# Human-Computer Interaction

2024/2025

Lecture 11

## 3D User Interfaces

universidade de aveiro
deti departamento de electrónica, telecomunicações e informática

Universidade de Aveiro
Departamento de Electrónica,
Telecomunicações e Informática

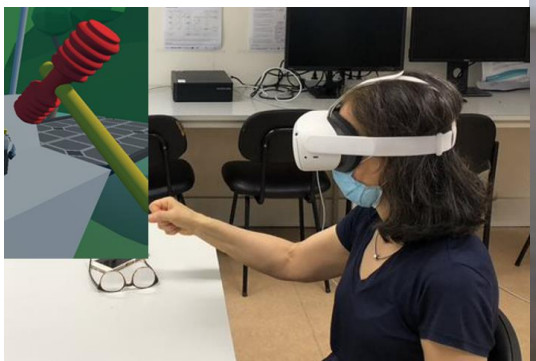
# 3D User Interfaces

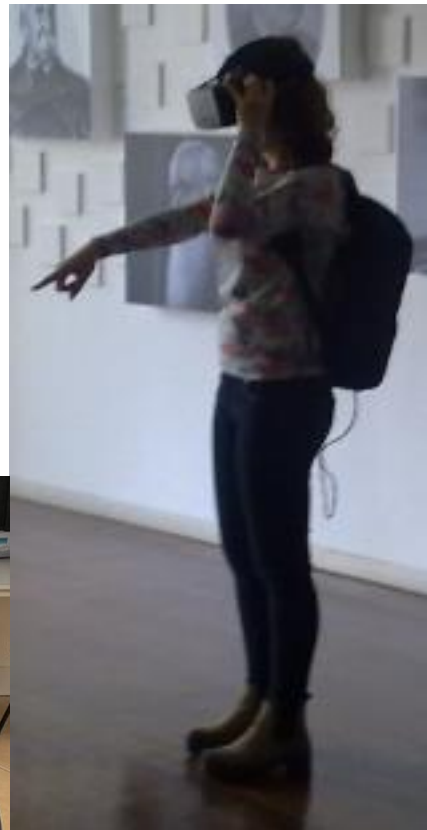
**Beatriz Sousa Santos**

- **I – 3D User Interfaces**
  - Definition and specificities

- **II – Technologies allowing 3DUIs**
  - EXtended Reality (Virtual, Augmented and Mixed Reality)
  - Main parts of a XR system
  - Human factors

- **III - Interaction in 3DUIs**
  - Interaction tasks and techniques

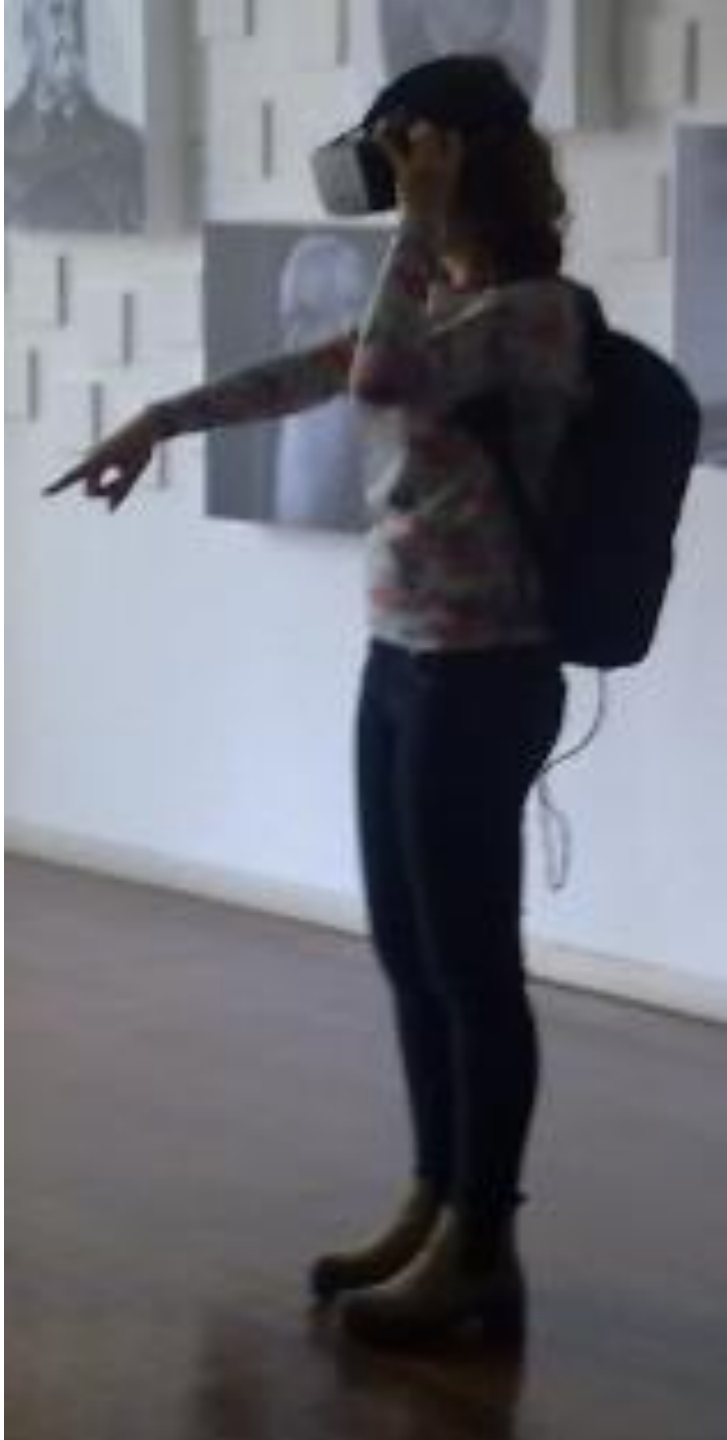




## What is a 3D User Interface?

- Not easy to define…
- a UI that involves 3D interaction
- the user's tasks are performed **directly in a 3D spatial context**
- based on 3D spatial input …

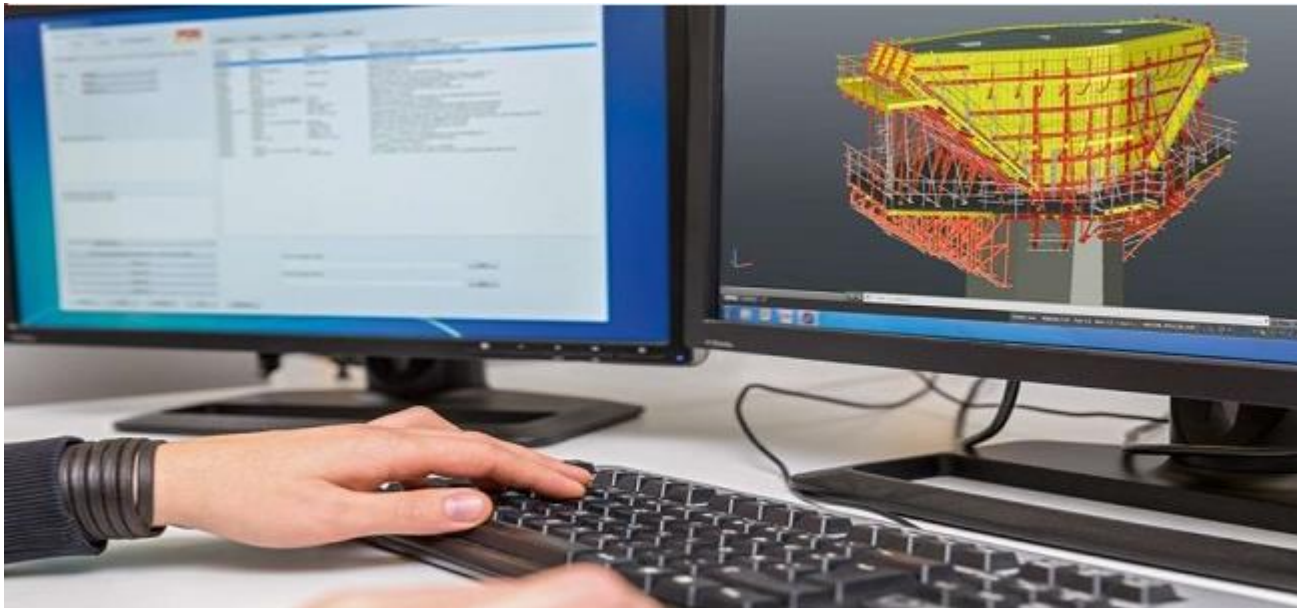
(Jerald, 2016),



# Is this a 3D User Interface?

- The system displays a virtual 3D space, but the user interacts indirectly with this space—e.g.,
  - by manipulating 2D widgets,
  - entering coordinates,
  - or choosing items from a menu
- e.g. CAD (Computer Aided Design) system

- **It is not a 3D UI!**



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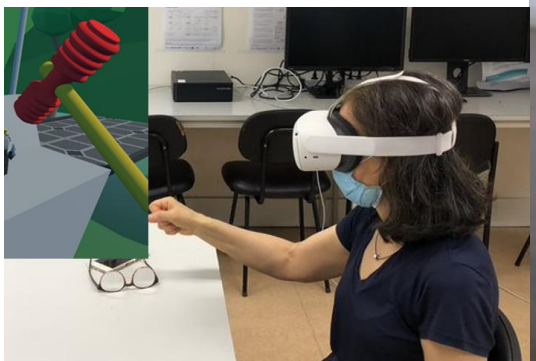
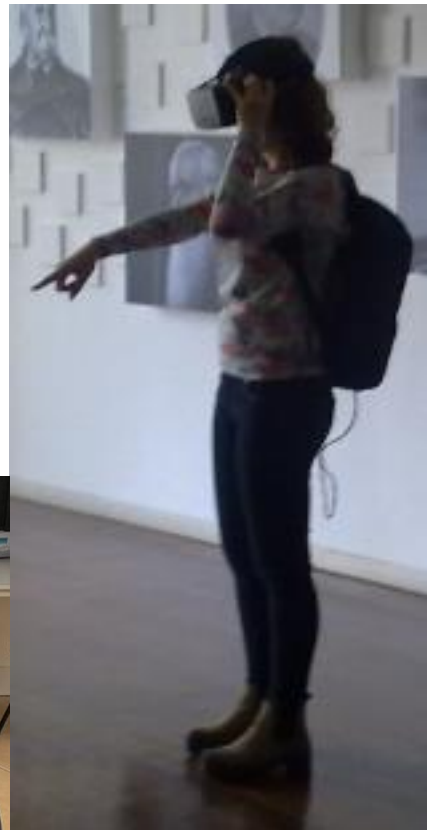




## Technologies allowing 3D User Interfaces

- **Extended Reality (XR)**

Umbrella term encompassing all technologies that simulate or blend the real and virtual:

- Virtual Reality (VR)
- Augmented Reality (AR)
- Mixed Reality (MR)

Creates immersive, interactive experiences by merging digital content with the real world or fully immersing users in virtual environments

- Virtual Reality (VR) is a **high-end user interface** that involves ***real-time simulation*** and ***interaction*** through ***multiple sensorial channels***." (vision, sound, touch, …)

## XR Systems/applications are very specific

- Interactive Systems typically having 3DUIs:
  - Extended (Virtual, Augmented and Mixed) Reality systems
- Are particularly difficult to design and implement:
- **If poorly designed/implemented may jeopardize users' health/comfort**
- Involve very specific H/W
- **Human factors are central**

## Using Human-Centered Design (HCD) is fundamental

- Remember, it involves:
- Early and continual **focus on users** and their **context**
- **Iterative design**
- Several rounds of **evaluation** (starting early)

These ideas are 60 years old!

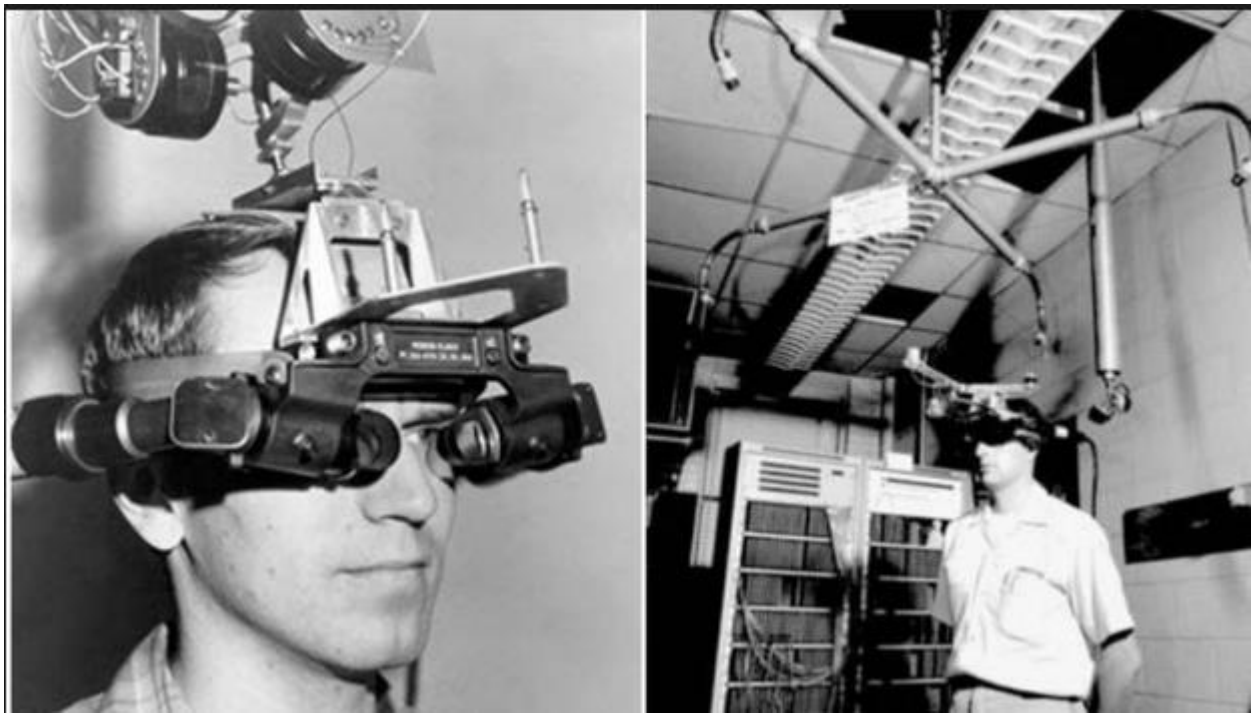
Ivan Sutherland's 1965 Vision:

"**The ultimate display**"

"**Don't think of that thing as a screen**, think of it as a window, a **window** through which one **looks into a virtual world.**

The challenge … is to make that virtual world look real, sound real, move and respond to interaction in real time, and even feel real."

# The first AR Head-Mounted Display (HMD)



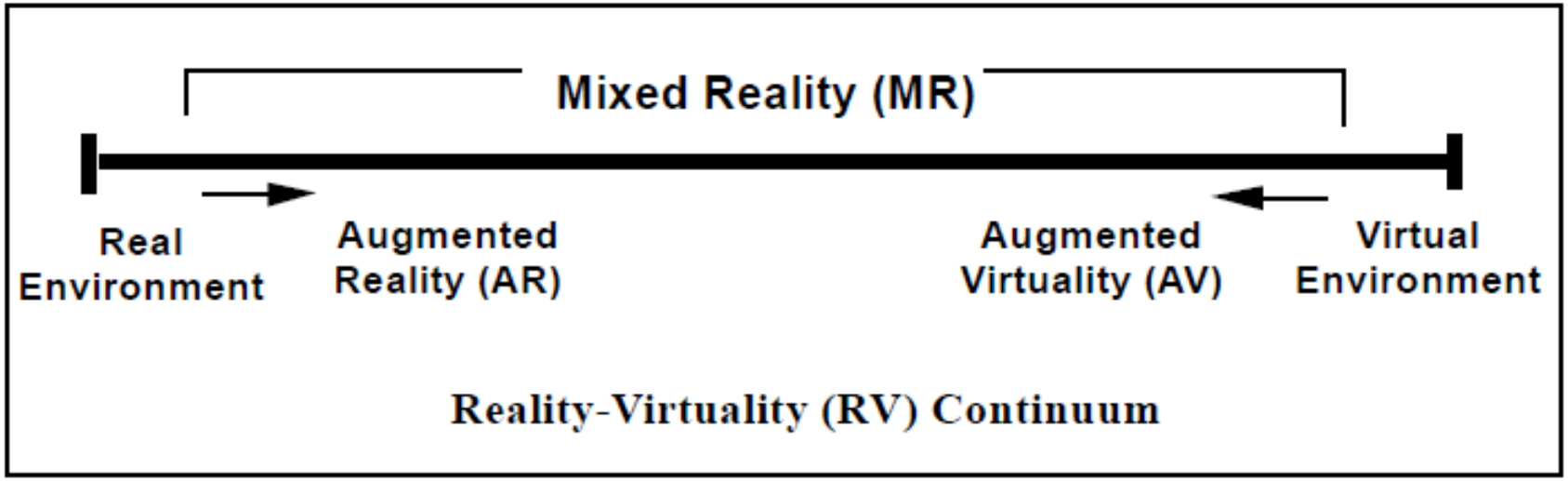
[Ivan Sutherland - Head Mounted Display]

[What is Virtual Reality | IxDF]

## Mixed reality

"...anywhere between the extrema of the *virtuality continuum*"

**(Milgram et al., 1994)**



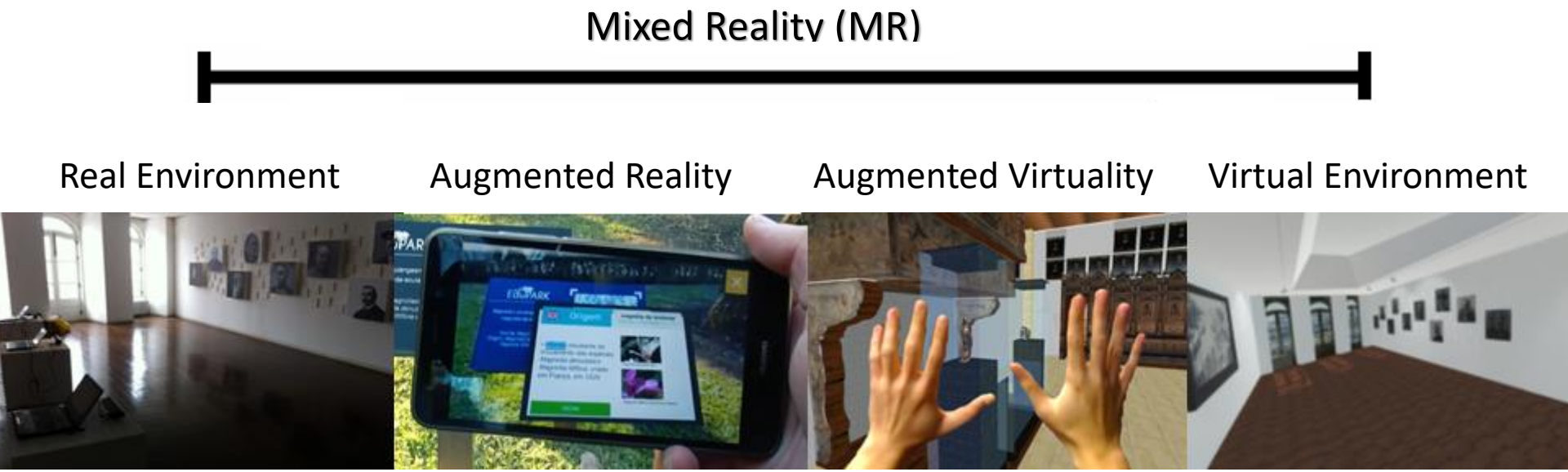

Terminology evolves…

What is Mixed Reality? | Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems

# Reality Virtuality “Continuum”

"...anywhere between the extrema of the *virtuality continuum*"

**(Milgram et al., 1994)**




Terminology evolves…

[What is Mixed Reality? | Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems]

# VR Applications

Expanding from a **research field** into a **commercially viable technology**:

- Education and training (e.g. military, medical, hazardous industries…)
- Ergonomics evaluation, project review (automotive industry, architecture…)
- Medicine (physical and cognitive therapy, surgery planning, pain relief …)
- Culture, entertainment (museums, games, …), sales and marketing
- Data visualization (e.g. science, oil industry)
- Etc.

# Virtual Reality in practice – Medical simulators

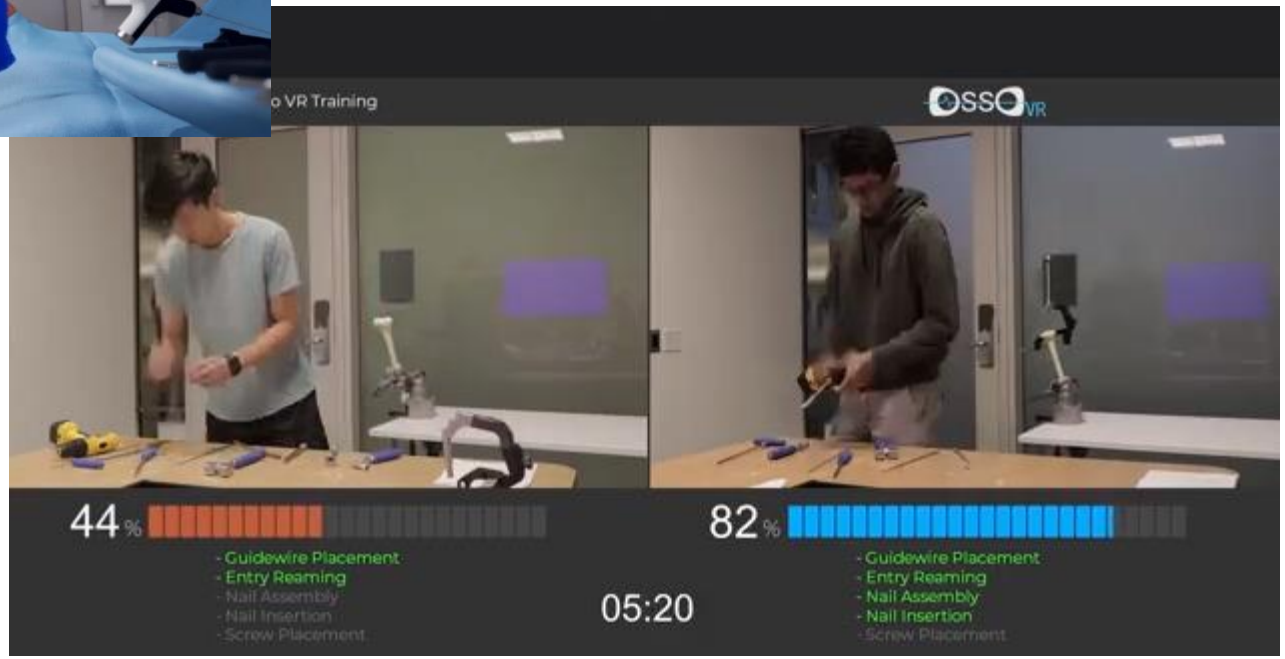
Combining imaging from MRIs, CT scans and angiograms to create a 3D model that physicians can see and manipulate — like VR game  Stanford Medicine


Virtual reality system helps surgeons, reassures patients | Medical Center Development | Stanford Medicine

Virtual reality, augmented reality can improve surgeons' training | STAT

Surgeons new to complex procedures can practice through spaced-repetition, and then measure skill through Assessment reports.

Osso VR validation study results indicate that **VR training will shorten the learning curve.**




[Osso VR]

[Osso VR | Collaborative Training]

# Virtual Reality in practice - industry
# A success case for many years: Automotive industry

Extensively used in :
- Design, Project review,
- Ergonomic studies,
- Production, Marketing


- Accelerates the process
- Decreases costs
- Fosters innovation …

How McLaren Automotive uses VR to design its sportscars and supercars

# AR Applications

"make the computer **interface invisible** and make interacting with the computer **as natural as interacting with real world** objects, removing the separation between the digital and physical"

(Billinghurst et al., 2015)

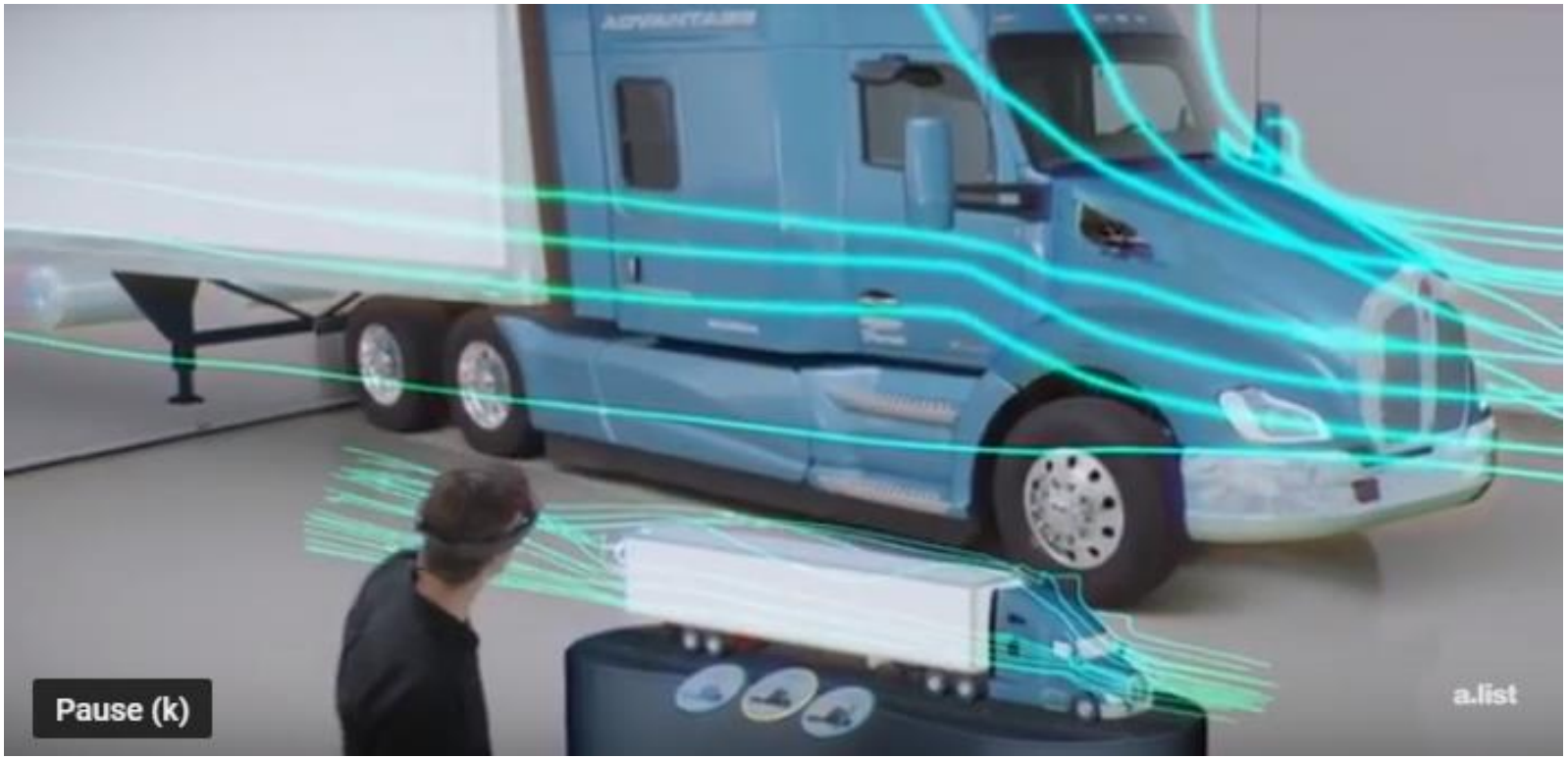
AR interfaces are designed to enhance interactions in the real world

Education/training Medicine Marketing Industry…



# AR in practice - industry

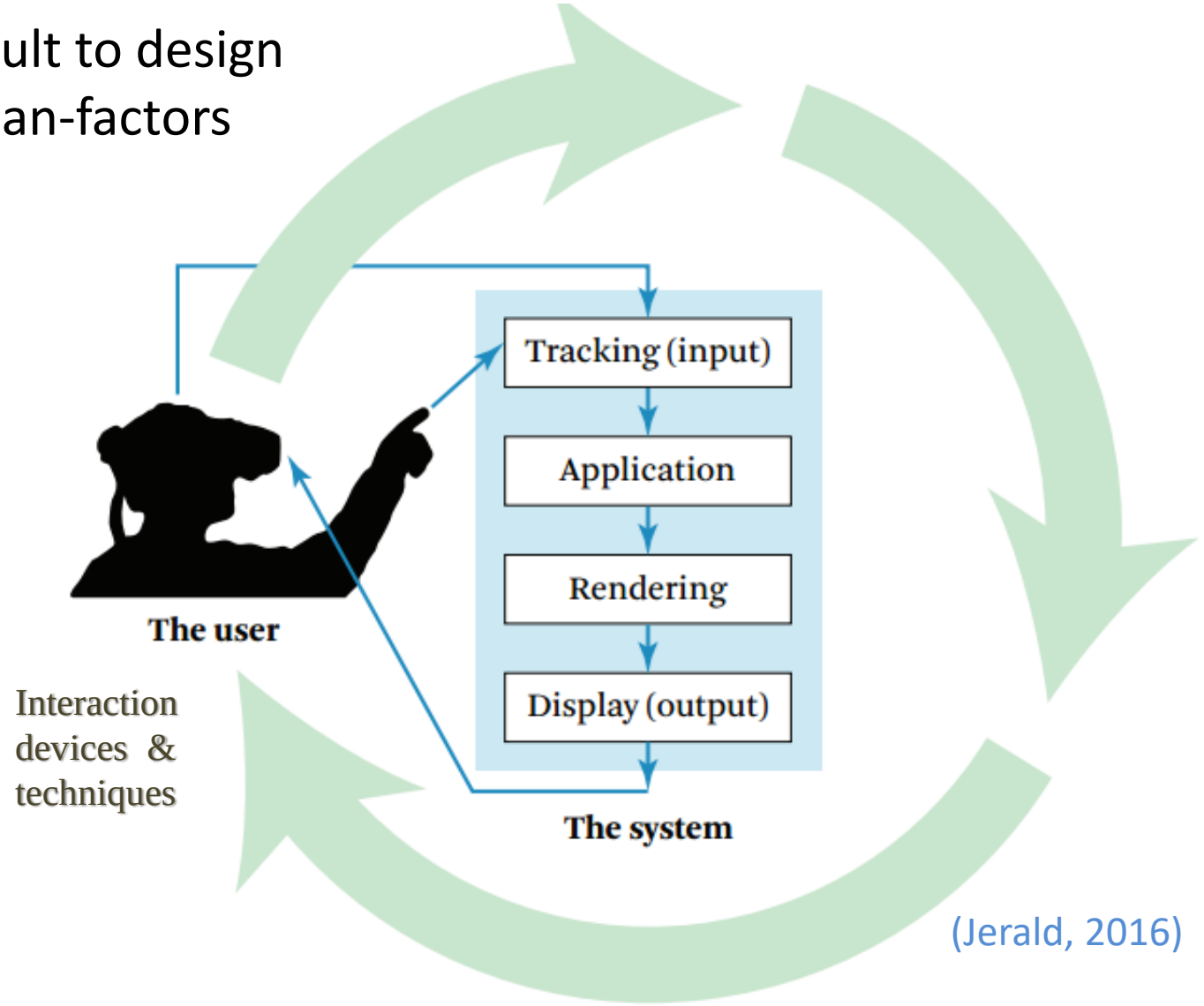
How Augmented Reality Is Driving Today's Automotive Industry




How Augmented Reality Is Driving Today's Automotive Industry

# Virtual Reality Systems

Are most difficult to design regarding human-factors




(Jerald, 2016)

## Crucial technologies for VR

- **Visual displays**
- **Graphics rendering system**
- **Tracking system**
- **Database system**
- **Interaction devices**
- **Interaction techniques**

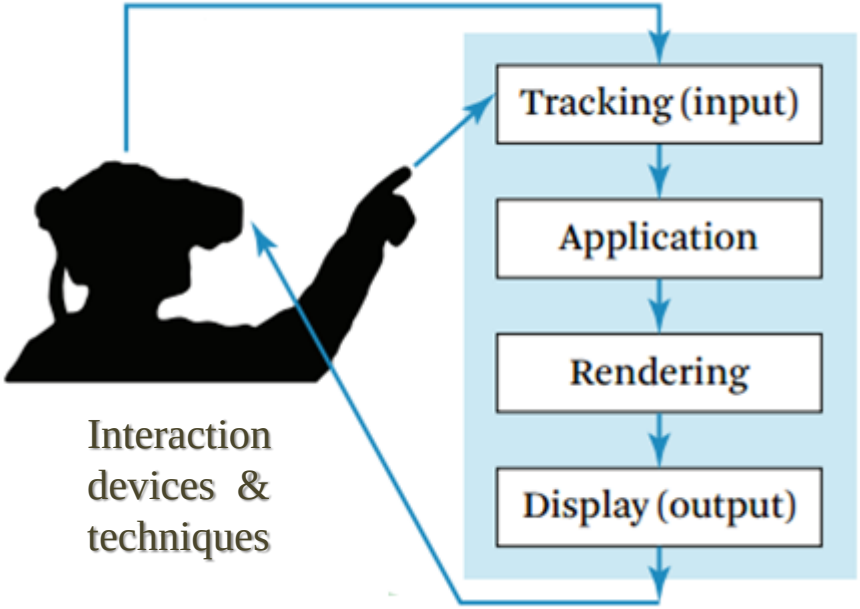
If possible:

- **3D Sound and haptic displays**

## for AR

**+ Cameras and registering**

# Specific Hardware and UIs




- Trackers:
  - Magnetic (AC, DC)
  - Optical
  - Ultrasonic
  - Inertial, …
- Navigation and manipulation interfaces:
  - Tracker-based
  - Controllers
  - Cameras
  - Eye trackers ...
- Gesture interfaces:
  - Cameras
  - Gloves ...
- Output Devices:
  - Stereoscopic displays (HMDs, …)
  - Haptic devices …

# Expanding from a **research field** into **commercially viable**

Accessible Head-Mounted Displays (HMDs):
- Oculus Rift
2014; ~300 USD

**Made VR economically viable in many more situations!!**

Was widely used in research and many applications

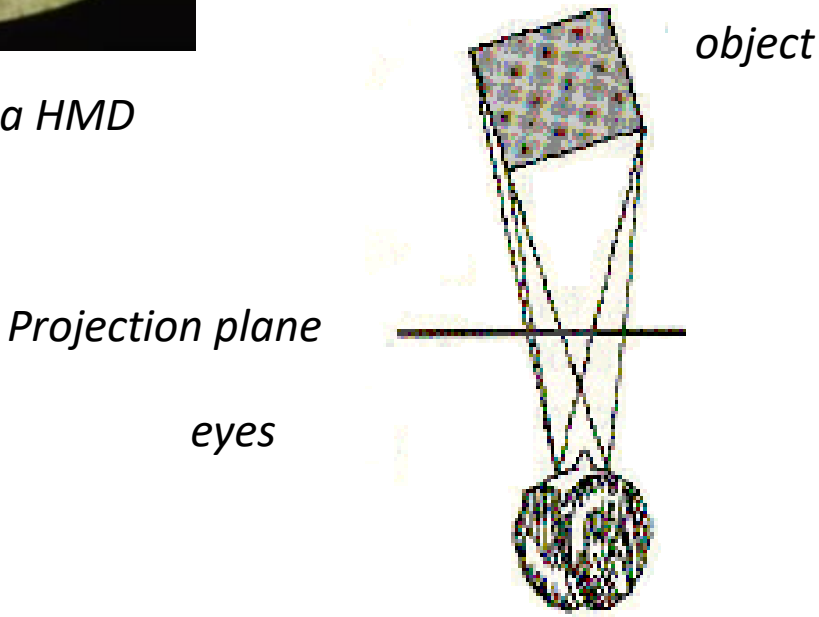
Oculus Rift - Wikipedia

# Stereoscopic displays for XR

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

*Two images for the two eyes provided by a HMD (Head-Mounted Device)*

*Right eye image* *Left eye image*



# All in one systems for XR…

- **Oculus Quest 3 specs:**
- Video see through
- Display panel: LCD
- Display resolution: 2064 x 2208 per eye (Oculus Rift had 1080×1200 per eye)
- FOV Horizontal - 110º vertical – 96º
- 120Hz
- 4 Internal cameras
- Octa-core Kryo
- 128GB.
- Lithium-ion battery with 2.3 hours playtime, depending on what is played
- 6 DOF Inside-out head and hand tracking.
- Two touch controllers.
- ~500USD – Sep/2024

[Meta Quest 3: Mixed Reality VR Headset - Shop Now | Meta Store]

# HMD for professional purposes (aerospace industry)

AUTOMATIC IPD SYSTEM
VOICE COMMANDS
GESTURE RECOGNITION (LEAP MOTION)

~6000 USD




XTAL Virtual and Mixed Reality Headsets | Vrgineers.com

## 3DUIs may use also speech and gestures

- Both allow **interacting at a distance**

- Gestures are a form of **nonverbal communication**

- Different **types of gestures:**

  **- In-air gestures**
  Hand/arm movements detected by cameras or sensors

  **- Full-body gestures**
  Physical movements tracked by systems (trackers, cameras,…)

  **- Touch gestures**
  Tap, swipe, pinch, rotate (direct manipulation)

## Gestures in eXtended Reality

Provide:

- Natural embodiment
- Intuitive object manipulation
- Controller-free interaction
- Enhanced presence

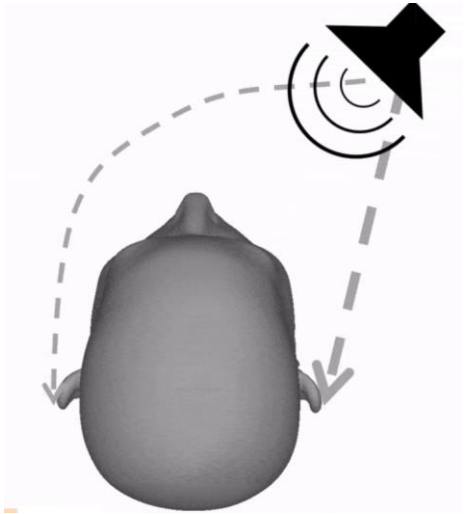
# Gestures in eXtended Reality

- Should be as simple as possible
- Users should not need to learn a completely new language
- Watch out for arm fatigue
  (avoid over gesturing/ gorilla arm effect)
- Consider the social nature of gestures and conventions

How to Design Gesture Interactions for Virtual and Augmented Reality | IxDF

Quantifying the 'Gorilla Arm' Effect in a VR Text Entry Task via Ray-Casting:

# Displays producing other stimuli

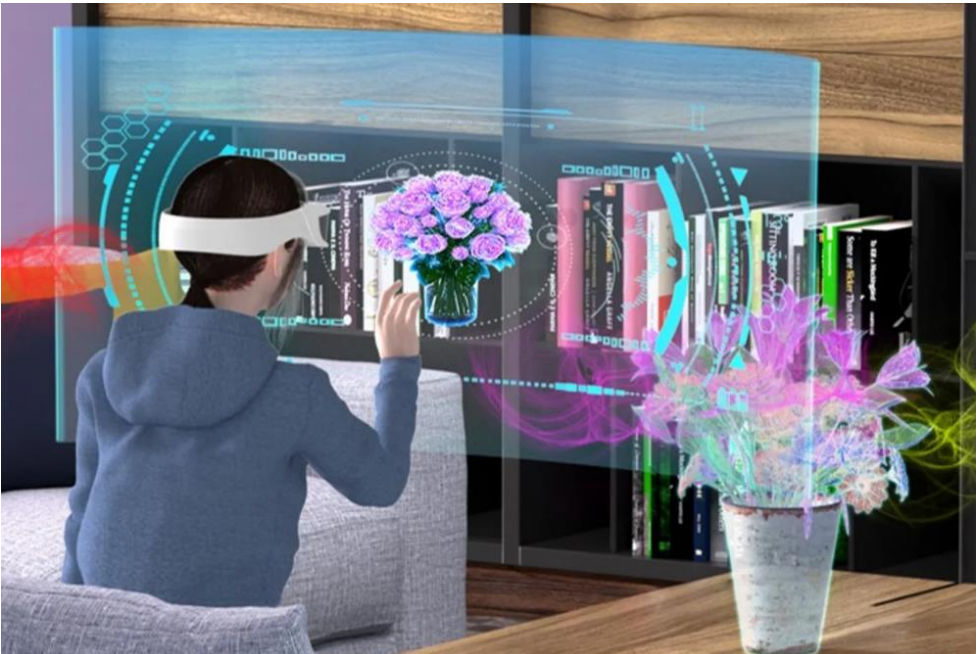


Sound in VR

VR-system-lets-you-stop-and-smell-the-roses | SciAmerican

Touch Haptic Device

Touch and force feedback



Home | HaptX

Game engines also contributed to expanding into **commercially viable** …

- Unity


Unity Real-Time Development Platform | 3D, 2D, VR & AR Engine

- Unreal


The most powerful real-time 3D creation tool - Unreal Engine

- ….

Making **much easier to develop XR applications**

# Human factors in XR

- Unlike most Interactive systems, eXtended Reality (particularly VR) systems may easily **jeopardize the health and safety of the user** ….
- Their development implies **extra care with human factors**…

# **Human factors in XR**

## Adverse Health Effects

**Motion sickness** (cybersickness)
- Visual Scene Motion
- Motion Sickness and Vection

Eye Strain, Seizures, and Aftereffects
- Accommodation- Vergence Conflict
- Binocular-Occlusion Conflict
- Aftereffects

Physical issues related to H/W
- Physical Fatigue
- Headset fit
- Injury
- Hygiene

(Jerald, 2016)

**Adverse health effects** result if **systems are not properly developed** concerning:

- **Latency**

- Calibration (e.g. IPD)

- Tracking accuracy

- Field of view (FOV)

- Refresh rate

- Flicker

- Speed of imagery motion, etc.

Latency should be < tenths ms

e.g. Interpupilary distance (IPD) should be calibrated to the users


XTAL Virtual and Mixed Reality Headsets | Vrgineers.com

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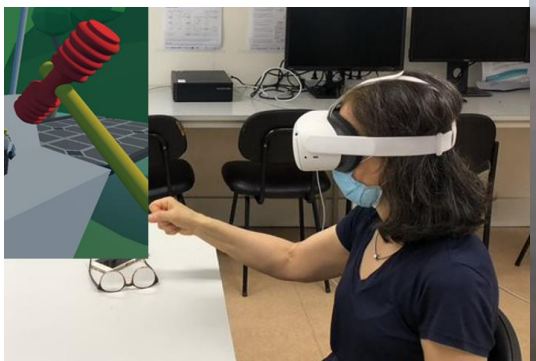
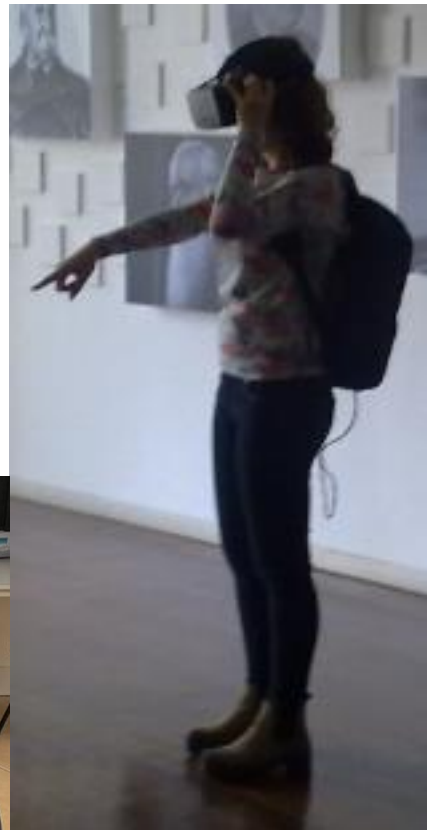


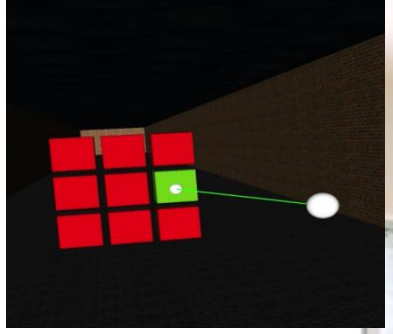


# Interaction in 3DUIs

- " Interaction is the communication that occurs between a user and the application … mediated through … input and output devices." (Jerald, 2016)

- What makes 3D interaction difficult?
  - Spatial input
  - Lack of constraints
  - Lack of standards
  - Lack of accuracy
  - Fatigue
  - …

# Universal interaction tasks in Virtual Environments (VEs)



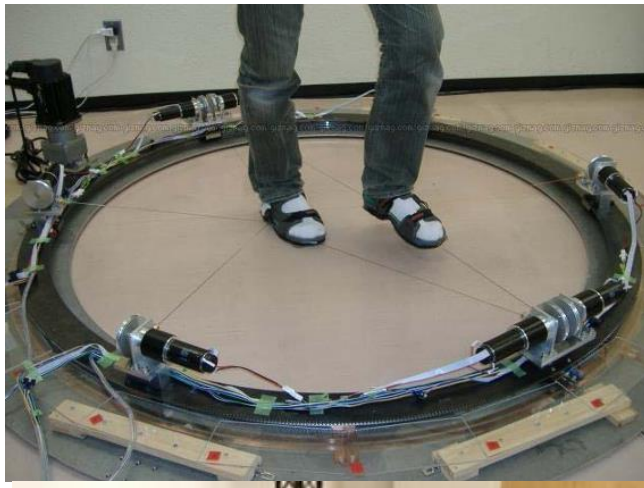
- Navigation
  - Travel – motor component
  - Way finding – cognitive component
- Selection and Manipulation
  - grasping, pointing, indirect
  - Bimanual, hybrid
- Symbolic input

## Navigation – travel and wayfinding

- Travel refers to the **user's movement** within the virtual environment,
- Wayfinding involves the cognitive process of **determining and following a route** to a destination.
- Travel focuses on the physical movement
- Wayfinding is about **planning and navigation**.
- Both are crucial for creating immersive and engaging VR experiences

# Travel

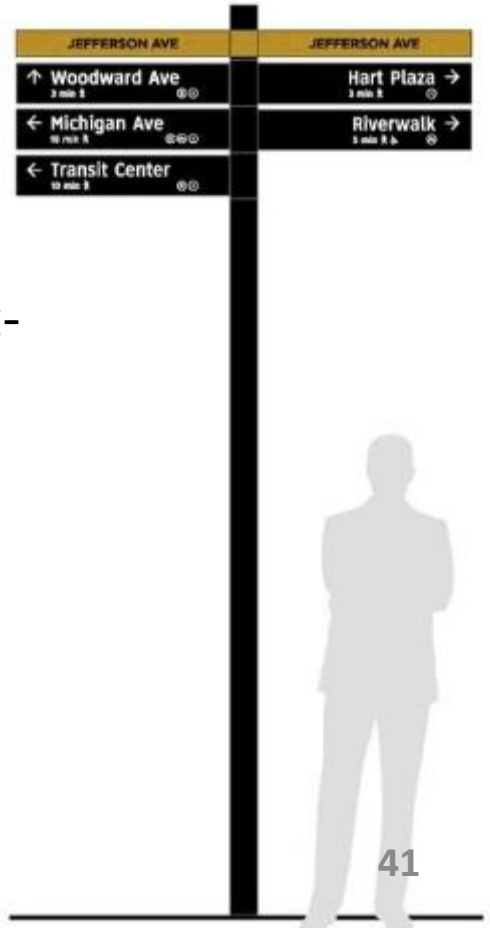
- Travel may be done in different ways:
  - walking,
  - running,
  - teleporting,
  - steering …
- Consider both natural and magic travel techniques
- Provide multiple travel techniques to support different travel tasks in the same application
- The most common travel tasks should require a minimum amount of effort from the user




Travel | La Viola 2020

# Navigation

- Ensures users can easily explore and engage with a virtual world
- May involve providing users with a virtual map and step-by-step guidance to reach their destination




- Virtual world should provide sufficient environment-based wayfinding cues:
  - visual/auditory cues,
  - interactive elements,
  - landmarks and signage,
  - virtual agents,
  - path guides, maps…

## Selection and Manipulation

- Human hand allows to manipulate physical objects quickly and precisely, without much thinking about it

- Creating new 3D UI manipulation techniques is a strong **research area**

- 3D manipulation techniques **map user input** captured by input devices, into the desired action **in the virtual world**

## Selection and Manipulation parameters

**selection**
distance and direction to target; initial orientation; target size; density of object around the target, number of targets to be selected; target occlusion

**positioning**
distance and direction to initial position, distance and direction to target position, translation distance, required precision of positioning

**rotation**
distance to target, initial orientation, final orientation, amount of rotation, required precision of rotation

**scaling**
distance to target; initial scale; final scale; amount of scale; required precision of scale

# Manipulation Techniques and Input Devices
# the device impacts design

- the input device has a major impact on the possibilities for manipulation
- control dimensions (i.e., DOFs) and integration of control
- force vs position control, e.g., joystick vs mouse
- device placement and form factor,
  e.g., power grip vs precision grip

(La Viola, 2017)

# Manipulation techniques for Grasping – Simple Grasping

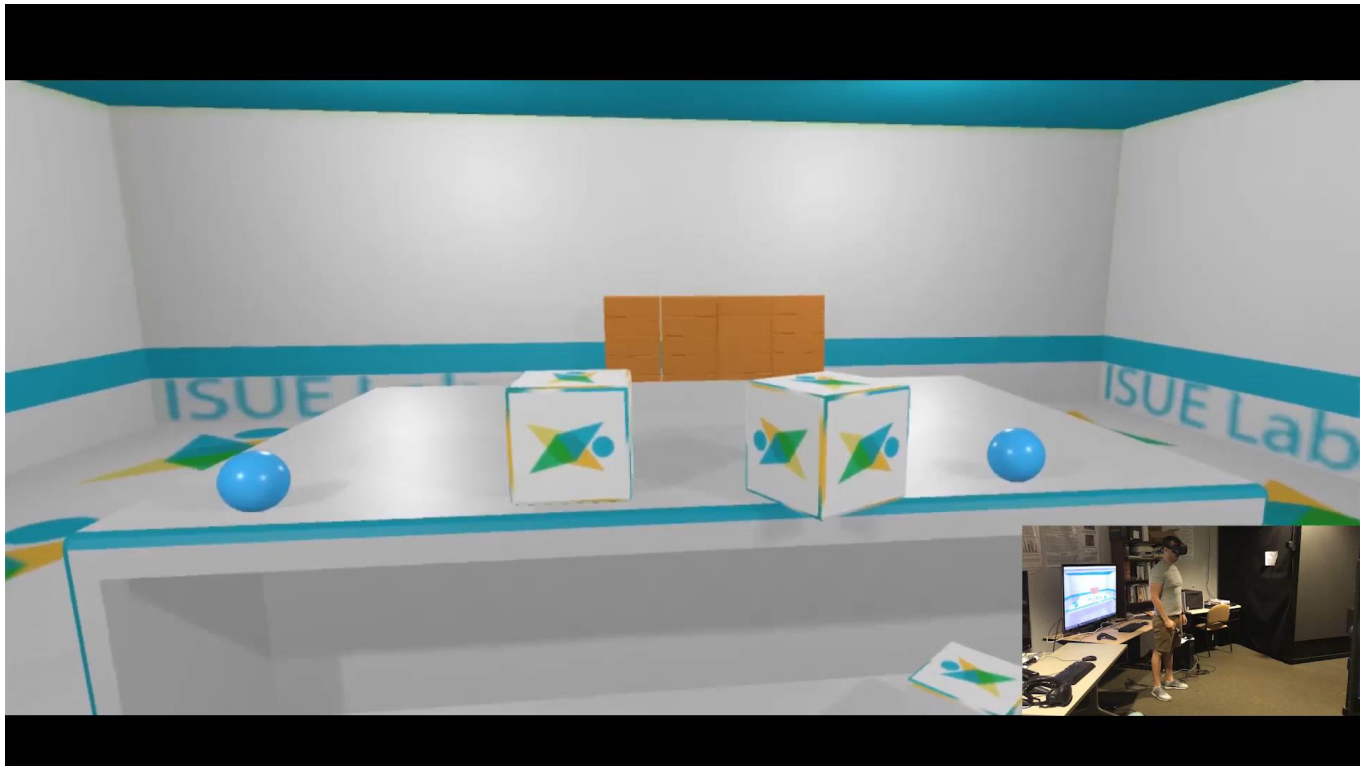

- direct mapping of the user's hand motion to a virtual hand

- very intuitive

- only objects within the area of user reach can be selected and manipulated

Grasping Metaphor - Simple Grasping

# Manipulation techniques for Grasping – GoGo



[Grasping Metaphor - GoGo Interaction]

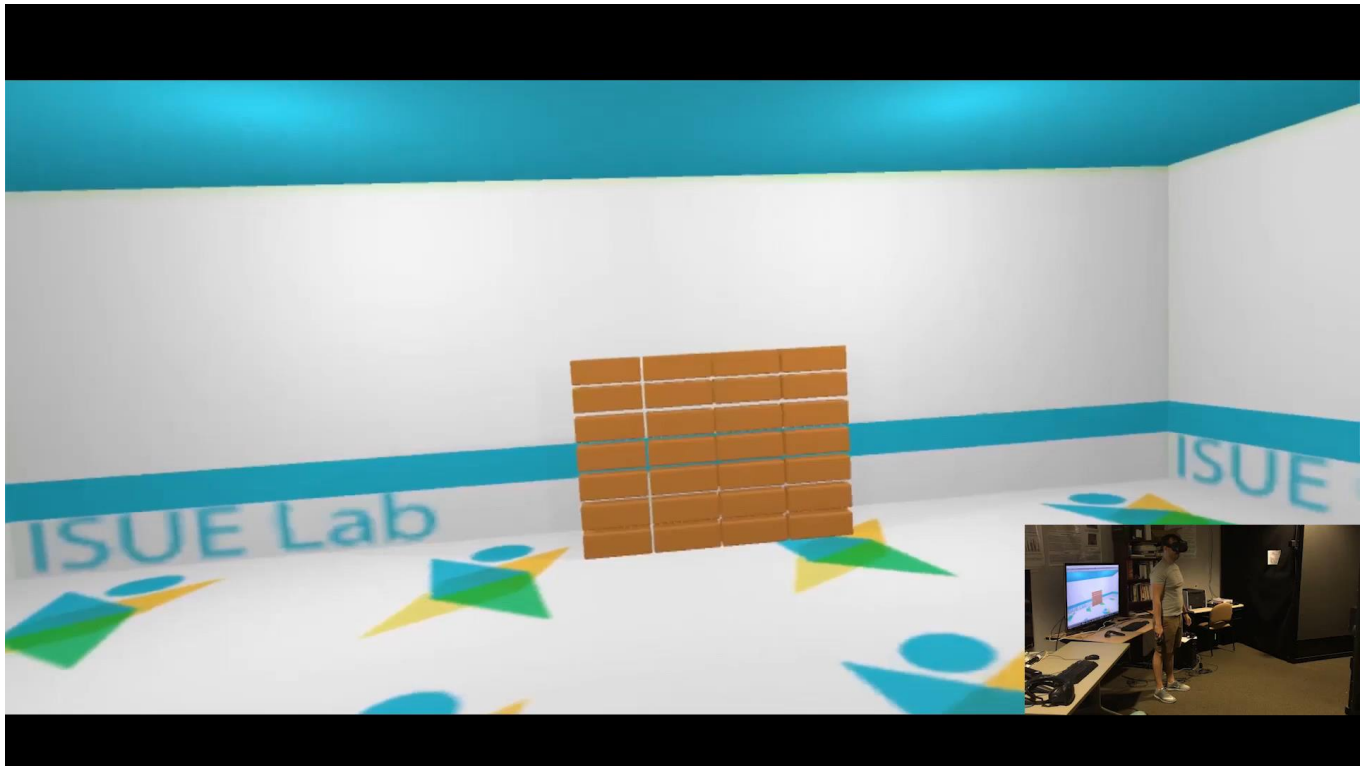
- improve simple grasping

- unobstrusive technique to “extend” the length of the virtual arm

- at close range, it uses one-to-one mapping

- beyond a specific distance, mapping is non linear

# Selection techniques for Pointing – Ray Casting



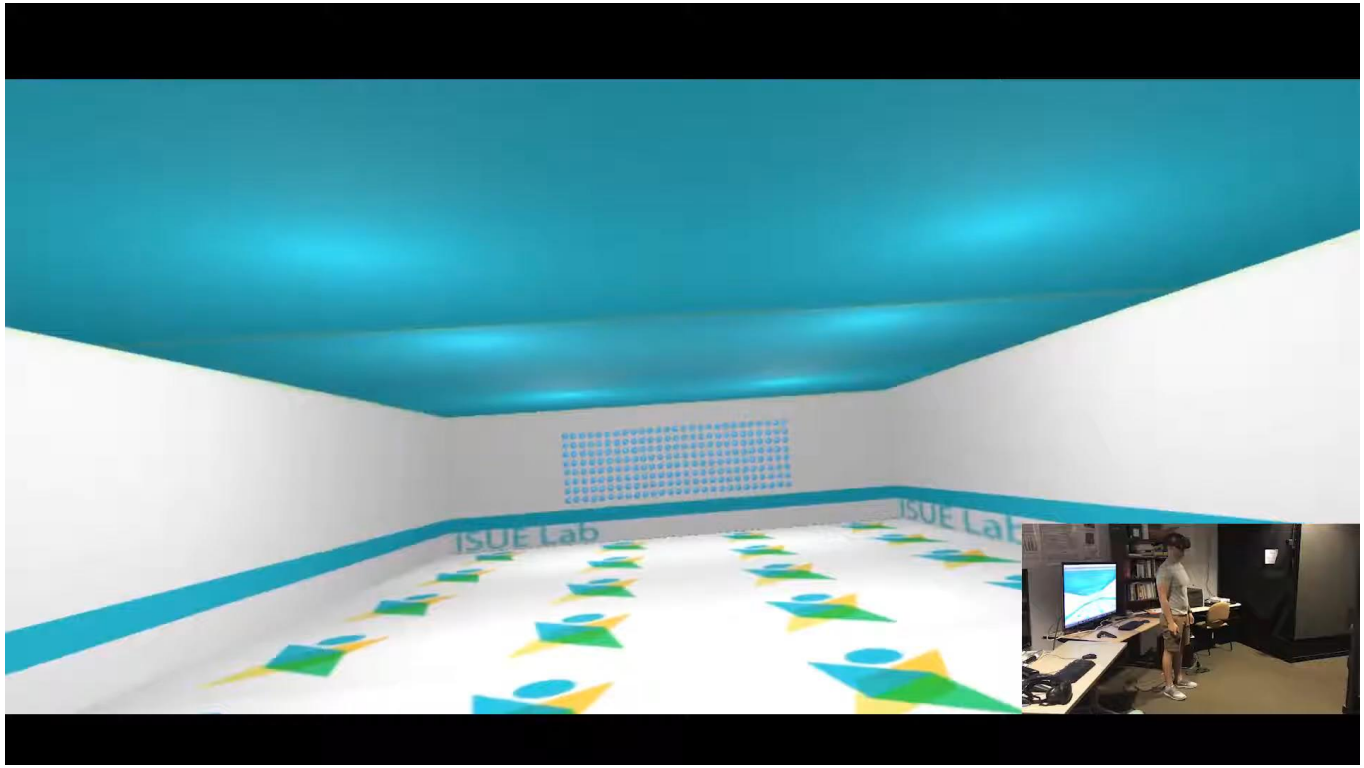

[Pointing Metaphor - RayCasting]

- user points at object with a virtual ray defining the direction of pointing

- not very good for selection of small or faraway objects

- the farther the object the greater the jitter/error

# Selection techniques - Pointing – Flashlight



[Pointing Metaphor - Flashlight]

- avoids precision and accuracy required for ray casting method

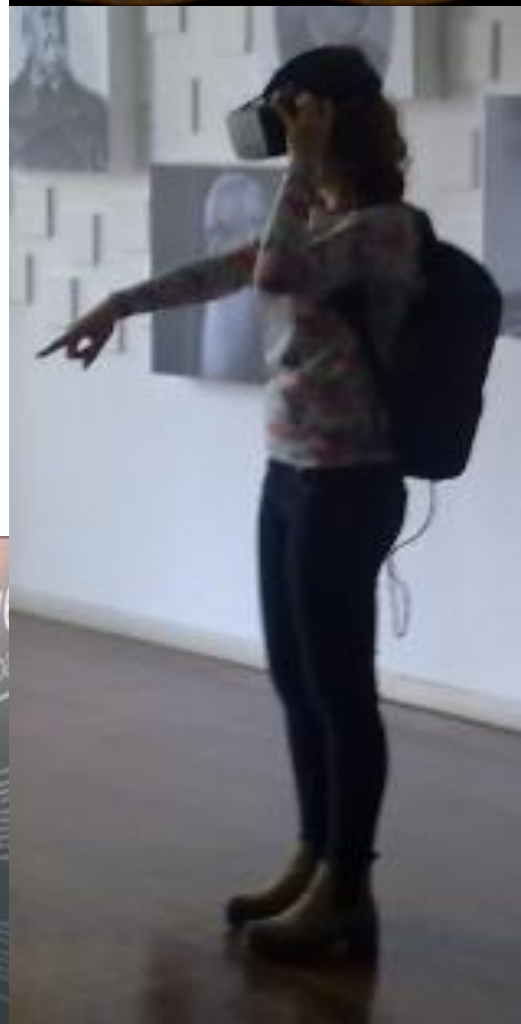
- direction is as in ray casting

- ray replaced by conic selection volume (such as a flashlight)

# Example: The Imaginary Museum
# an interactive exhibit

- The user was immersed in a virtual replica of a room
- Could explore virtual contents (text, videos, 3D models)
- And set their own virtual exhibits

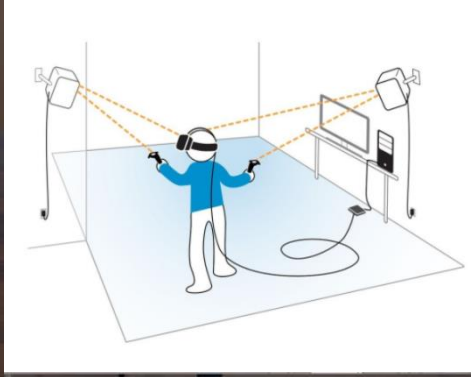
- Tasks: navigation + selection + manipulation
- Interaction techniques: walking + hand gestures

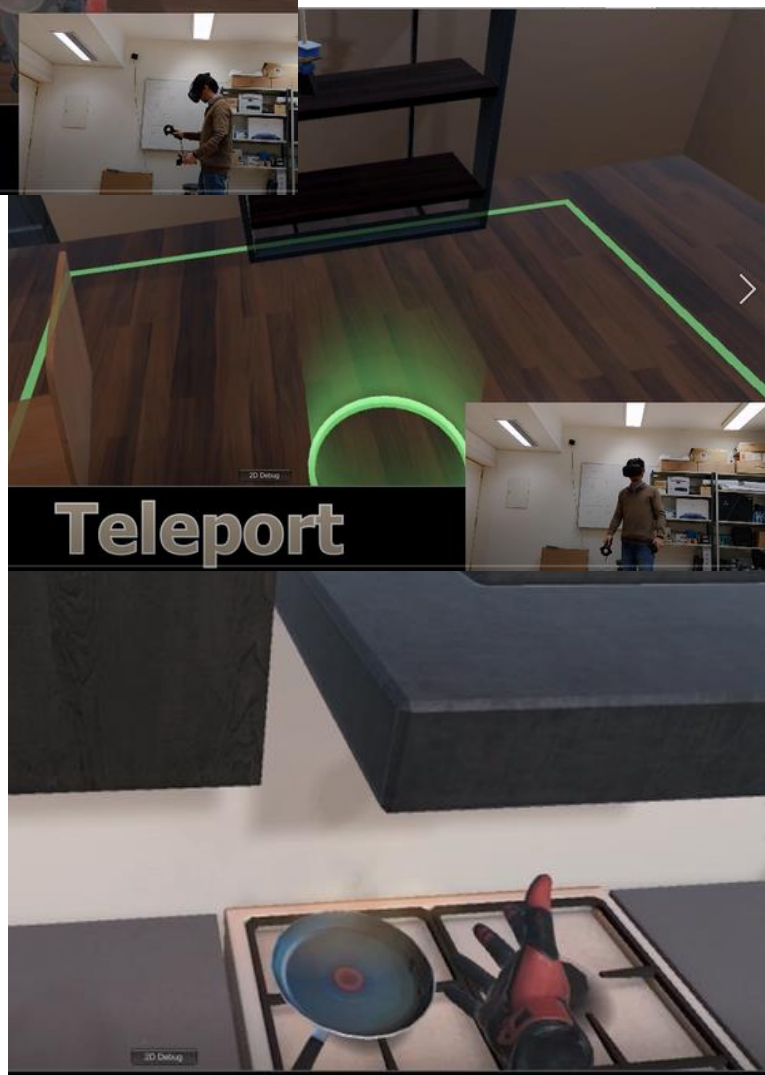


# Imaginary museum

- direct mapping of the user’s walking into the virtual world
- very intuitive, but unpractical for large Virtual Worlds

**Example:**
**Virtual escape room**




Tasks: navigation
+ selection + manipulation

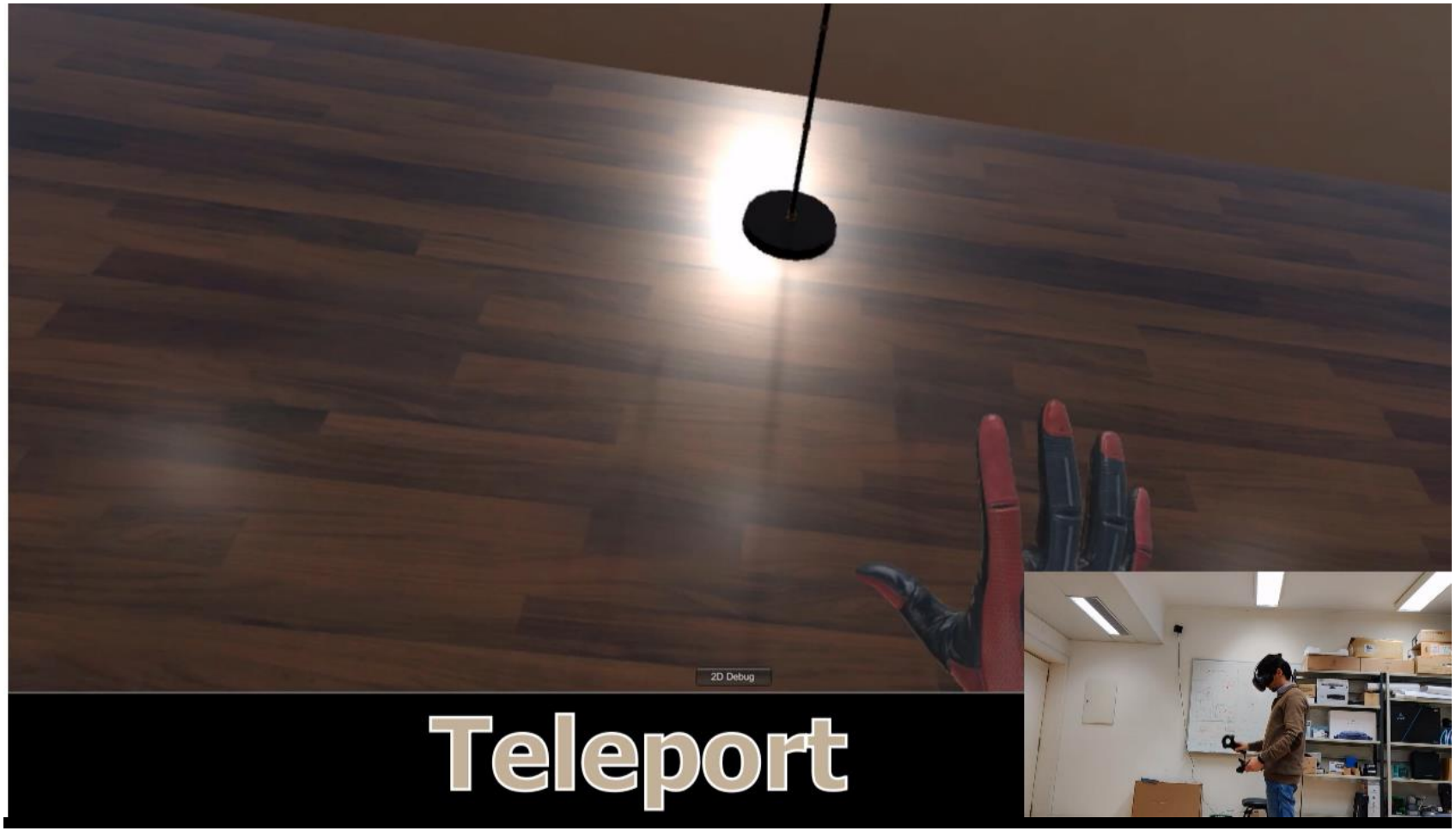
different interaction techniques

Navigation – Walking + Teleport

Manipulation

input devices:
(HTC Vive)
controllers

# Virtual escape room



# Concluding remarks concerning developing 3DUIs and XR systems

- **Usability** is one of the most important issues
- A **Human-Centered Design** approach should be used (highly iterative)
- **Safety** and **comfort** are crucial, as well as **security**
- **Implementation details are critical** to ensure usability, safety and comfort
- All applications **should be carefully tested**
- **There are guidelines and evaluation methods that should be used…**

**or research methods if it is a new situation**

# Books to probe further


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

- La Valle, S., *Virtual Reality*, Cambridge University Press, 2023

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- LaViola, J., Kruijff, E., McMahan, R., Bowman, D., Poupyrev, I., *3D User Interfaces: Theory and Practice*, 2nd ed. Addison Wesley Professional, 2017

- Bowman, D., 3D User Interfaces, *The Encyclopedia of Human-Computer Interaction*, 2nd Ed. 3D User Interfaces | The Encyclopedia of Human-Computer Interaction, 2nd Ed.



## Acknowledgements:

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