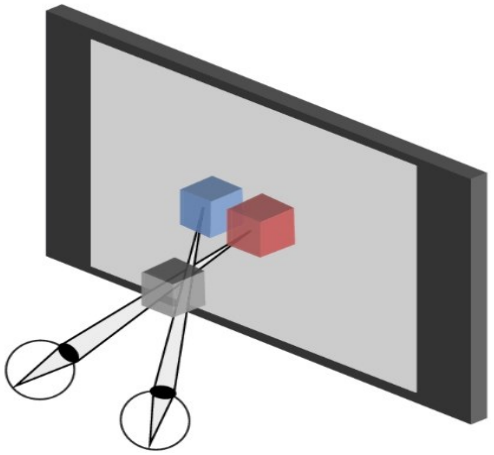




The Vergence Accommodation conflict

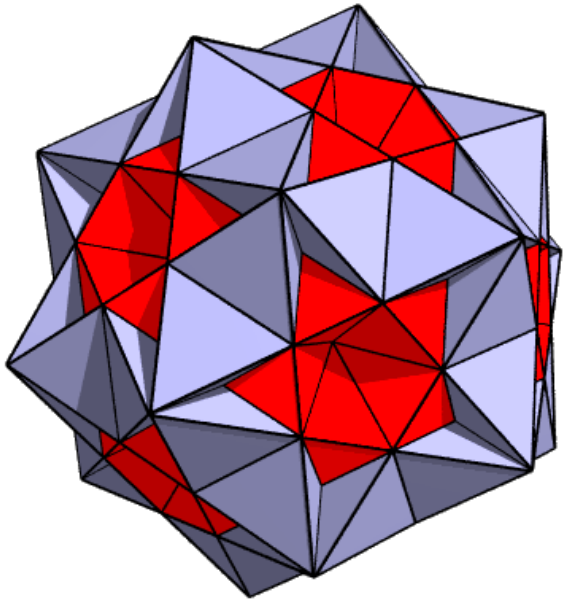
- Occurs when your brain receives mismatching cues between the distance of a virtual 3D object (vergence), and the focusing distance (accommodation) required for the eyes to focus on that object.
- It occurs while looking at stereoscopic imagery (3D TV/cinema, HMDs)
- In traditional stereoscopic technologies, the virtual image is focused at a fixed depth away from the eyes, while the depth of the virtual objects, and the amount of eye convergence, varies depending upon the content
- It can contribute to:
  - focusing problems,
  - visual fatigue,
  - eyestrain,

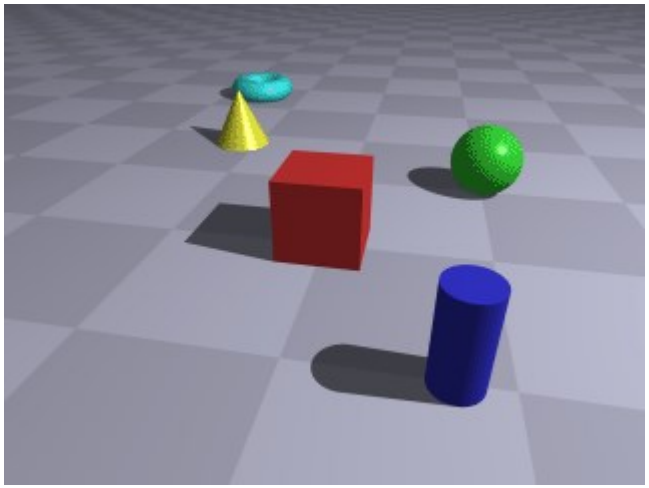
  while looking at stereoscopic imagery,
  and effects last after ceasing looking



- It is less severe when it is properly taken into account in content creation and display
  https://xinreality.com/wiki/Vergence-Accommodation_Conflict

Wiggle stereoscopy





Simple stereogram viewing technique; no glasses are needed

Alternates between the left and right images of a stereogram

Most people can get a crude sense of dimensionality due to persistence and parallax

3D with moving images: the Pulfrich effect

- **3D effects with nothing more than "normal" video**

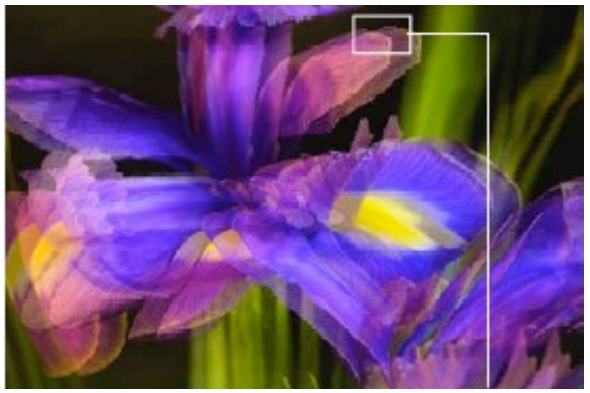
- To experience the Pulfrich Effect use a pair of sunglasses
- Look through one of the dark lenses with one eye and nothing through the other
- Place the dark glass on the leading side of the motion
- In this case: dark glass on left
- Be sure to look at the screen with both eyes

http://www.youtube.com/watch?v=1mnWI_u_zBg

Implications for Stereo Viewing devices

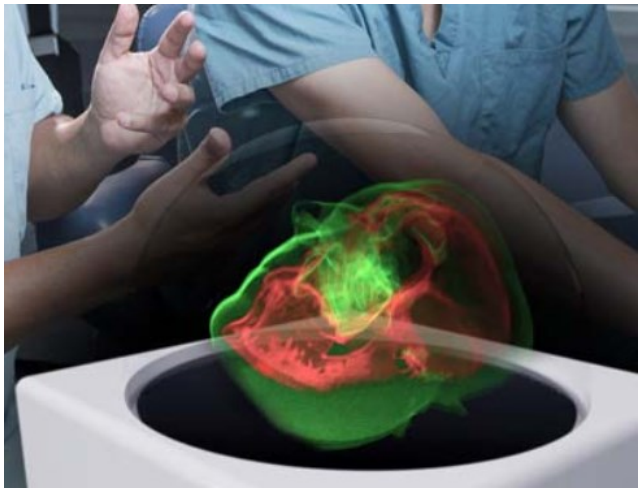
- Need to present **two images** of the same scene (one for the **right eye** and another for the **left eye**)

- The two images can be presented:
  - **at the same time** on two displays (HMD)
  - **time-sequenced** on one display (active glasses)
  - **spatially-sequenced** on one display (auto-stereoscopic displays)



Left eye, right eye images
(Burdea and Coiffet., 2003)

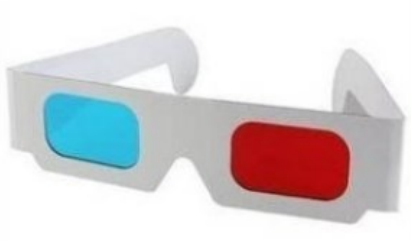
- All stereoscopic displays provide at least stereo parallax
- Autostereoscopic displays do not need any eyewear
- Volume displays provide a “real” 3D image
- VR systems use the first type (stereoscopic displays)



https://voxon.co/

https://www.youtube.com/watch?v=FVYoWsxqK8g

Common ways to produce a 3D sensation



- Anaglyphs: two colored images and color coded glasses (red/cyan(green))
- Two images with different light polarization and polarizing glasses
  - Linear and circular

- Double frame-rate displays combined with LCD shutter glasses

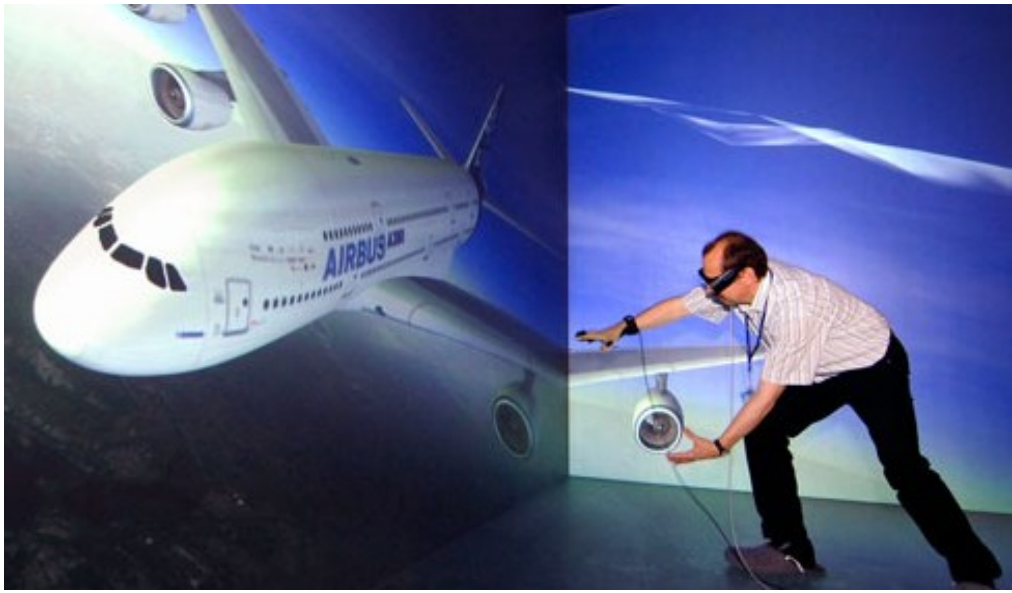
- Autostereoscopic displays
  - Parallax barrier and lenticular lens
- Head Mounted Displays (HMDs)

https://3dvision-blog.com/4124-anaglyph-shutter-polarized-glasses-or-autostereoscopic-3d-solution/

Show the right image to the right eye and the left image to the left eye!

- All these technologies provide:
  - stereo parallax
- When combined with head tracking, they can provide
  - movement parallax

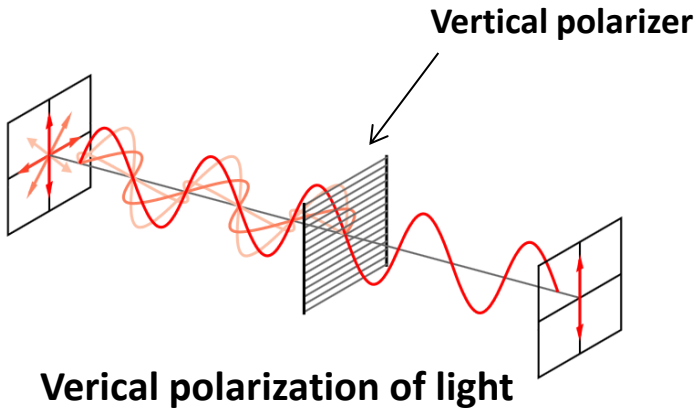
for a single viewer



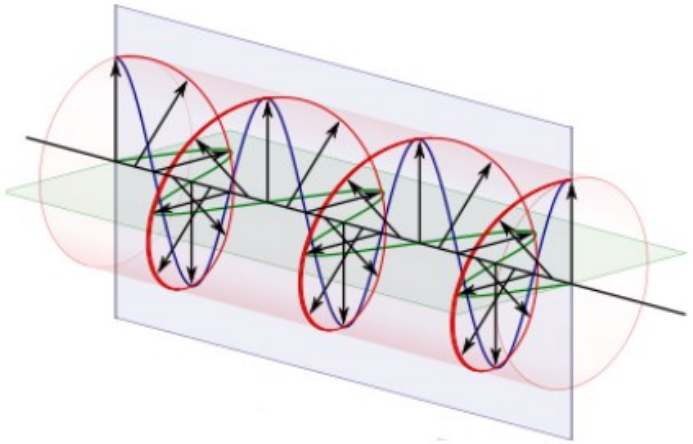
- Virtual Reality uses:
  - Different light polarization and polarizing glasses
  - Double frame-rate displays combined with LCD shutter glasses

Polarized light stereoscopy

- 3D movies have used polarized technology since the 1930s
- Two images are projected on the same screen through different polarizing filters
- Gray linear-polarizing filters are easily manufactured, thus correct color rendition is possible
- Two types of polarization can be used:
  - Linear
  - Circular ⇦



Verical polarization of light



Circular polarized light

https://en.wikipedia.org/wiki/Polarized_3D_system

Polarized glasses for stereoscopic displays

https://www.inition.co.uk/extraordinary-technology/stereoscopic-3d-displays/

- Advantages of polarized glasses:
  - are generally inexpensive
  - don't require any power
  - do not suffer from flicker
  - don't require synchronization with the display

- Disadvantages:
  - The images for polarized glasses may have to share the screen simultaneously, and therefore cannot have full resolution
  - There are incompatible polarized systems (circular or linear polarized)
  - The head should not be tilted to maintain the 3D effect with linear polarization

Shutter glasses for stereoscopic displays

- Active-shutter glasses are small LCD screens that alternately dim the left and right "lenses" in succession
- They are synchronized with the display usually through IR or radio signals
- Each eye can see the image intended for it
- Can be bought for < 100€
- Need a battery

Passive (polarized) *versus* active (shutter)?

- Passive
  - cheaper
  - lighter
  - batteryless
  - syncless glasses
- Active
  - Better image quality

Main Properties of Visual Displays

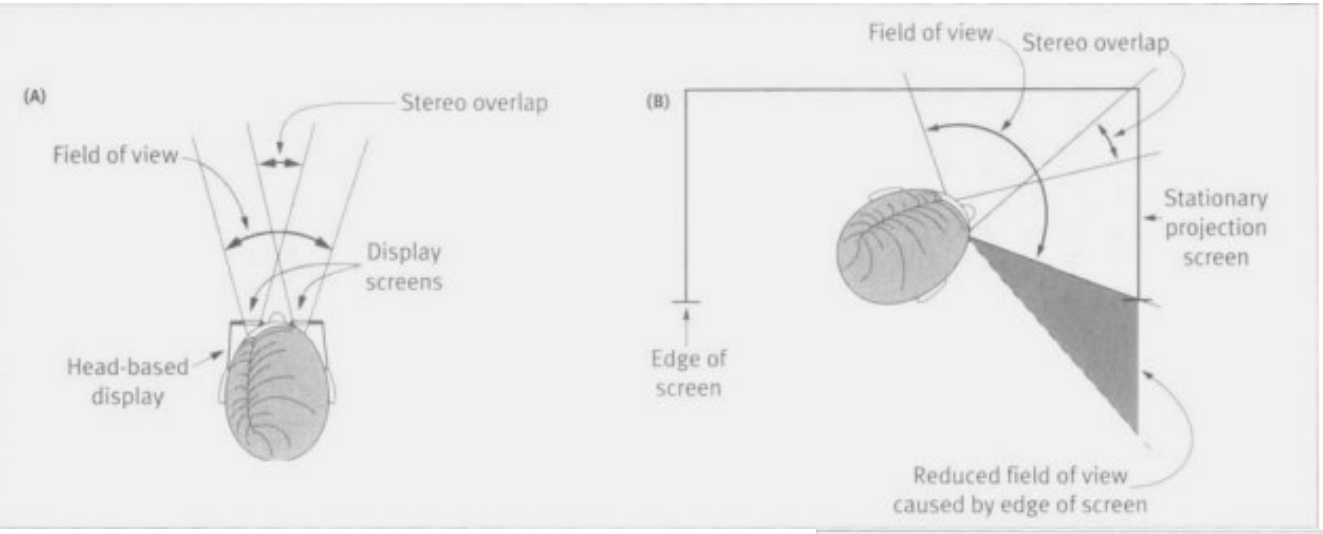
Visual presentation properties:

- Color
- Spatial resolution
- Contrast
- Number of display channels
- Focal distance
- Opacity
- Masking
- Field of view (FOV)
- Field of regard (FOR)
- Head position information
- Graphics latency tolerance
- Temporal resolution

Logistic Properties:

- User mobility
- Interface with tracking
- Environment requirements
- Associability with other sense displays
- Portability
- Throughput
- Encumbrance
- Safety
- Cost

Field of view (FOV) and Field of regard (FOR)



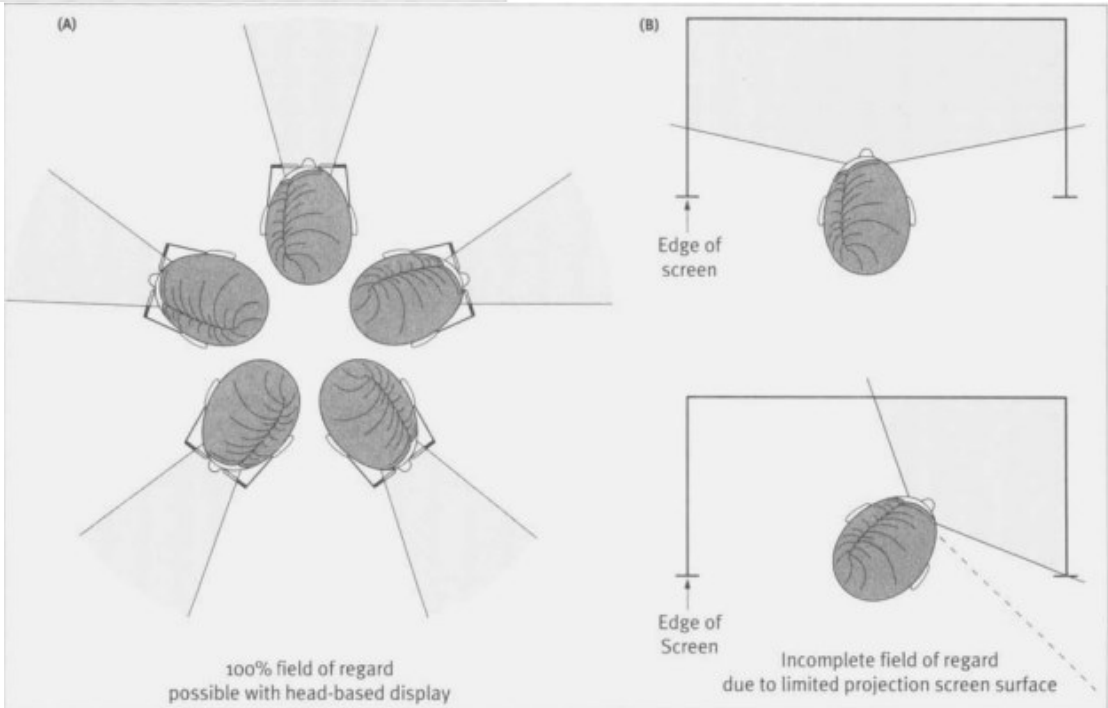
FOV is the amount of the viewer's visual field covered by a display.

(Sherman and Craig, 2003)

FOR is a measure of the amount of coverage a given display provides when head motion and other factors are considered

(A) Head-based displays can easily provide a 100% FOR,

(B) stationary displays are limited to the area of the screens



Visual Displays: two possible taxonomies

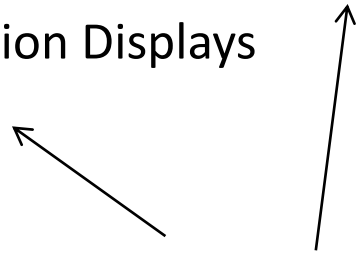
(Burdea and Coiffet, 2003)

- **Personal displays:**
  - HMDs (VR/AR)
  - Binoculars
  - Monitor-based displays/active glasses
  - Autostereoscopic displays
- **Large volume displays:**
  - Caves
  - Walls, domes
  - …

…

(Sherman and Craig, 2003)

- Head-based (occlusive)
- Non-occlusive head-based
- Handheld
- Monitor- based (Fishtank)
- Projection Displays



Stationary displays

Personal Displays

A Visual display that outputs a virtual scene destined to be viewed by a single user. Such image may be monoscopic or stereoscopic, monocular (for a single eye) or binocular (displayed on both eyes).

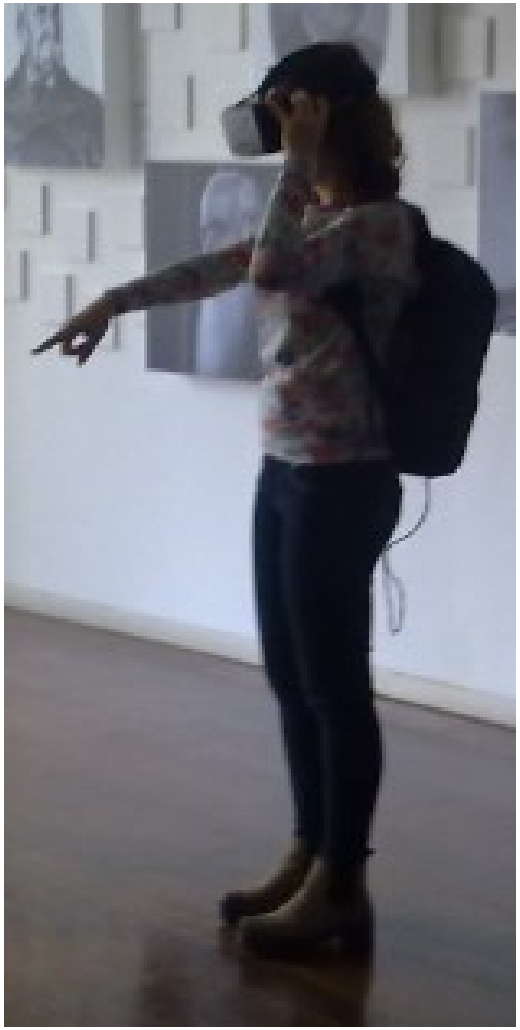
- Head Mounted Displays (HMDs)

- 3-D Binoculars (hand supported)

- Auto-stereoscopic displays
  (desk supported)

The low cost Head-Mounted Displays:

Oculus Rift



2014, DK2:

- low persistence OLED display to eliminate motion blur and judder (two of the biggest contributors to simulator sickness)
- It also makes the scene appear more visually stable, increasing the potential for presence
- 960×1080 pixels per-eye display improves clarity, color, and contrast.

Price: ~~$400

http://www.oculusvr.com/

Oculus Rift S specifications

Release date	May 21, 2019
Lifespan	2019-Present
Introductory price	$399.99
Display	Fast-switch LCD 2560×1440 (1280×1440 per eye) @ 80 Hz
Sound	Integrated speakers
Input	6DOF inside-out tracking through 5 built-in cameras
Controller input	2nd generation Oculus Touch motion tracked controllers

Evolving to standalone (all in one) systems…

Oculus Quest 2 specs:

Smaller, lighter, and higher resolution than Oculus Quest

Display panel: LCD

Display resolution: 1832 x 1920 per eye (Oculus Rift had 1080×1200 per eye)

72Hz at launch, 90Hz to come

Internal cameras

Qualcomm Snapdragon XR2

6GB RAM.

Lithium-ion battery with 2-3 hours playtime, depending on what is played

6 DOF head and hand tracking.

Two touch controllers.

~300USD – Sep/2020

HMD for professional purposes as of 2019

AR smartglasses in 2021: the devices, apps and new tech coming

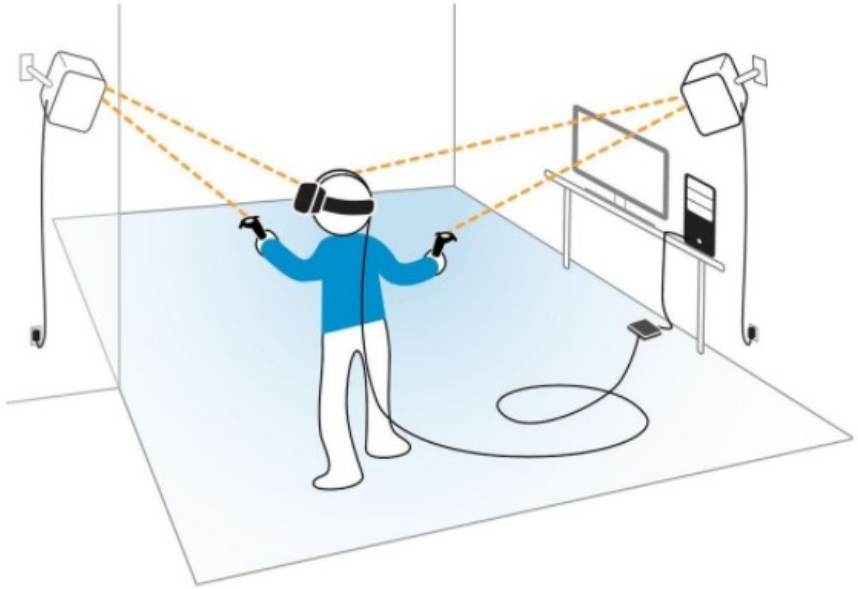
https://www.wareable.com/ar/ar-glasses-state-of-the-union-8461

"Some of the current best mixed and augmented reality headsets, as the Magic Leap 1 and the Microsoft Hololens 2 are too bulky for non-enterprise use."

HTC Vive

Price: ~~$700 / 2019

https://www.vive.com/eu/



Example of different HMDs from the same maker

GAMER

VIVE VR System

- Everything needed to enter the world of VR gaming.
- Experience full immersion with 360-degree controller and headset tracking.
- Play seated, standing or room-scale with SteamVR™ Tracking.

€599.00

PROFESSIONAL

VIVE Pro Starter Kit

- Designed for pro-level users and a wide-range of business usages.
- Includes VIVE Pro HMD. Refined fit, balance and comfort for extended usage.
- Spectacular graphics and 3D spatial audio deliver deep immersion.
- Up to 3.5M x 3.5M room-scale stage.

€1,199

ENTERPRISE

VIVE Pro Full Kit

- Elevate your business with cutting-edge innovations in VR.
- Includes VIVE Pro HMD with second-generation controllers & base stations.
- Features SteamVR™ Tracking 2.0
- Up to 7M x 7M room-scale stage.

€1,156.20* (EXVAT)

HTC Vive Pro

Headset Specs

Screen:	Dual AMOLED 3.5" diagonal
Resolution:	1440 x 1600 pixels per eye (2880 x 1600 pixels combined)
Refresh rate:	90 Hz
Field of view:	110 degrees
Audio:	Hi-Res certificate headset Hi-Res certificate headphones (removable) High impedance headphones support
Input:	Integrated microphones
Connections:	Bluetooth, USB-C port for peripherals
Sensors:	SteamVR Tracking, G-sensor, gyroscope, proximity, IPD sensor
Ergonomics:	Eye relief with lens distance adjustment Adjustable IPD Adjustable headphones Adjustable headstrap

HMD only:
<1000 USD
2019

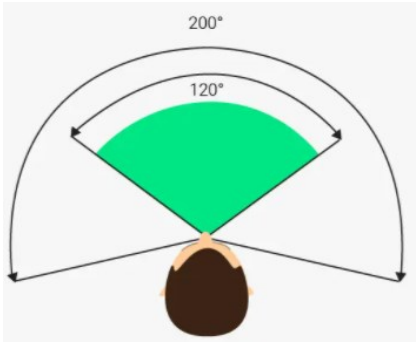
https://www.vive.com/eu/product/vive-pro/

Field of View comparison

Pimax Vision 8K X	156°×104°
Pimax 5K+	140°×101°
Valve Index	**108°×105°**
Samsung Oddysey+	103°×107°
HP Reverb (G1)	98°×92°
Oculus Quest	**96°×94°**
HTC Vive Cosmos	95°×86°
HTC Vive (2016)	86°×86°
Oculus Rift (2016)	86°×86°
Oculus Rift S	**86°×85°**

https://uploadvr.com/field-of-view-tool-database/

The FOV of a given headset is notoriously difficult to consistently measure, because it actually changes depending on the distance between your eye and the lens. That distance is determined by the shape of your face and the fit of the headset.



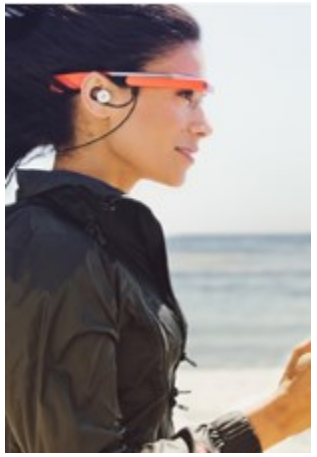
Human FOV is ~ 210°×150°.

Headsets using Smartphones: Google Cardboard

< 10 USD / 2020

https://en.wikipedia.org/wiki/Google_Cardboard

Popular Augmented Reality Headsets:
Google Glass
(2013)



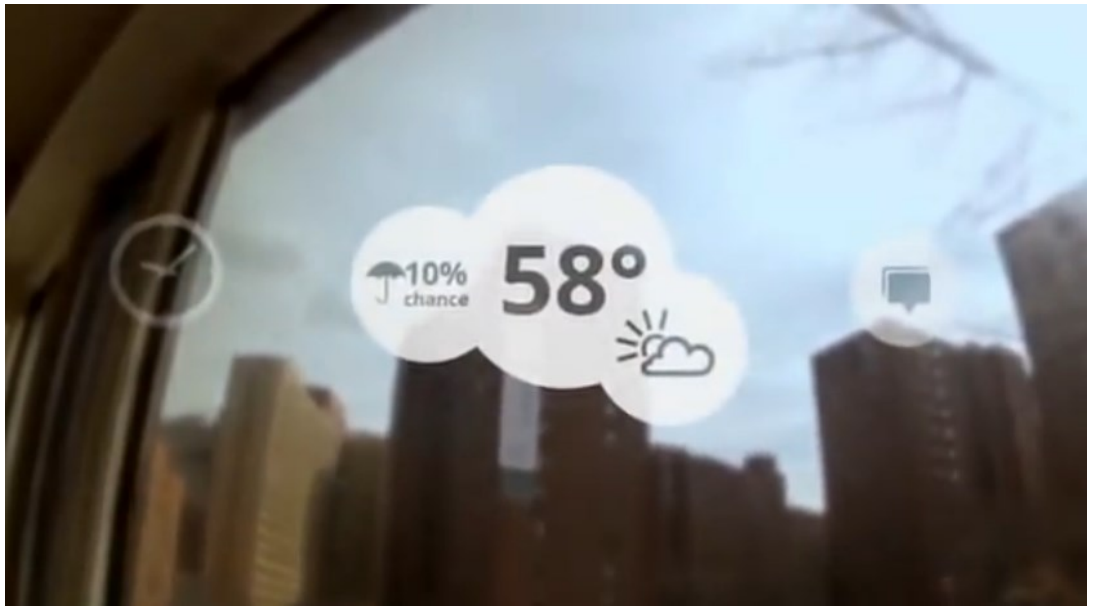
Display - reflects light into the wearer's eye

Camera – photos and video

Touchpad – on the side

Micro – voice control

1500 $



https://www.wired.com/story/google-glass-2-is-here/

https://www.google.com/glass/start/

Google glass (2020)

Glass Enterprise Edition 2
~1000 USD

https://www.blog.google/products/hardware/glass-enterprise-edition-2/

https://www.wired.com/story/google-glass-2-is-here/

https://www.theverge.com/2019/5/20/18632689/google-glass-enterprise-edition-2-augmented-reality-headset-pricing

https://www.theverge.com/2020/2/4/21121472/google-glass-2-enterprise-edition-for-sale-directly-online

Hololens 2

Microsoft AR glasses

3500 USD

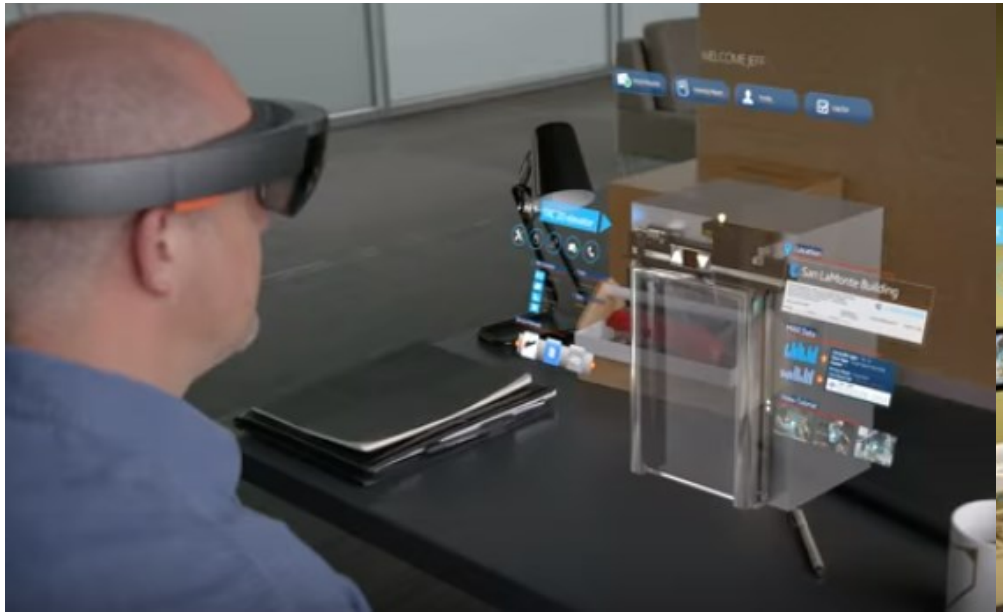
Include Eyeball and hand tracking

Review: + ergonomics; - visual effects

https://www.microsoft.com/en-us/hololens/

https://arstechnica.com/gadgets/2019/11/microsofts-hololens-2-tracks-your-eyeballs-to-see-what-youre-looking-at/?amp=1

Preparing the visit:



On site:

https://www.youtube.com/watch?v=8OWhGiyR4Ns

Large Volume Displays

- Allow several co-located users to view view of the virtual world

  - *monitor*-based large volume displays

  - *projector*-based large volume displays

- Allow more freedom of motion *vs*. personal displays.

Projector based Large-volume displays

- CAVE type displays
- Wall-type displays
- Domes

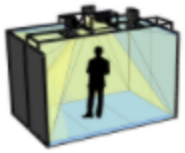
…

CAVE
(Cave Automatic Virtual Environment)

- Room in which each of the surfaces – the walls, floor and ceiling – may be used as **projection screens to create a highly immersive VE**
- Users typically wear **stereoscopic eyewear** and
- Interact with visual stimulus via wands, data gloves, joysticks, …

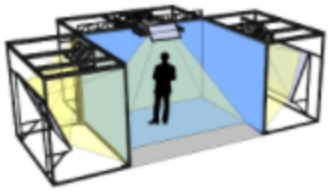
https://steantycip.com/vr-cave/

Examples of several CAVE configurations and prices



VisCube M4

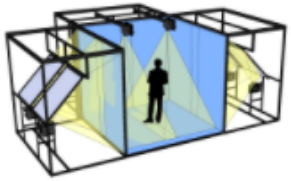
Low cost CAVE VR system
Ultra compact, 10′ tall
3 walls+floor, 12′ front wall
1920×1200 or **2560×1600**
3D active stereo



VisCube C4

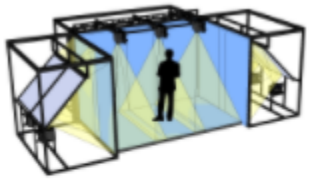
Affordable CAVE VR system
Fits under 9′ ceiling
3 walls + floor, 12′ front wall
1920×1200 or **2560×1600**
3D active stereo

http://www.visbox.com/products/cave/



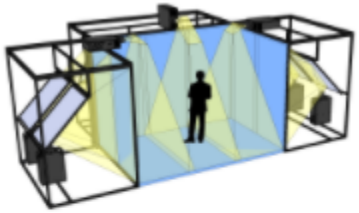
VisCube C4-T2

Tall and high resolution CAVE
Compact, 10.5′ tall
3 walls+floor, **10′ x 9′ walls**
2840×2560 per surface
3D active stereo



VisCube C4-T3

High Resolution CAVE
Fits under 9′ ceiling
3 walls+floor, 12′ wide front wall
4096×2560 front/floor
2880×2560 sides
3D active stereo



VisCube C4-T3X

Extreme resolution CAVE
Compact, 12′ tall
3 walls+floor, 13′ wide front wall
6000×4096 front/floor
4096×4096 sides
3D active stereo

Dome-type displays

http://pacificdomes.com/immersive-virtual-reality-dome-environments/

Advantages:

- Accommodate many users (tens to hundreds)
- Give users more freedom of motion

Disadvantages:

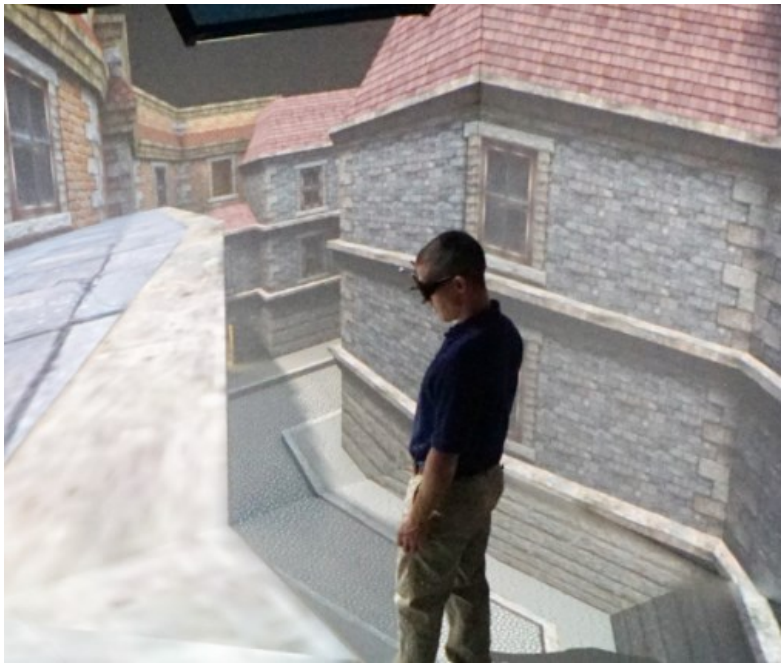
- Large cost (up to millions of dollars)
- Even with several displays resolution is low (larger area)

Visual Displays: another taxonomy (Sherman and Craig, 2003)

- Head-based (occlusive)
- Non-occlusive head-based
- Handheld
- Monitor- based (Fishtank)
- Projection Displays

Benefits of Stationary Displays (monitor and projection based)

- Longer user endurance (i.e., can stay immersed for longer periods)
- Higher tolerance for display latency
- Greater user mobility (fewer cables)
- Less encumbering
- Lower safety risk
- Better for group viewing



Benefits of Head-based Displays (Occlusive and Non-occlusive)

- Lower cost (for lower resolution models)
- Complete field of regard
- Greater portability
- Can be used for augmenting reality
- Can occlude the real world
- Less physical space required
- Less concern for room lighting and other environmental factors

Benefits of Hand-based Displays

- Greater user mobility
- Greater portability
- Can be combined with stationary VR displays

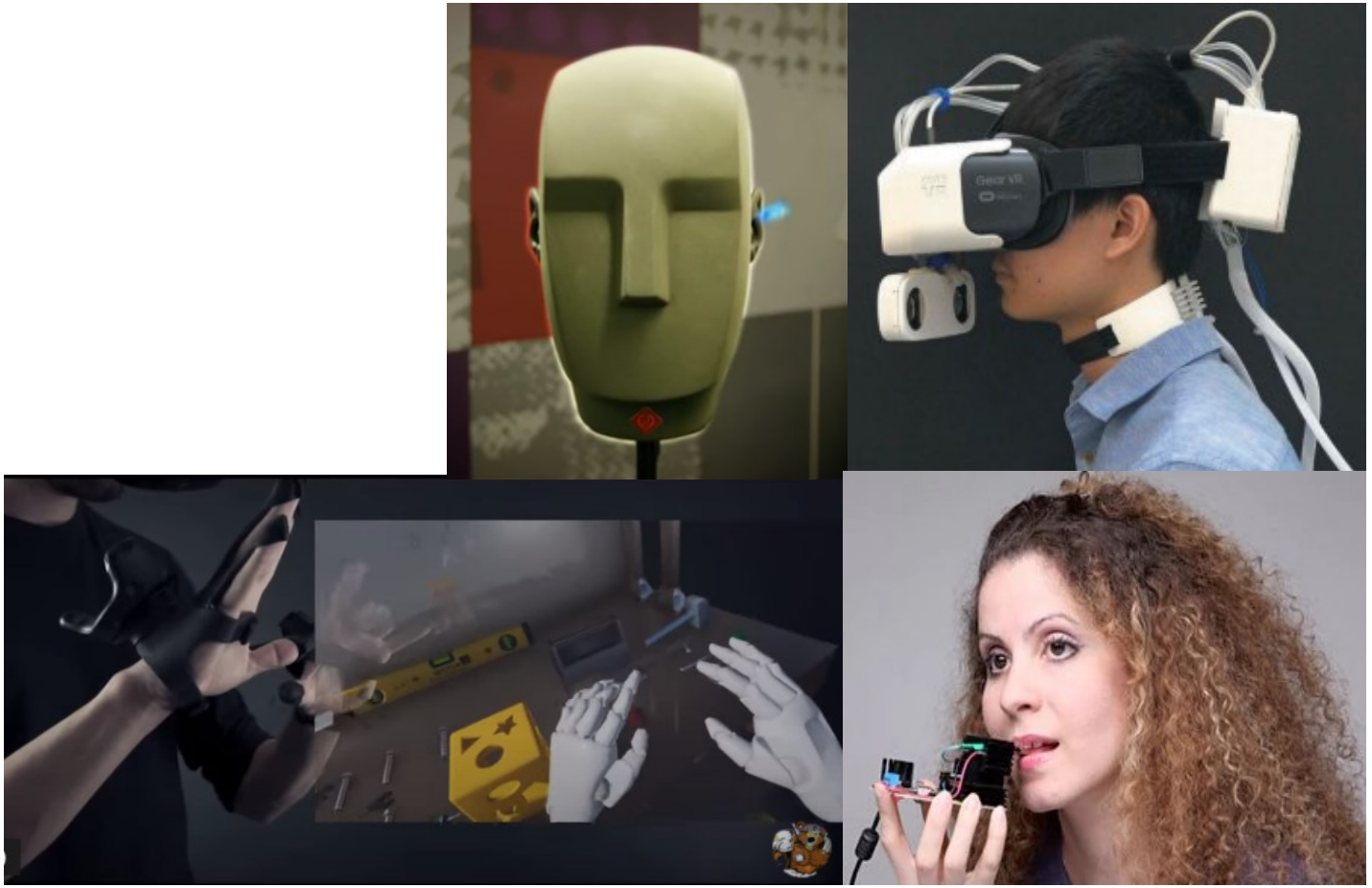
Main bibliography

- Jerald, J., The VR Book: Human-Centered Design for Virtual Reality, ACM and Morgan & Claypool, 2016

- Craig, A., Sherman, W., Will, J., *Developing Virtual Reality Applications: Foundations of Effective Design*, Morgan Kaufmann, 2009

Next episode of Output devices…

Displays to other senses: sound, touch, and smell, …



Haptic interfaces

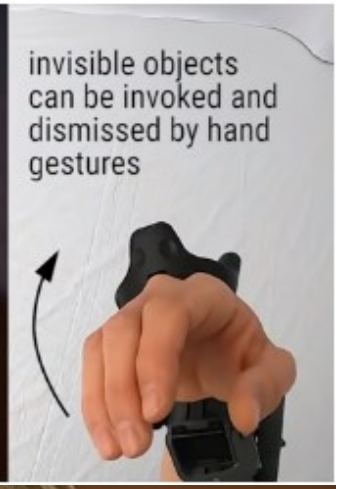
- From Greek *Hapthai* meaning the sense of touch
- Increase in realism
- but devices: high cost, high bandwidth, safety concerns

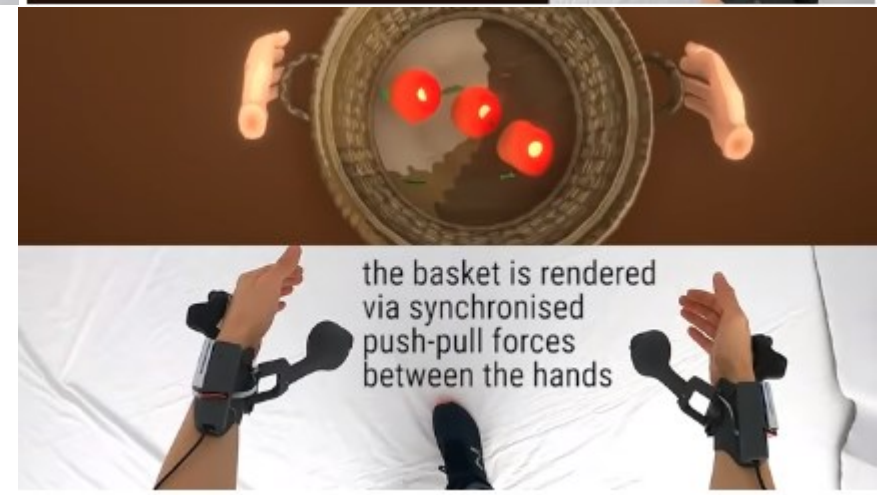
Coming devices: gloves and vests…

https://www.youtube.com/watch?v=AX-Oz5hocyI
https://teslasuit.io/
http://plexus.im/

Haptic PIVOT,

simulates physical forces such as momentum and gravity





https://www.microsoft.com/en-us/research/blog/physics-matters-haptic-pivot-an-on-demand-controller-simulates-physical-forces-such-as-momentum-and-gravity/?OCID=msr_blog_pivot_uist_tw

(October 2020)