Universidade de Aveiro
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Output Devices
Visual Displays

Realidade Virtual e Aumentada 2024

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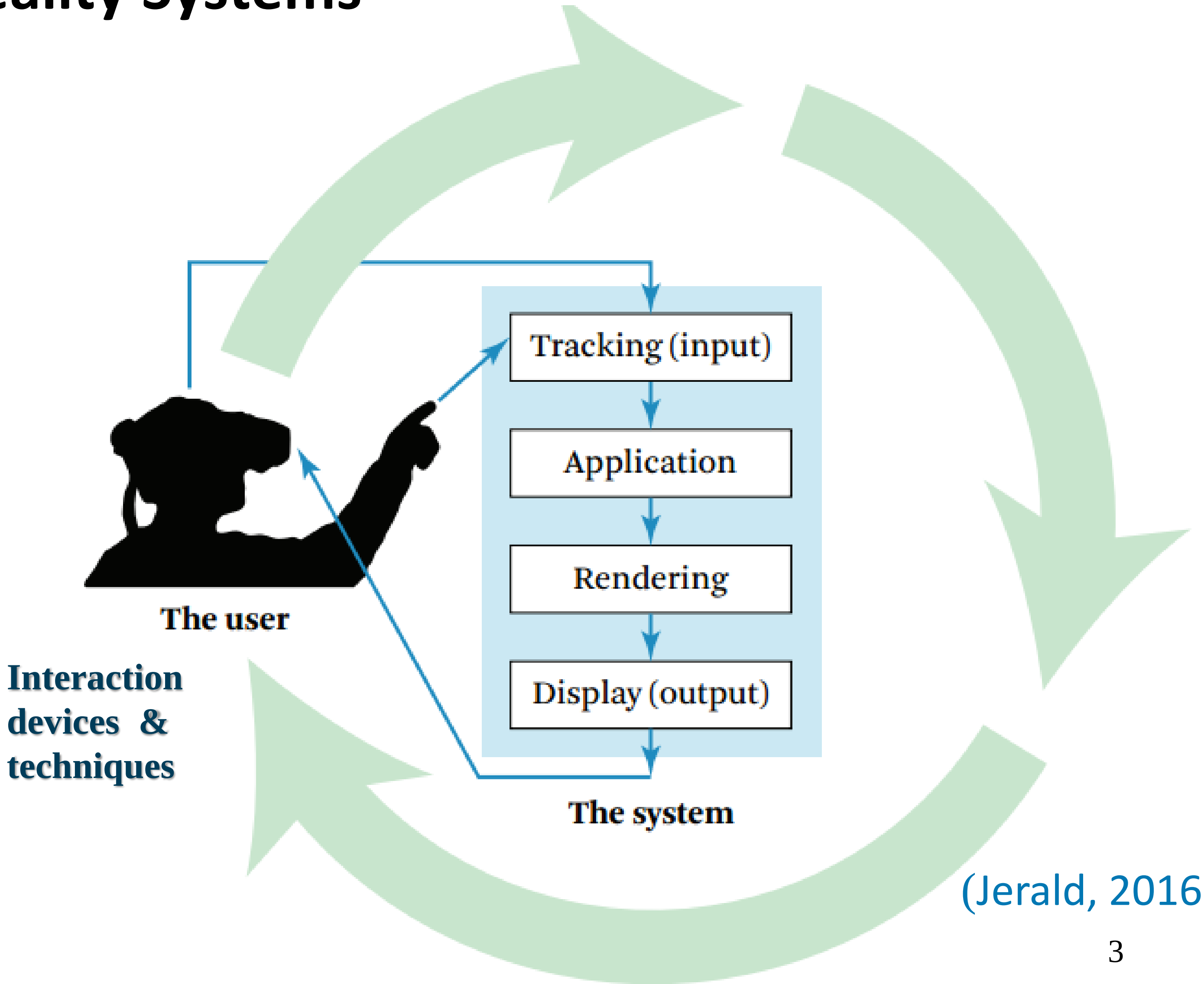
What is Virtual Reality?

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

Virtual Reality Systems



(Jerald, 2016)

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

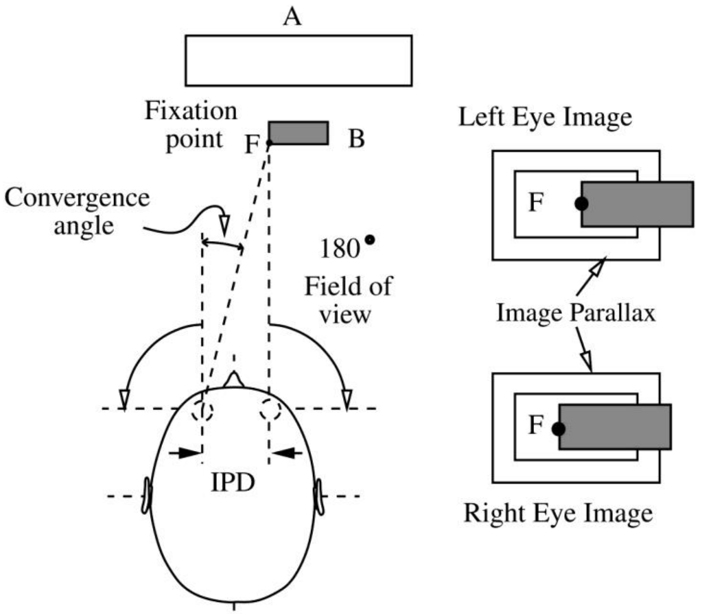
“is a computer interface that **presents synthetic world images** to one or several users interacting with the virtual world.”

(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)

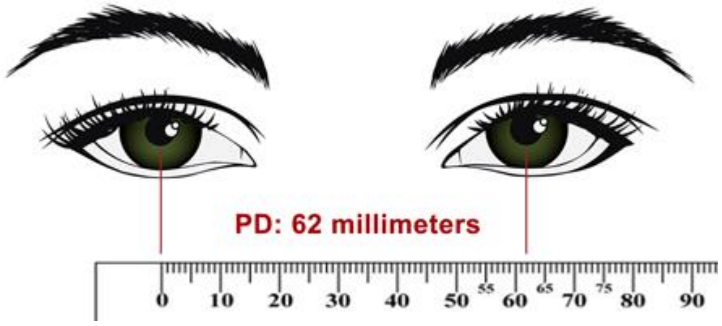
- Vision is the dominant sensorial channel

- Depth perception in mono images is based on:

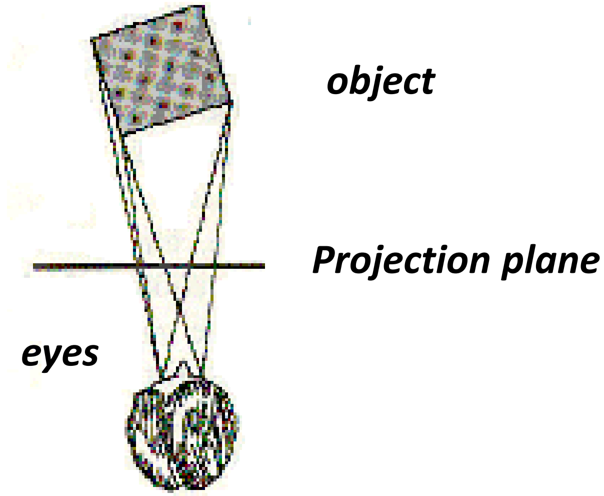
  - occlusion (one object partially covering another)
  - perspective (point of view)
  - familiar size (we know the real-world sizes of many objects)
  - shadows (casted on objects)

- 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

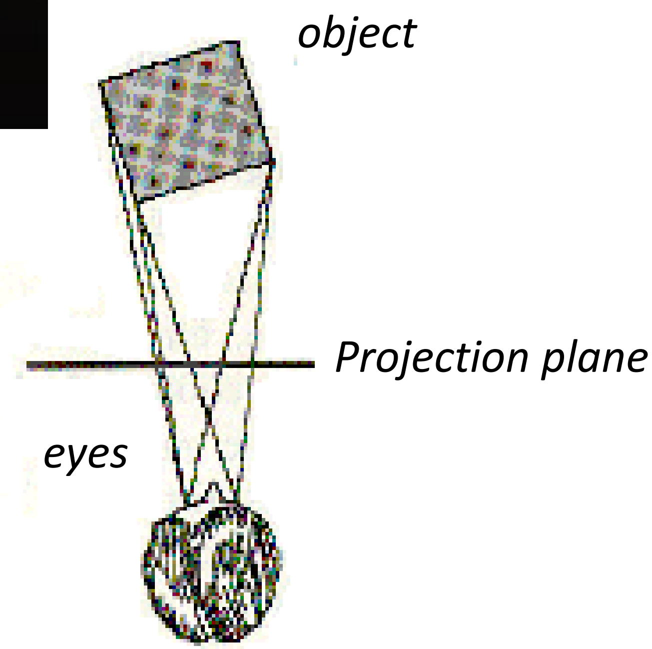
'binocular vision‘ , 'binocular depth perception' , 'stereoscopic depth perception'

- 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

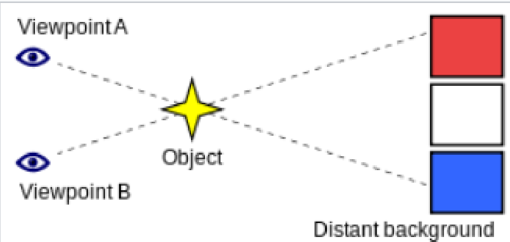
Right eye image Left eye image

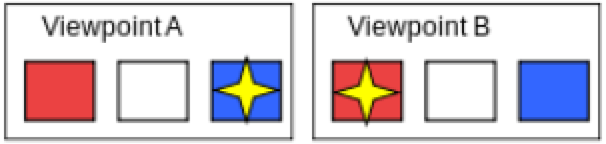


- Many of the perceptual cues we use to visualize 3D structures are available in 2D projections

- 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

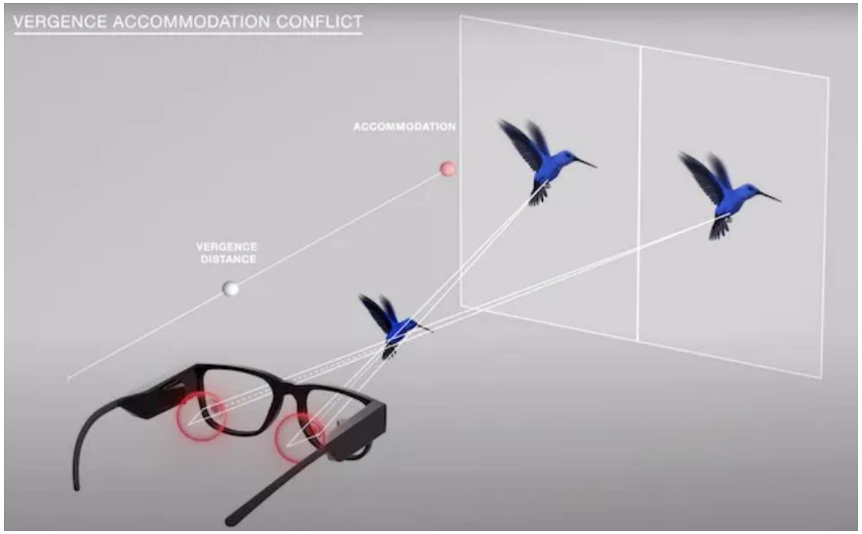




The Vergence Accommodation conflict

- Occurs when your brain receives **mismatching cues** between:

  - the **distance of a virtual 3D object** (vergence),
  and
  - the **focusing distance** (accommodation) required to focus on the object



- It can contribute to:
  - **focusing problems,**
  - **visual fatigue,**
  - **eyestrain,**

  while looking at stereoscopic imagery,
  effects last after ceasing looking

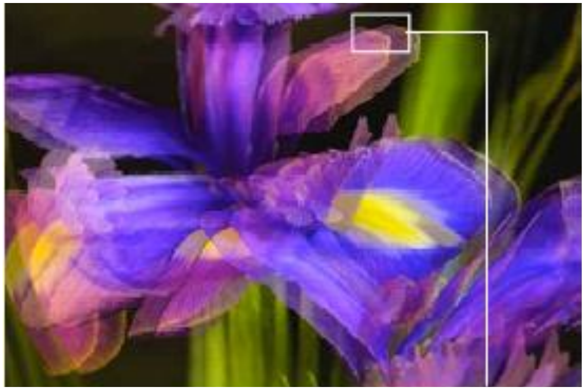
- It is less severe when properly taken into account in content creation and display

https://xinreality.com/wiki/Vergence-Accommodation_Conflict

Implications for Stereo Viewing devices

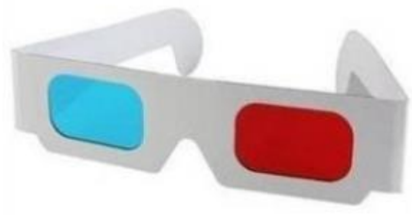
- Need to present **two images** of the same scene (one for the right eye and another for the left eye)

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



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

Common ways to produce a 3D sensation



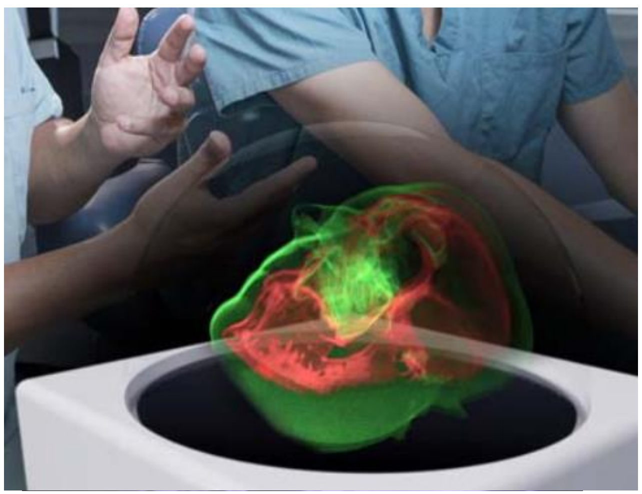
- Anaglyphs: two colored images and color coded glasses (red/cyan(green))
- Two images with different light polarization and polarizing glasses
  - Linear and circular

- Double frame-rate displays combined with LCD shutter glasses

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

[Anaglyph, Shutter, Polarized Glasses or Autostereoscopic 3D Solution - 3D Vision](#)
[Anaglyph 3D - Wikipedia](#)

- 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)



volumetric technology

https://www.voxon.co/
https://www.gartner.com/en/information-technology/glossary/volumetric-displays

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

- All these technologies provide:
  - stereo parallax

  (apparent displacement of an object when seen from two different positions)

- When combined with head tracking, they can provide:
  - movement parallax for a single viewer

  (objects moving at a constant speed across the frame will appear to move a greater amount if they are closer to an observer)

- Virtual Reality uses:
  - Different light polarization and polarizing glasses
  - Double frame-rate displays and LCD shutter glasses
  - Two images in two screens (HMDs)

Polarized glasses for stereoscopic displays
(also used in 3D movies)

- 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

[Polarized 3D system - Wikipedia]

Main Properties of Visual Displays

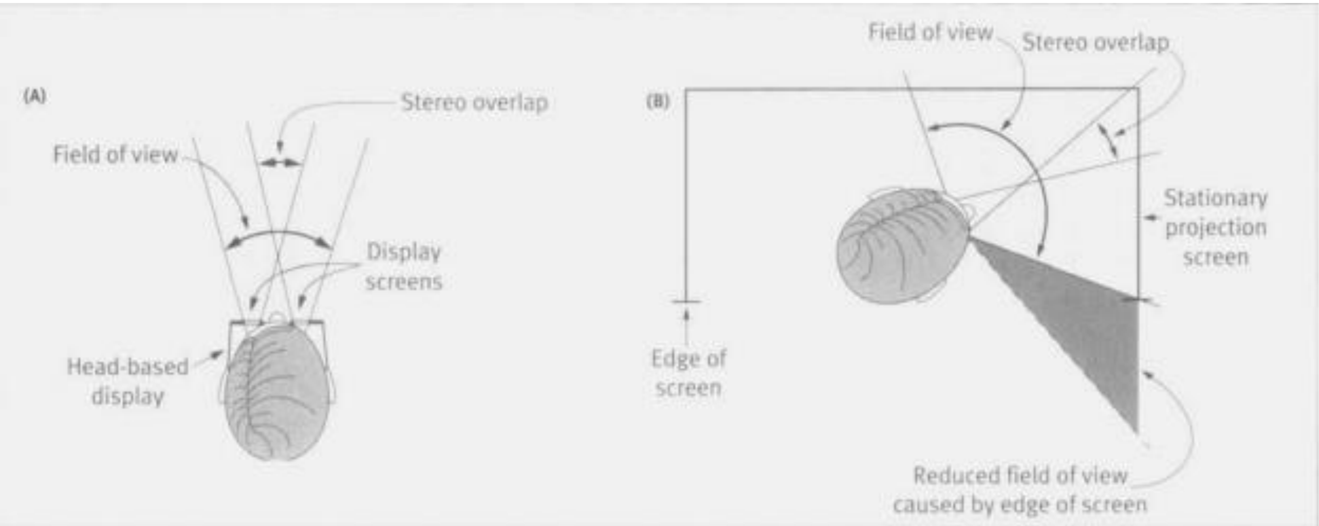
Visual presentation properties:

- 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)



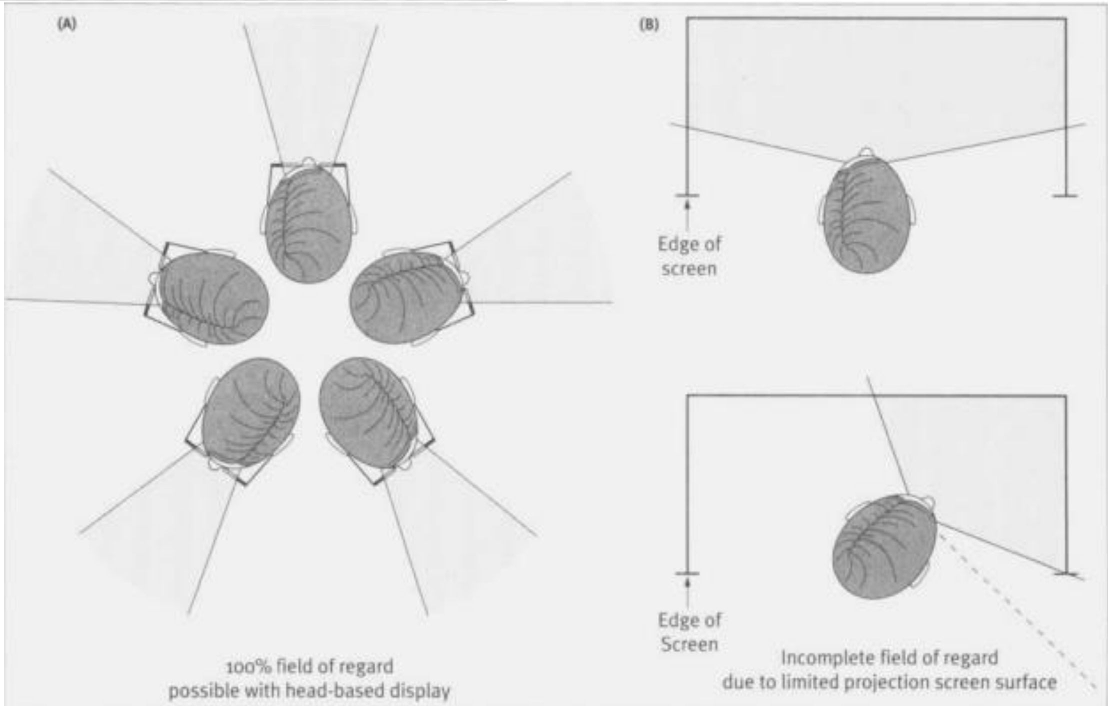
FOV is the amount of the viewer's visual field covered by a display.

(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

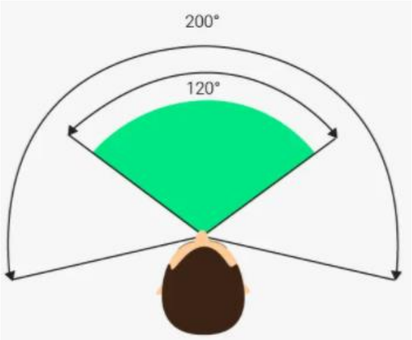


Field of View comparison

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°.

Visual Displays: two possible taxonomies

(Burdea and Coiffet, 2003)

- **Personal displays:**
  - HMDs (VR/AR)
  - Binoculars
  - Monitor-based displays/ 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.

- Head Mounted Displays (HMDs)

- 3-D Binoculars (hand supported)

The low cost Head-Mounted Displays have evolved e.g.:

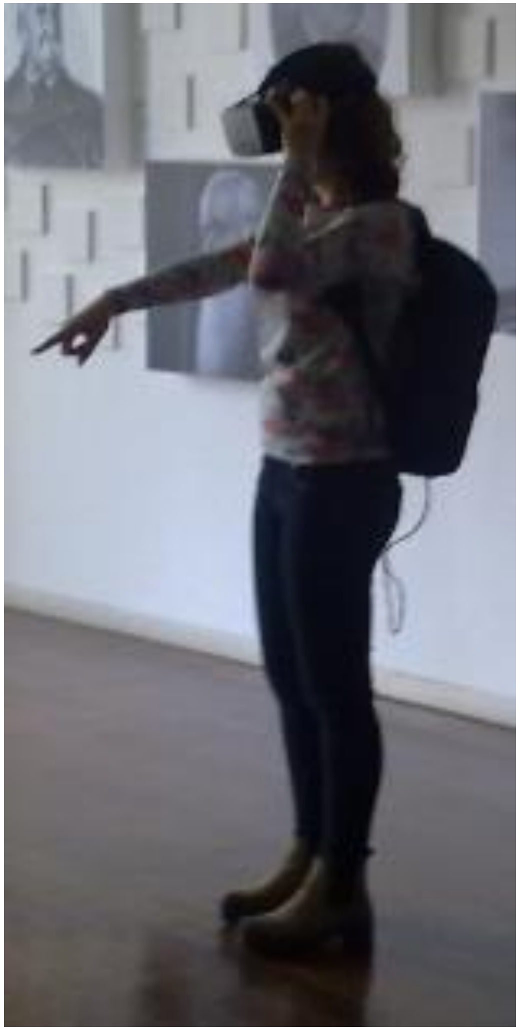
Oculus Rift

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/



To standalone (all in one) systems…

Oculus Quest 2 specs:

Smaller, lighter, and higher resolution than Oculus Quest

- Display panel: LCD
- VR Gaming without Cables or a PC
- 256GB Storage Capacity
- 1832 x 1920 Resolution Per Eye
- Qualcomm Snapdragon XR2 Platform
- Built-In IPD Adjustment with 3 Settings
- Cinematic 3D Positional Audio
- Headset Casting
- Two Touch Controllers Included

~500USD – Sep/2022

Oculus Quest 3 specs:

higher resolution, better FOV, better pass through

- Display panel: LCD
- 2064x2208 Resolution Per Eye
- FOV 110º horizontal; 96º vertical
- Refresh rate: up to 120Hz
- 256GB Storage Capacity

~500USD – Sep/2024

LCD vs OLED in HMDs

- LCD panels offer some benefits:
- Higher pixel density: reducing the "screen door effect
- Brighter display: beneficial for mixed reality applications
- Cost-effectiveness: generally less expensive to produce than OLED
- Reduced risk of burn-in: not susceptible to permanent image retention or burn-
- While OLED displays offer better contrast ratios and deeper blacks, the Quest 3's use of LCD panels provides a good balance of performance, cost, and reliability for its intended mixed reality applications.

Pico 4 and Meta Quest standalone VR headsets

- Pico 4 - better comfort and a wider field of view

- Quest 3 - more powerful processor, higher refresh rate, better passthrough capabilities

Hololens 2

Microsoft AR glasses

~3500 USD

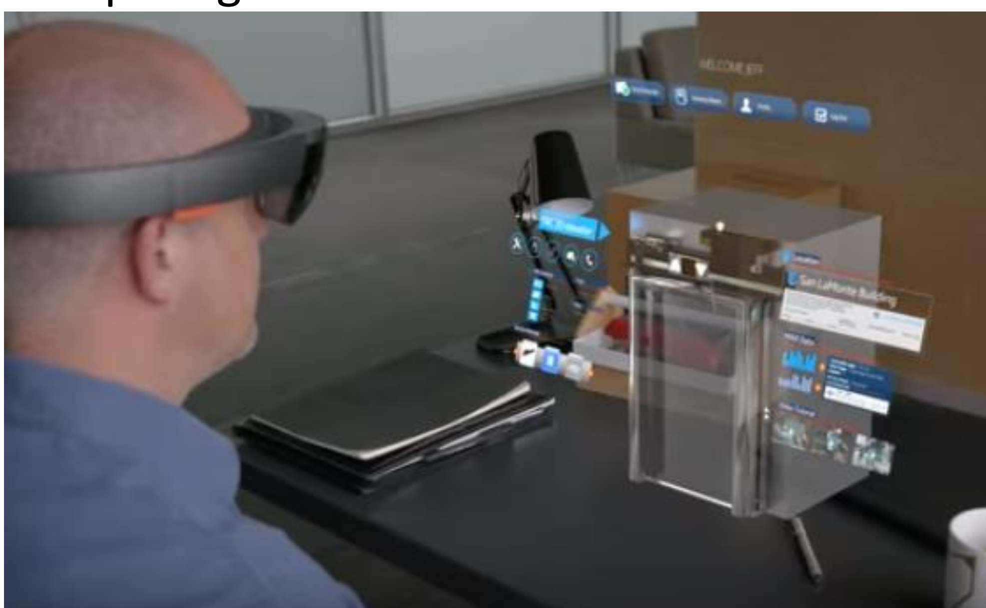
Include Eyeball and hand tracking

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

Hololens 2
Microsoft AR glasses

Discontinued, Dec/2024

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

“improve the Army’s HoloLens-based headsets with real-time threat updates… enabling Soldiers to see real time threats across the battlespace”

Palmer Luckey aims to turn US soldiers into Starship Troopers - The Verge

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/

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

- LaValle, S., *Virtual Reality - Virtual Reality*. Cambridge University Press, 2023 http://vr.cs.uiuc.edu/

- Bimber, J., R. Hainich, *Displays: Fundamentals and Applications*, CRC Press, 2011 https://learning.oreilly.com/library/view/displays/9781439867709/chapter-99.html

Papers

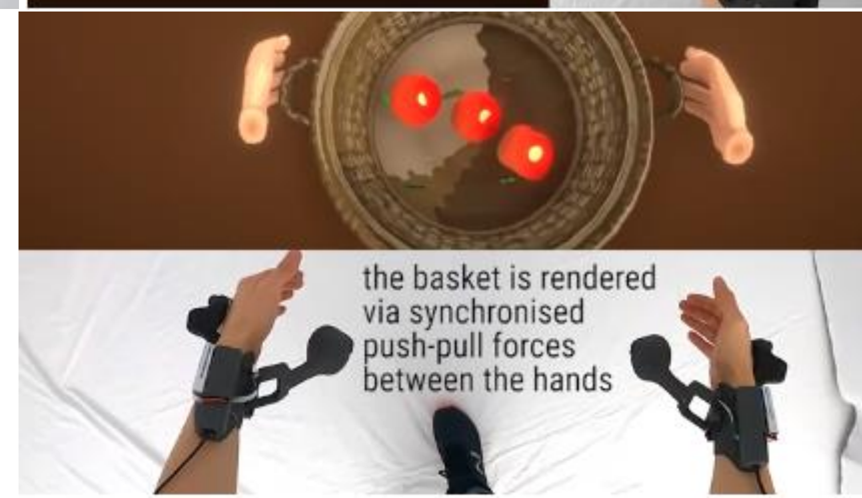
- Xiong, J., Hsiang, E. L., He, Z., Zhan, T., & Wu, S. Augmented reality and virtual reality displays: emerging technologies and future perspectives. *Light: Science and Applications*, *10*(1), 1–30, 2021. https://doi.org/10.1038/s41377-021-00658-8

More Output devices

Displays to other senses: touch, smell, …

Haptic PIVOT,

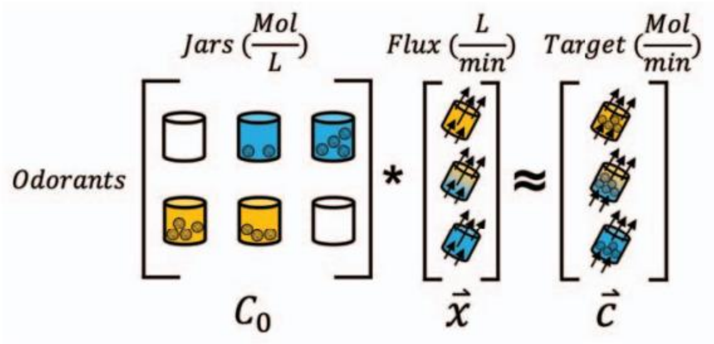
simulates physical forces such as momentum and gravity



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)

The Smell Engine



- Pairs with Unity and Includes:
- - Smell Composer framework that allows developers to configure odor sources in virtual space
- - Smell Mixer that dynamically estimates the odor mix that the user would smell, based on diffusion models and relative odor source distance
- - Smell Controller that coordinates an olfactometer to physically present an approximation of the odor mix to the user's mask

A. Bahremand *et al.*, "The Smell Engine: A system for artificial odor synthesis in virtual environments," *2022 IEEE Conference on Virtual Reality and 3D User Interfaces*, pp. 241-249
https://ieeexplore.ieee.org/document/9756819

https://www.youtube.com/watch?v=vV36-LQbsOU

A graspable olfactory display for virtual reality

A virtual wine cellar game, with wine glasses to be grasped and sniffed (a). By pressing the trigger button on the HTC Vive hand controller, the player releases wine bouquet from a virtual glass (b)

Simon Niedenthal, S et al., "A graspable olfactory display for virtual reality", *International Journal of Human-Computer Studies*, vol. 169, 2023
https://doi.org/10.1016/j.ijhcs.2022.102928

Gustatory Interfaces – first experiments

- Taste is very difficult to display as it is multi-modal sensation composed of chemical substance, haptics and sound

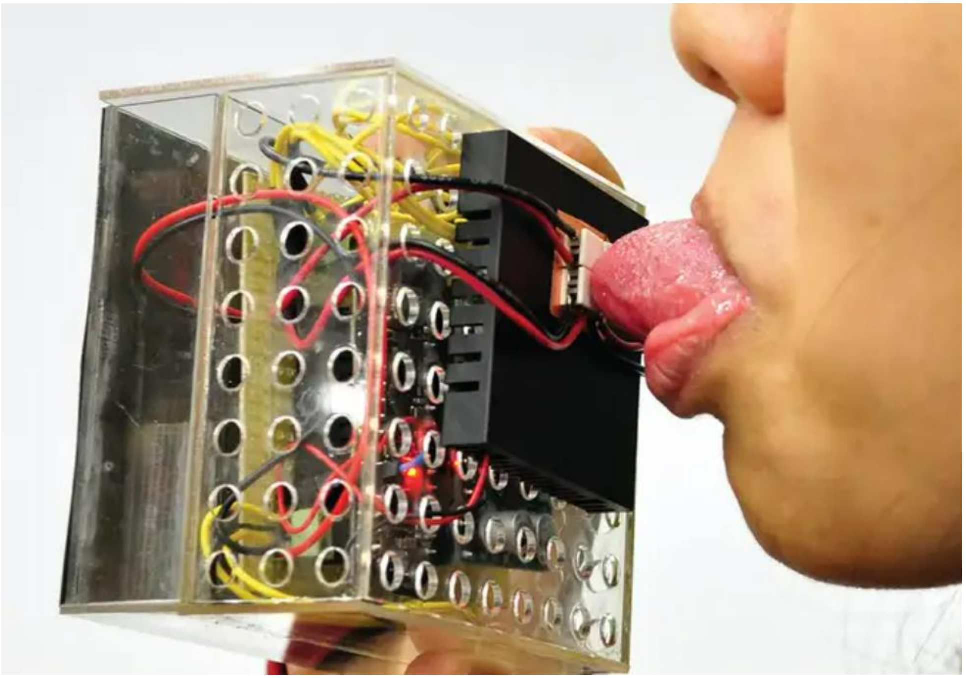
- Marginally addressed

- Few taste interfaces can be found in literature

- Food simulator addresses chewing simulation
  - releasing flavoring chemicals
  - resistance to the mouth
  - playing sound

Iwata, Hiroo, Yano, Hiroaki, Uemura, Takahiro, Moriya, Tetsuro (2004): Food Simulator: A Haptic Interface for Biting. In: IEEE Virtual Reality Conference 2004 VR 2004, 27-31 March, 2004, Chicago, IL, USA. pp. 51-58. http://doi.ieeecomputersociety.org/10.1109/VR.2004.40

Taste Interfaces



Virtually simulate the sensation of sweetness by applying thermal stimulation to the tip of the tongue

Ranasinghe , N. & E. Yi-Luen Do, “Virtual Sweet: Simulating Sweet Sensation Using Thermal Stimulation on the Tip of the Tongue”, User Interface Software and Technology (UIST '16 Adjunct), pp, 127–128, 2016

https://doi.org/10.1145/2984751.2985729

https://www.newscientist.com/article/2111371-face-electrodes-let-you-taste-and-chew-in-virtual-reality/