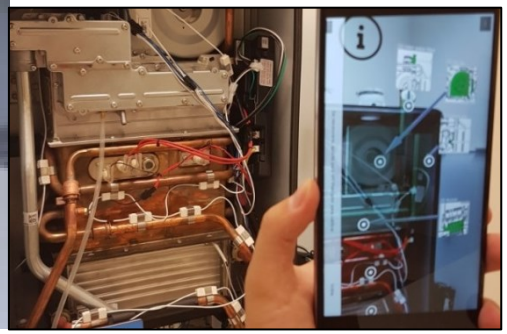
# Human-Centered Computing: The case of Mixed Reality Systems

Beatriz Sousa Santos



**December, 2018**

- I - Human-Centered Computing (HCC):
  - Brief introduction
  - User Experience and usability
  - Human-centered design
- II - Mixed, Virtual and Augmented Reality
  - Definitions, issues and applications
- III- Virtual Reality Systems design and implementation
  - Main parts of the system
  - Issues and guidelines
  - Example of a study
- IV- Concluding remarks

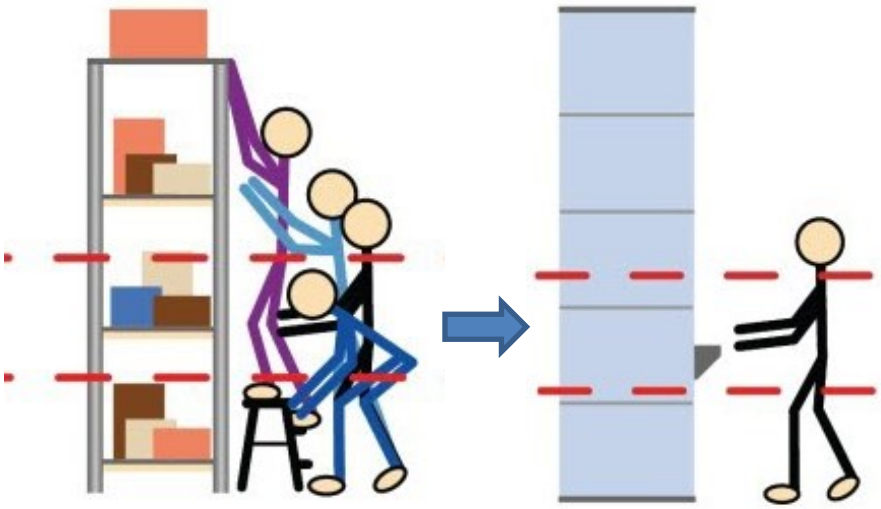
“The interface between humans and computers is harder than ever to define, we can interact with computers just by walking through a public space.”

**Sellen, A., Rogers, Y., Harper, R., & Rodden, T., “Human Values in the Digital Age”, *Communications of the ACM*, *52*(3), March 2009, pp. 58–66**

- Ergonomics and Human Factors developed fast after World War II

- Ergonomics

(focus mostly on physical issues)



- Human factors

(considers also cognitive issues)

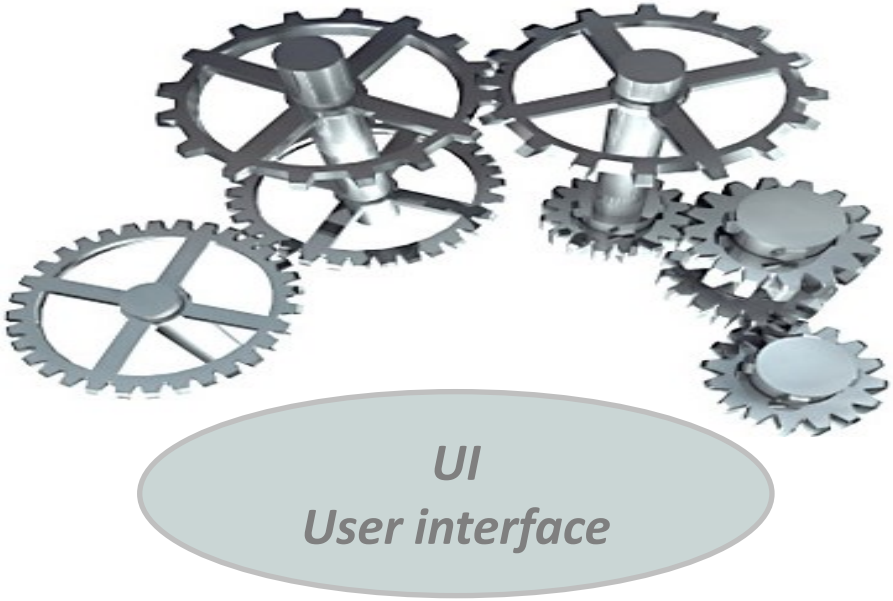
- **Human-Computer Interaction** emerged as new independent field within Computing in the 80s, mainly due to:
  - Lower price of technology
  - Technology migration (to be used by “non-computer expert users” )
  - Need to increase users productivity
- It expanded rapidly is currently an **interdisciplinary field**

# Interactive Computing Systems

- Interactive systems include a part which we don´t control:

  **The user(s)**, who:

  - is very complex
  - is not well known
  - we cannot control




This makes design **difficult**

- To the user **"the interface is the system"**

- The **user interface design involves a considerable effort**

**Human factors in Interactive Computing Systems**

**People** have:

- limitations (perceptual, cognitive, …)
- different capabilities and motivations
- different preferences

We should **study our users**

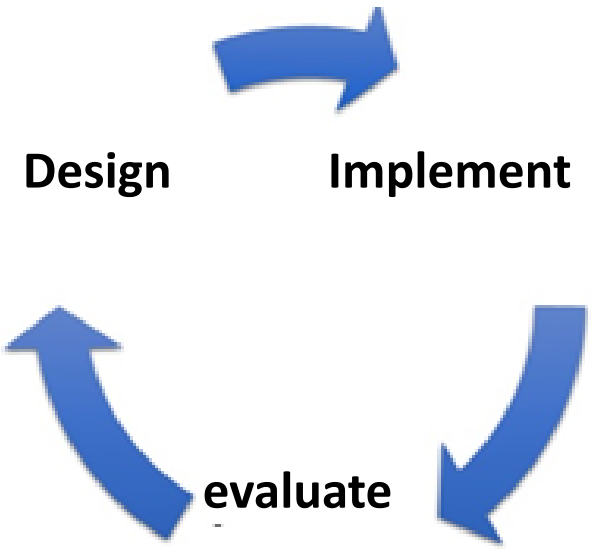
And their usage **context** …

# Interactive system design ≡ Human-Centered Design

**Know the principles and guidelines**

**Use adequate methods**

**Design**
**Implementation**
**Evaluation**
**re-design ….**
**evaluation**
**re-design ….**




**until we attain the usability/UX goals!**

# Human-Centered Design (HCD)

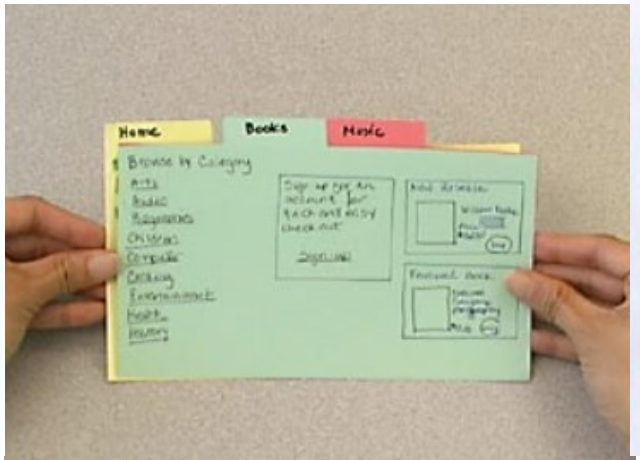
# aka User-Centered Design (UCD)

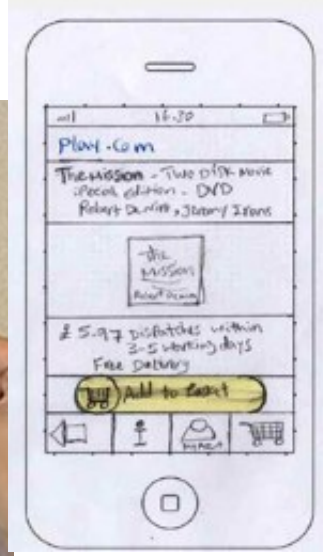
- early and continual **focus on users** and their **context**

- Several rounds of **evaluation** (starting early)

- **Iterative design**

  (alternatives tested with low fidelity prototypes)



# Usability

according to ISO 9241-11:

"the extent to which a product can be used by **specified users** to achieve **specified goals** with **effectiveness, efficiency** and **satisfaction** in a **specified context of use**"

How to measure it??

And evaluate an interactive system?

There is a plethora of **evaluation methods**:

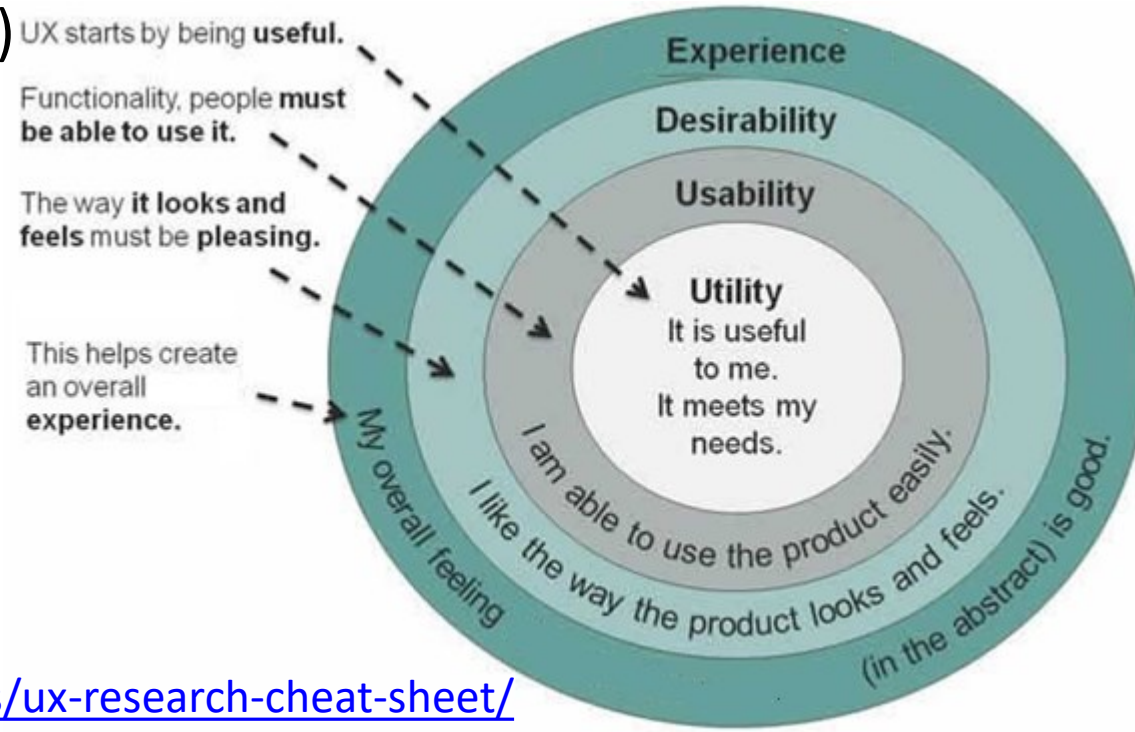
- analytical
- empirical

# User Experience (UX)

- The ease in which people interact with a system to achieve specific goals
- The experience a person as interacting with a product (encompasses all aspects)

Usability -> function

A positive UX has a greater impact than just usability



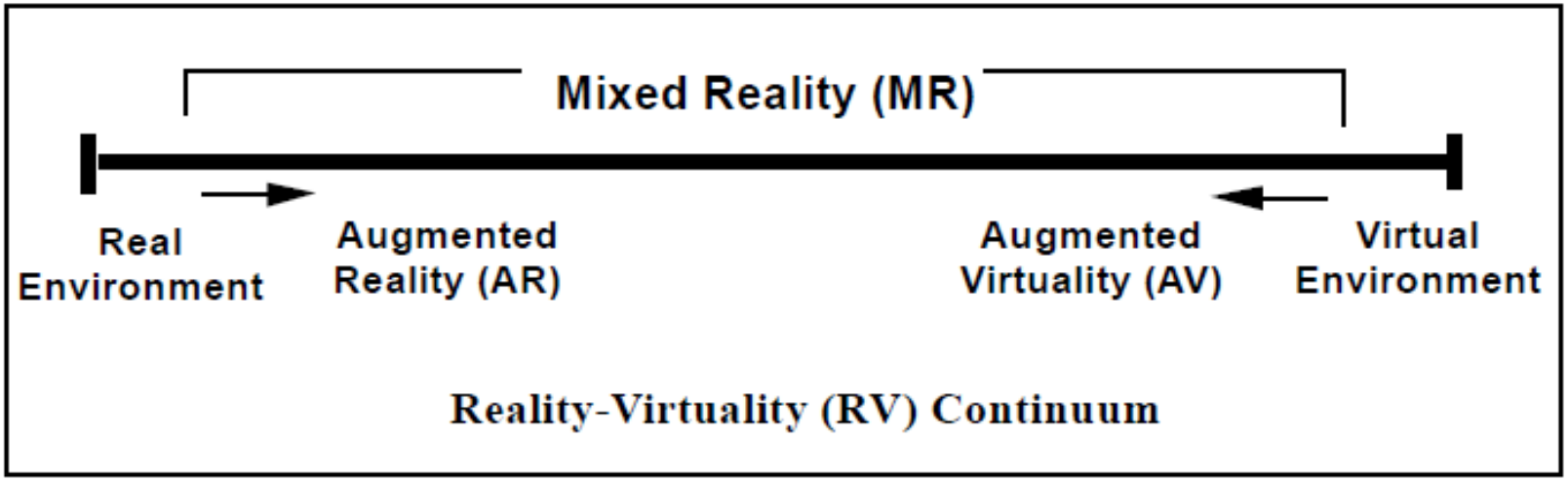

https://www.nngroup.com/articles/ux-research-cheat-sheet/

http://uxpa.org/resources/definitions-user-experience-and-usability

# Mixed reality

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

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



# Reality Virtuality “Continuum”

“Augmenting natural feedback to the operator with simulated cues”

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

Mixed Reality (MR)

Real Environment | Augmented Reality | Augmented Virtuality | Virtual Environment

(Steinicke et a., 2009)

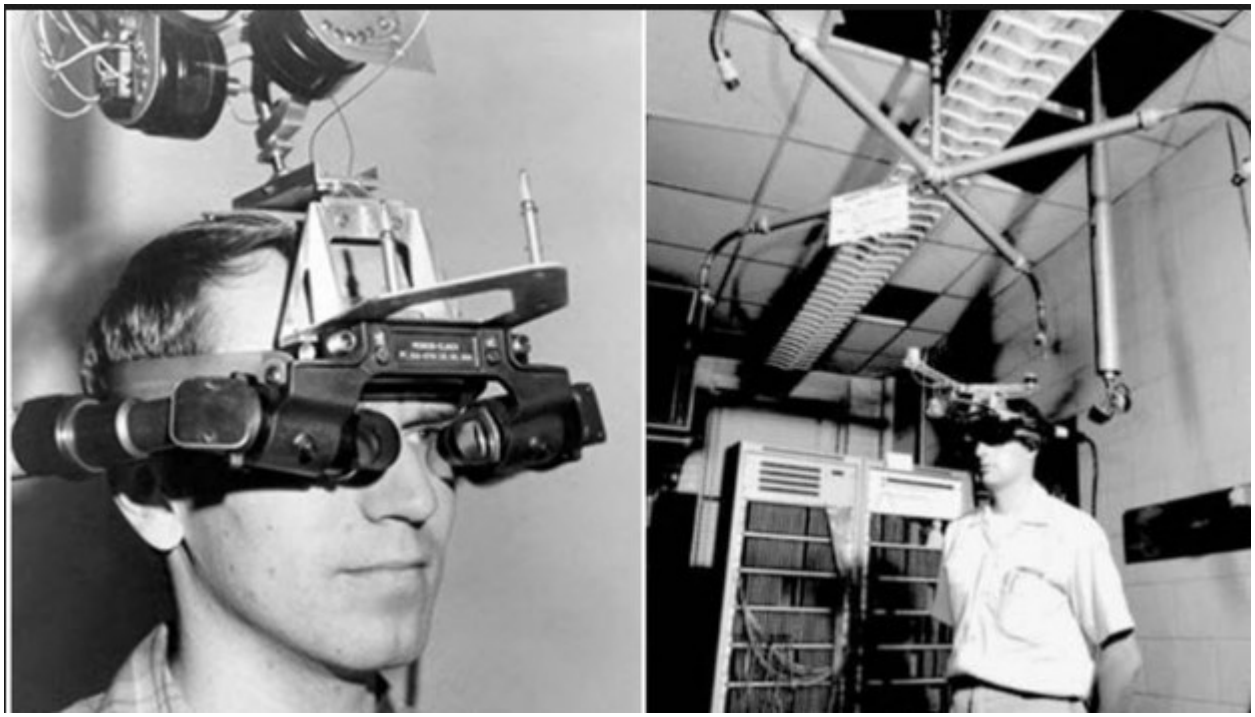
These ideas are >50 years old!

The ultimate display?

"The ultimate display would, …, 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 … and a bullet … would be fatal." **(Sutherland, 1965)**

# The first AR Head-Mounted Display (HMD)



Ivan Sutherland, MIT, 1966
https://www.youtube.com/watch?v=NtwZXGprxag

- “Virtual Reality (VR) is a **high-end user interface** that involves **real-time simulation** and ***interaction*** through **multiple *sensorial channels***.” (vision, sound, touch, smell, …) **(Burdea and Coiffet., 2003)**

- *“*Augmented Reality (AR) is a variation Virtual Reality …

VR completely immerses a user inside a synthetic environment, …

…**AR supplements reality, rather than completely replacing it**. “

**(Azuma, 1997)**

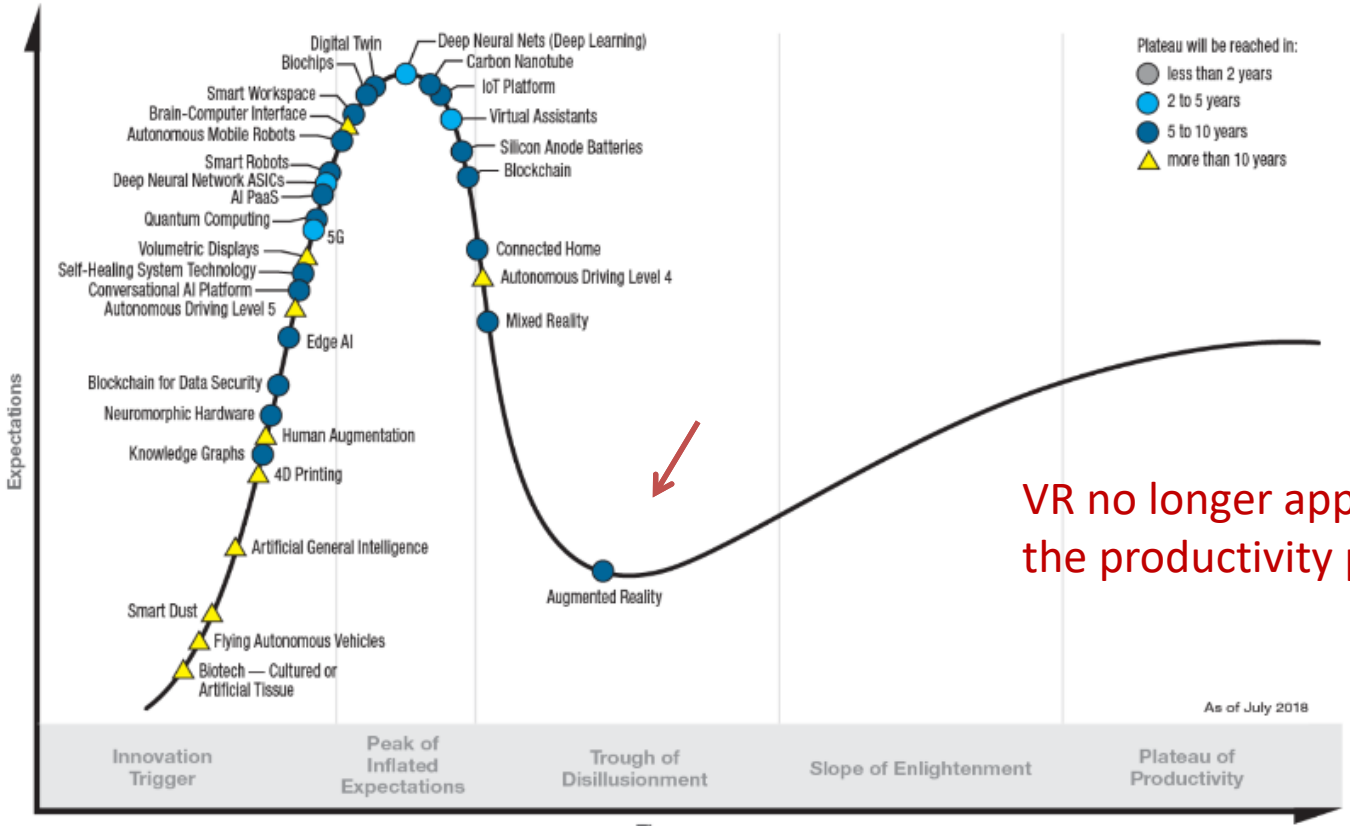
- Unlike most Interactive systems, Mixed Reality systems may **jeopardize the health and safety of the user** ….

- Their development implies **extra care with human factors**…

# What is the current state of VR/AR?

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

## Gartner's Hype Cycle for Emerging Technologies, 2018




VR no longer appears: it has reached the productivity platform

https://www.fourquadrant.com/gartner-hype-cycles-magic-quadrants/

# 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, cognitive therapy, surgery planning, pain relief …)
- Culture, entertainment (museums, games, …), sales and marketing
- Data visualization (e.g. science, oil industry)
- Etc.

# Surgery training

- Training complex procedures before performing them on patients

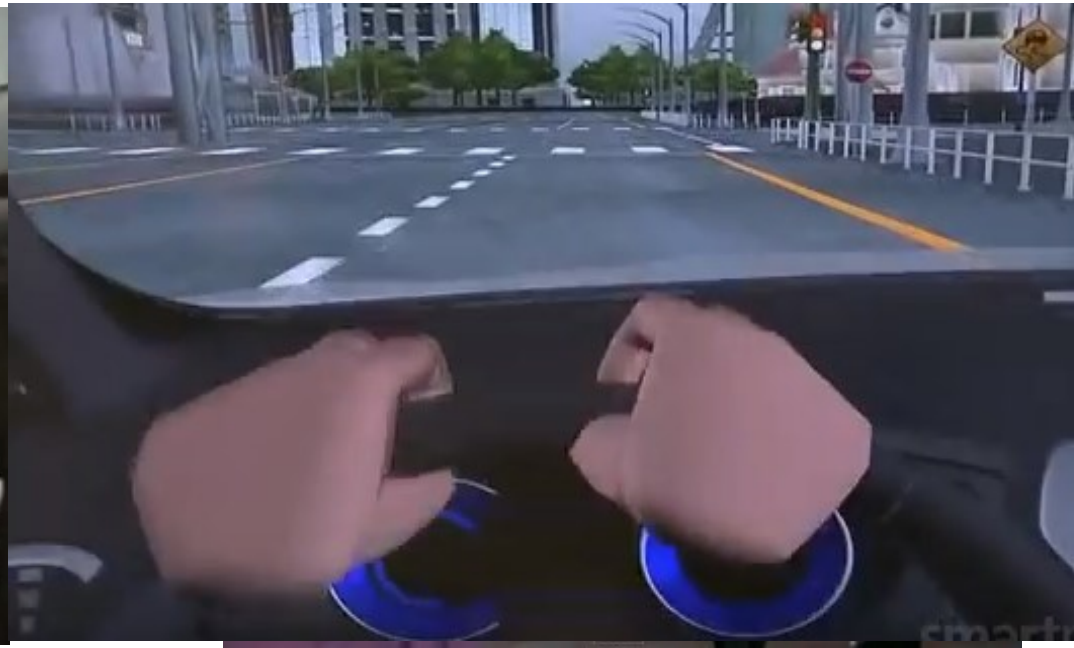

https://www.youtube.com/watch?v=aBQTtp_NbgI

# Automotive industry

- VR makes possible to:
  - multiply the number of innovative hypotheses studied
  - limit the number of physical mock-ups
  - cut development time and cost

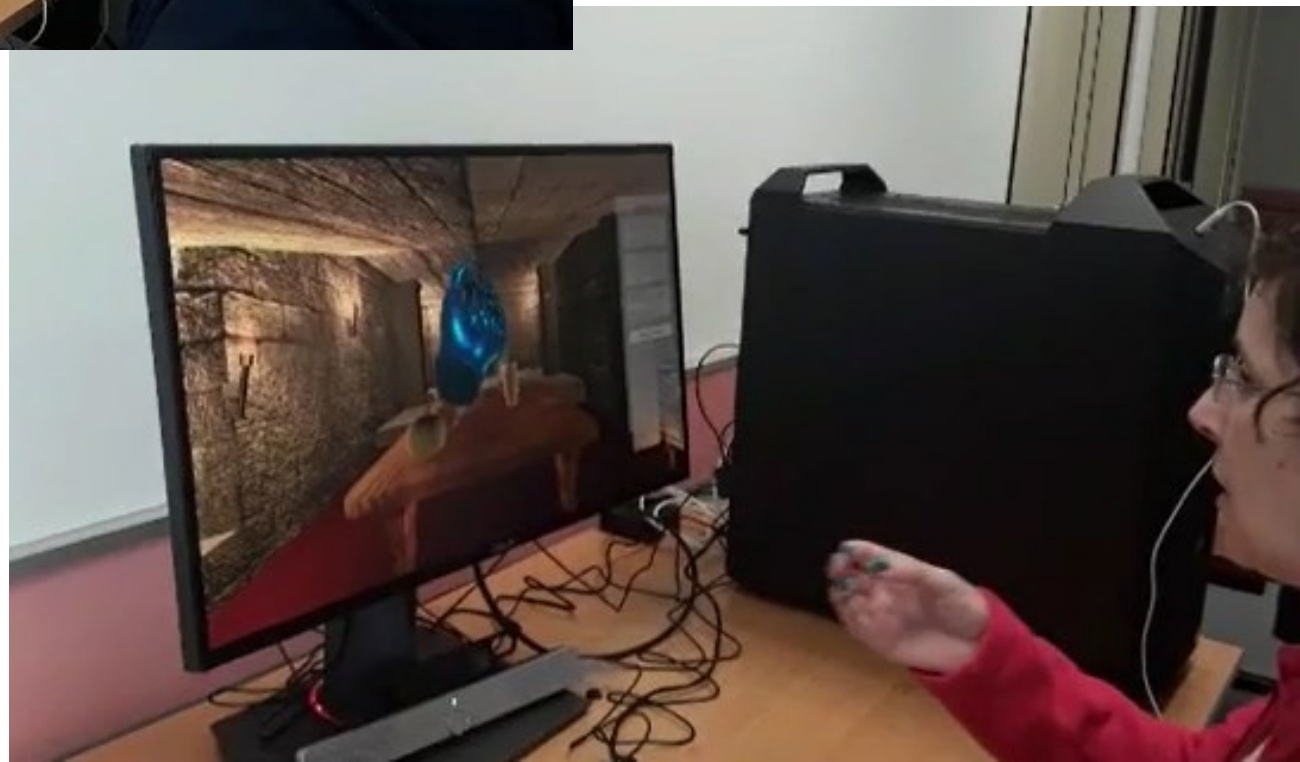
New models can be analysed even before any physical prototype exists

https://www.youtube.com/watch?v=BEFfp2QhHZU (VR at Ford)

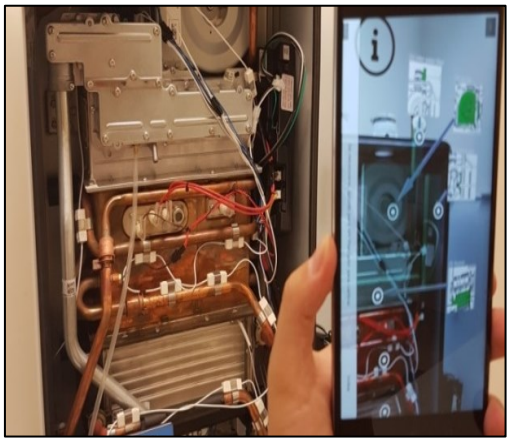
Mini-games to help recover arm movement for Stroke patients

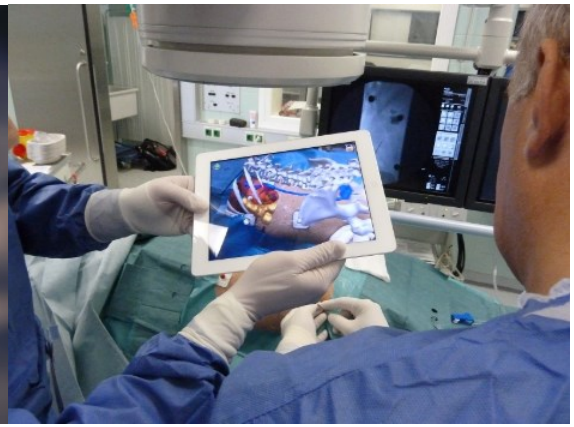
DETI + Centro Rovisco Pais



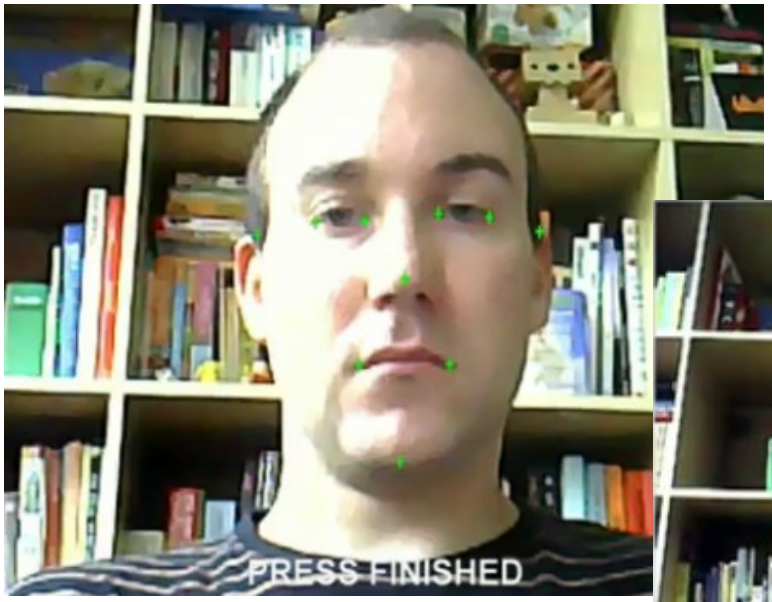
# AR Applications

- Maintenance and assembly
- Education and training
- Medicine
- Culture, entertainment
- Sales and marketing
- Etc…





# Commerce: Ray Ban Virtual Mirror





http://www.youtube.com/watch?v=Ag7H4YScqZs

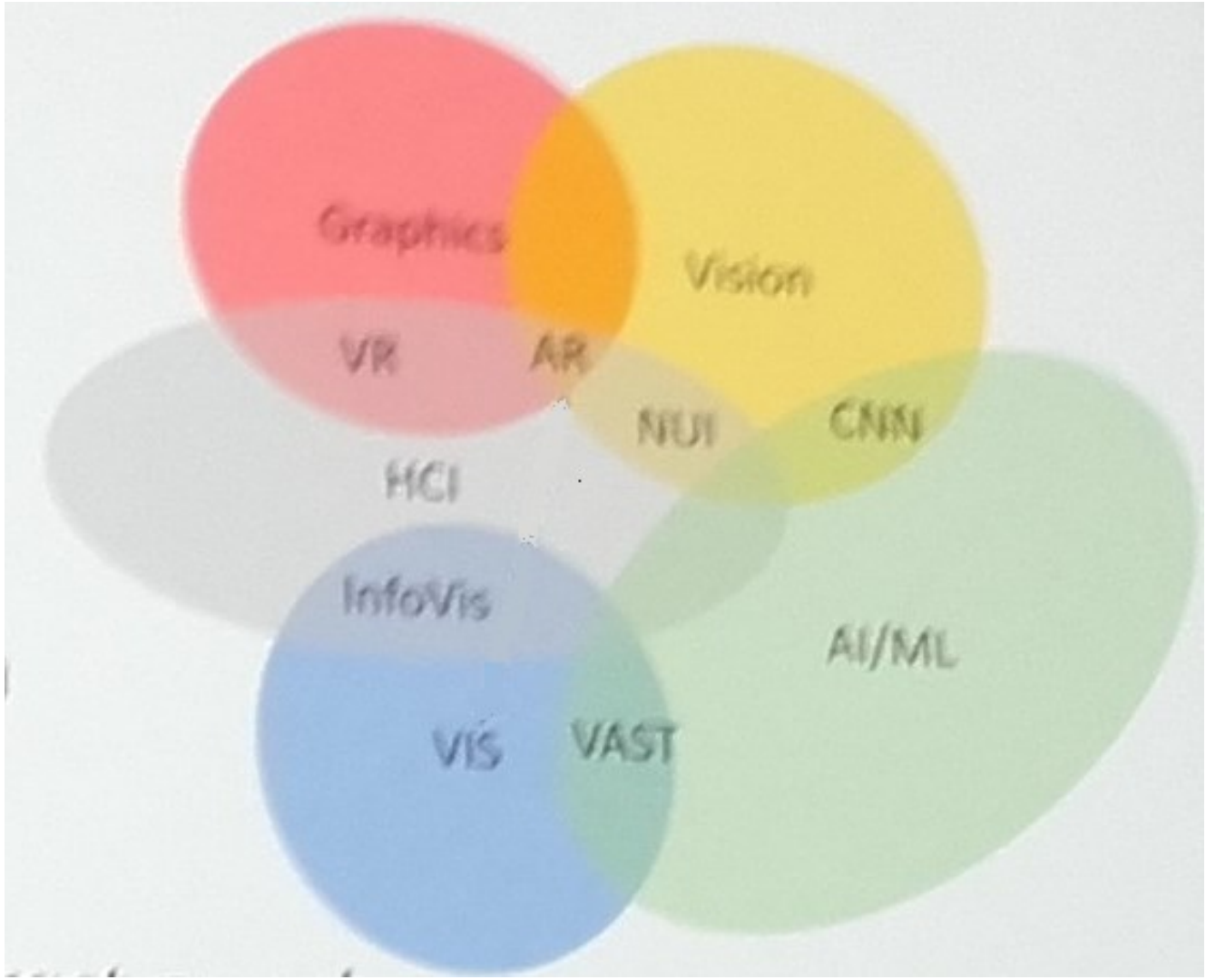
- Industry 4.0 offers many opportunities and challenges for VR and AR


https://www.i-scoop.eu/industry-40-virtual-reality-vr-augmented-reality-ar-trends/
https://www.eonreality.com/applications/augmented-virtual-reality-manufacturing/

- Situated Visualization offers many opportunities and challenges for AR

https://www.researchgate.net/publication/294088159_Situated_Visualization_in_Augmented_Reality

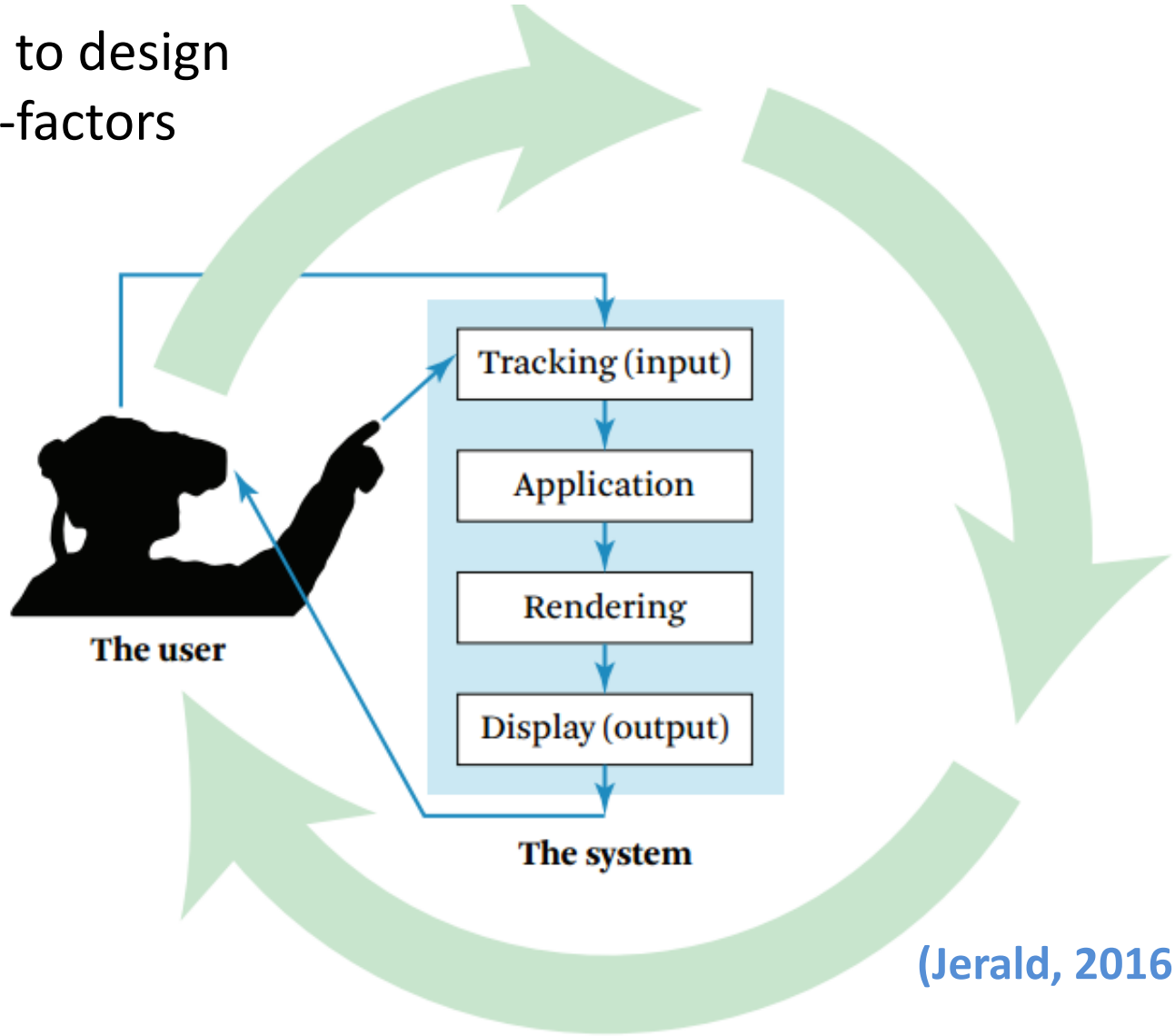
# MR is highly interdisciplinary within Computing




(Schmalstieg,2018)

# Virtual Reality Systems

Are most difficult to design regarding human-factors




(Jerald, 2016)

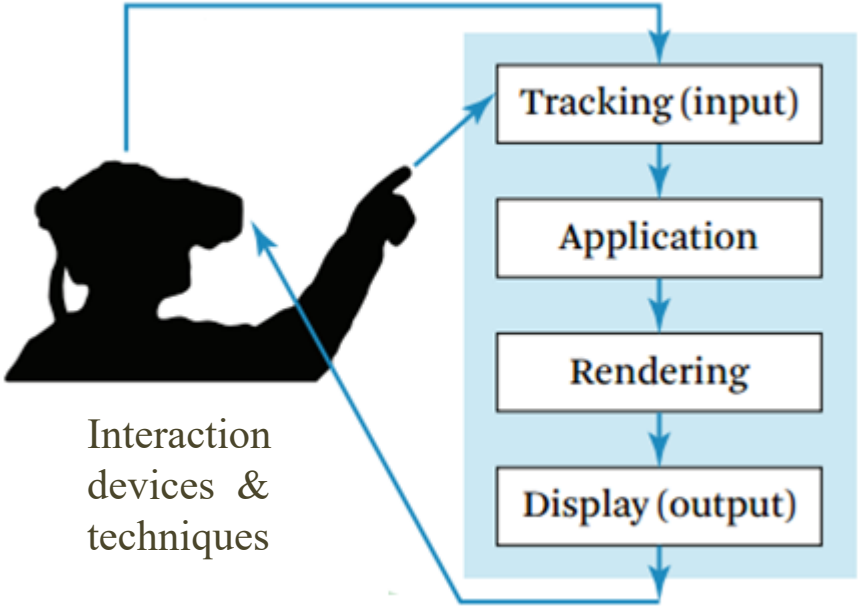
# Crucial technologies for VR

- **Visual displays** that immerse the user in the virtual world and block out from the real world
- **Graphics rendering system** that generates images (>50++ fps)
- **Tracking system** that reports user's position and orientation
- **Database construction and maintenance system** for building and maintaining models of the virtual world

# Other important technologies

- Synthesized **sound** including directional sound and simulated sound fields
- Display of synthesized forces and other **haptic** sensations
- **Interaction devices** allowing users to interact with virtual objects
- **Interaction techniques** that substitute for the real interactions possible with the physical world

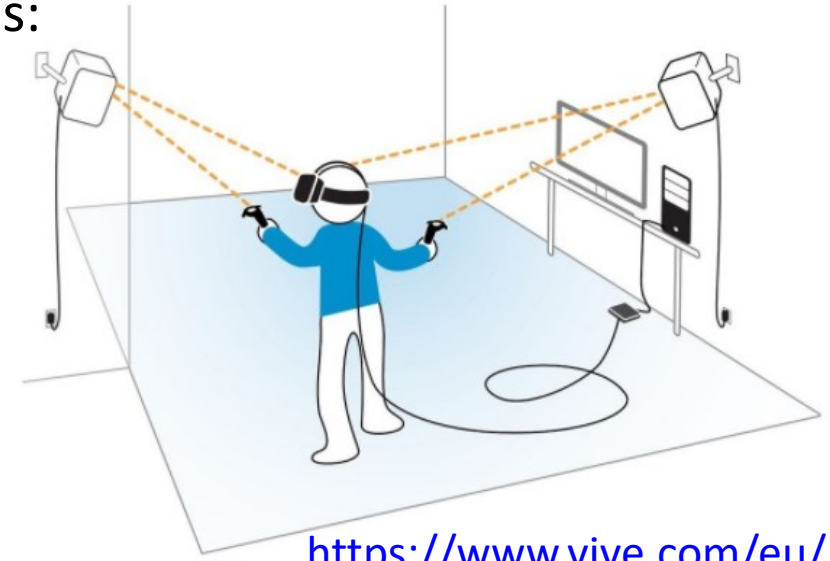
# Tracking and Input devices




- Trackers:
  - Magnetic (AC, DC)
  - Optical
  - Ultrasonic
  - Inertial,
  - Mechanical
  - Hybrid ...

- Navigation and manipulation interfaces:
  - Tracker-based
  - Controllers
  - 3D mice, ...

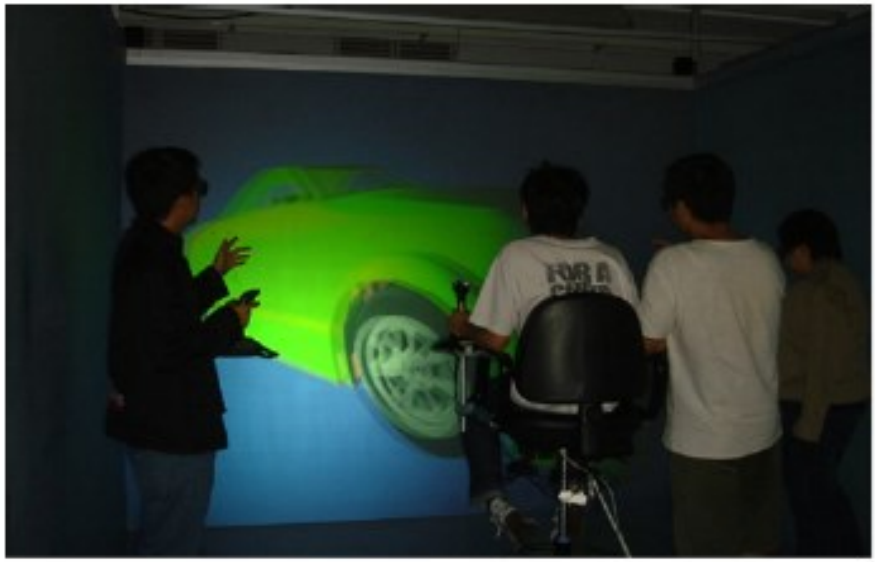
- Gesture interfaces:
  - Depth cameras
  - Gloves ...



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

# VR- Several degrees of immersion/ types of displays

- Desktop VR
- Semi-immersive VR
- Fully immersive VR

https://www.tomsguide.com/us/best-vr-headsets,review-3550.html

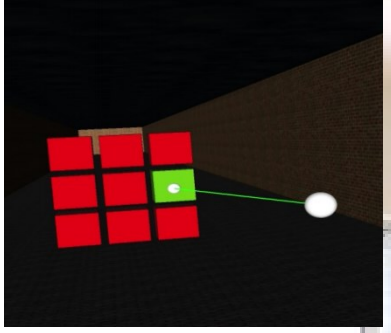
# Interaction

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

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

- Goals of **interaction design** in VR applications:
  - **Performance** (efficiency, accuracy, productivity)
  - **Usability** (ease of use, ease of learning, user comfort and satisfaction)
  - **Usefulness** (users focus on tasks, interaction helps users meet goals)

# Universal interaction tasks for VEs



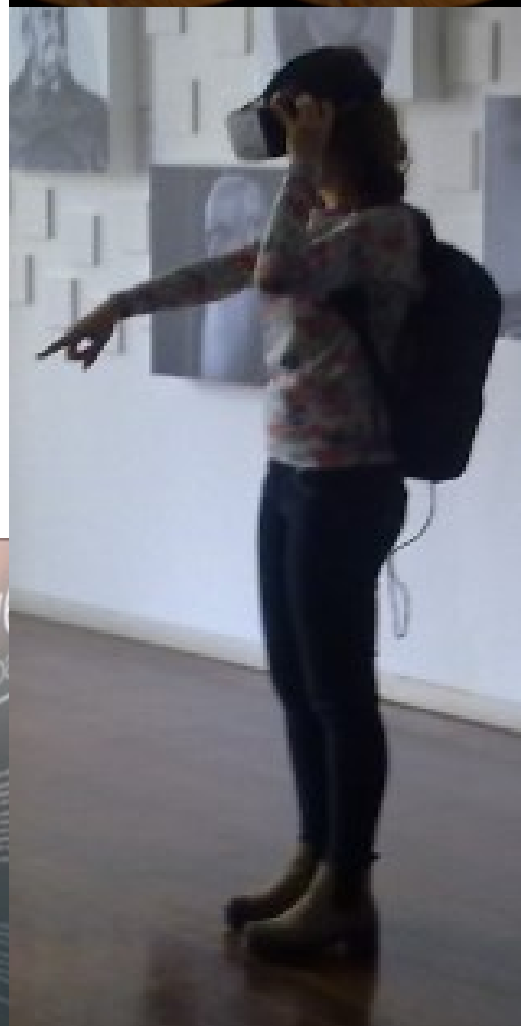
- Navigation
  - Travel – motor component
  - Way finding – cognitive component
- Selection
- Manipulation
- System control
- Symbolic input

(La Viola *et al*., 2017)

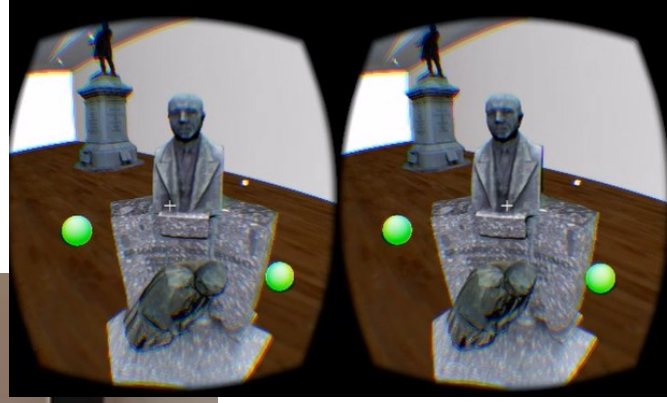
# The Virtual Museum: an interactive exhibit

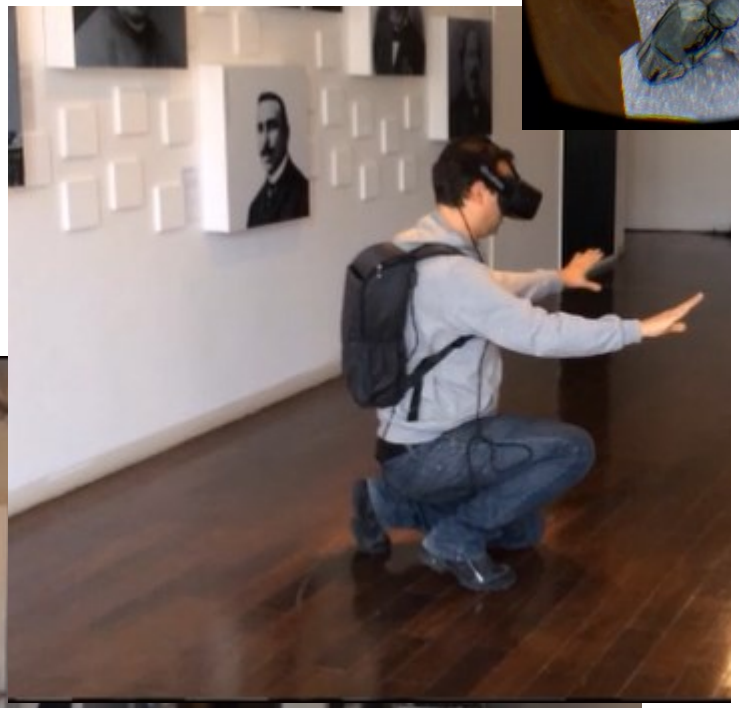
- Tasks: navigation + selection + manipulation

- Interaction methods: walking + gestures
  - 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



- Placing 3D virtual objects in a virtual exhibit using spatial gestures





- While walking in the real/virtual worlds (1 : 1 mapping)

# Another example:

Same tasks; very different interaction techniques – input device

Navigation

Selection

# Guidelines for Easy-to-Use 3D Interaction Techniques

- Floating objects are the exception
- Objects don’t interpenetrate
- Interaction should be only with Visible Objects
- Perspective and occlusion are the strongest depth cues
- People see the object, not the cursor
- ….

# Guidelines for Proper VR Usage

Meant to **minimize** the onset and severity of **cyber sickness**; largely qualitative

**During system development**

- Minimize latencies and make them stable;
- Avoid pulsating light sources of low frequency;
- Reduce spatial frequency content in large displays;
- Assure HMDs have properly aligned optics and sufficient resolution;
- Reduce intensity and duration of loud 3-D sound sources;
- Use accurate trackers and remove sources of interference;
- Assure consistency in multimodal displays.

**Before Immersion**

- Screen users whenever possible for susceptibility to cybersickness;
- Place warning labels and educate users of potential adverse effects from VR exposure;
- Limit exposure to users that are free from drugs and alcohol consumption;
- Encourage users to be well rested before exposure;
- Discourage VR usage by those with cold, flu, binocular anomalies, susceptibility to migraines or photic seizures.

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

- Latency

- Calibration

- Tracking accuracy

- Field of view (FOV)

- Refresh rate

- Flicker, etc.

# Adverse Health Effects

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

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

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

(Jerald, 2016)

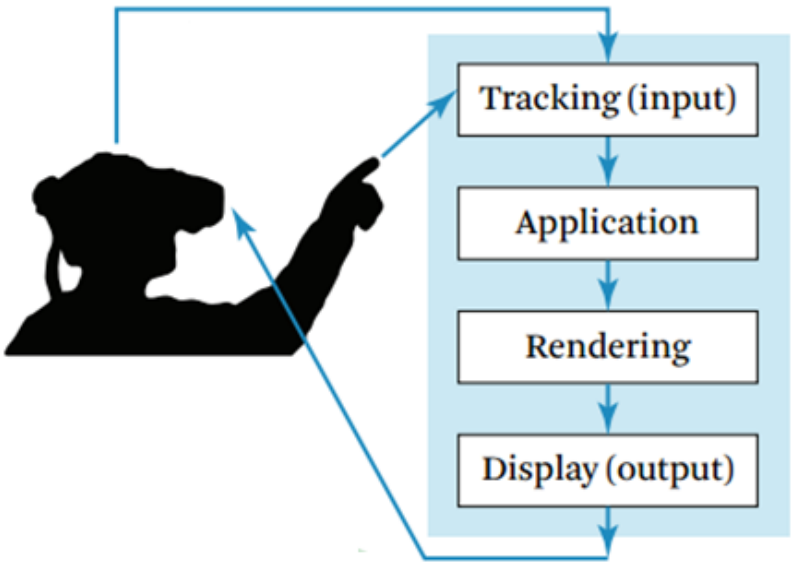
# Latency

Latency - effective delay

Should be << 100 ms and should be consistent (in immersive VEs)

Sources of system delay:

- Tracking
- Application
- Rendering
- Display
- Synchronization among components




(Jerald, 2016)

# Motion Sickness (cyber sickness) Theories

## Sensory Conflict Theory:

Is the most accepted for the initiation of motion sickness symptoms
Particularly conflict of the visual and vestibular senses is important

## Evolutionary Theory:

(aka poison theory) offers a reason for why motion makes us sick:
The brain interprets sensory mismatch as a sign of intoxication

## Postural Instability Theory:

predicts that sickness results when a user lacks or has not yet learned strategies for maintaining postural stability

There are other theories …

# Concluding remarks concerning developing MR systems

- **Usability** is one of the most important issues
- A Human-Centered Design approach should be used (highly iterative)
- **Safety** and **comfort** are crucial
- 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…**

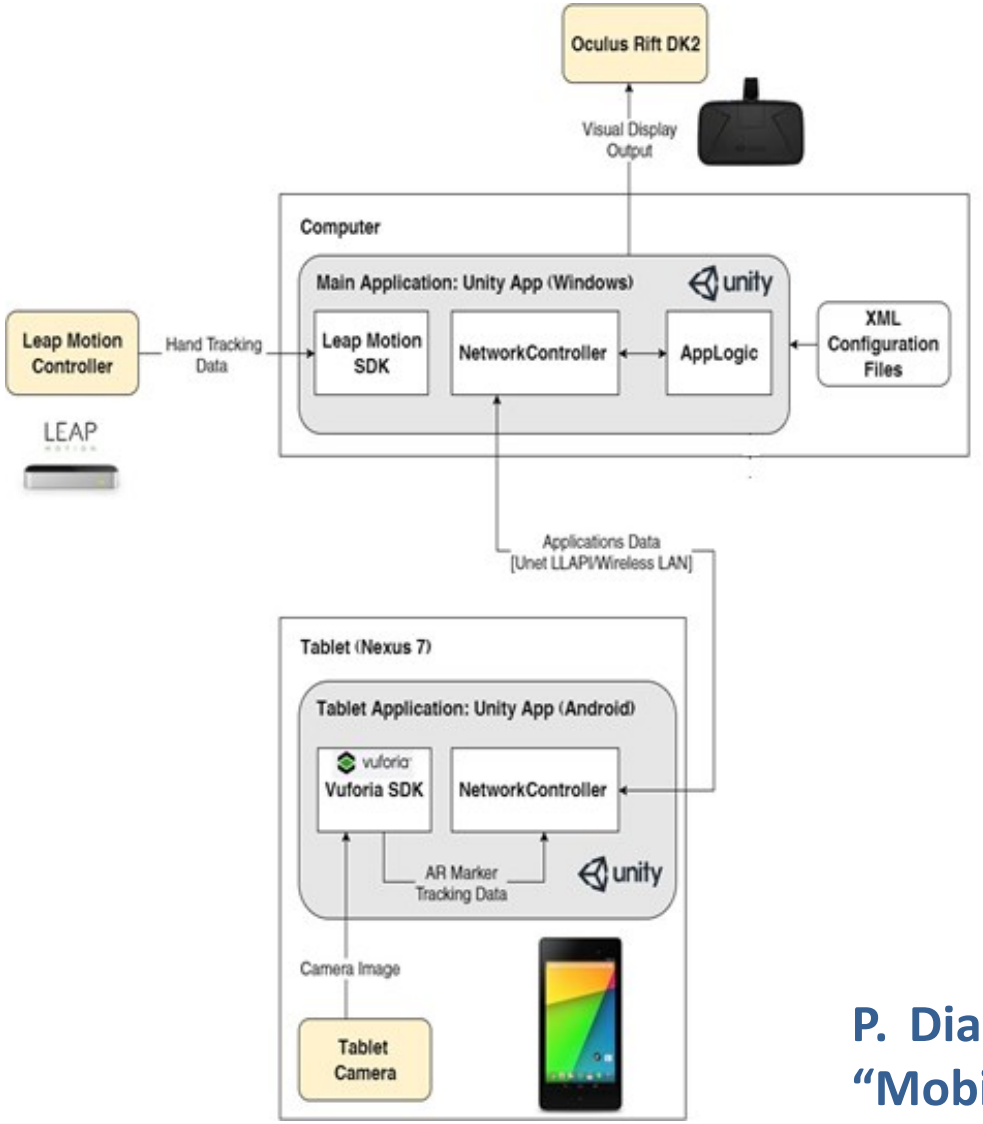
**or research methods if it is a new situation**

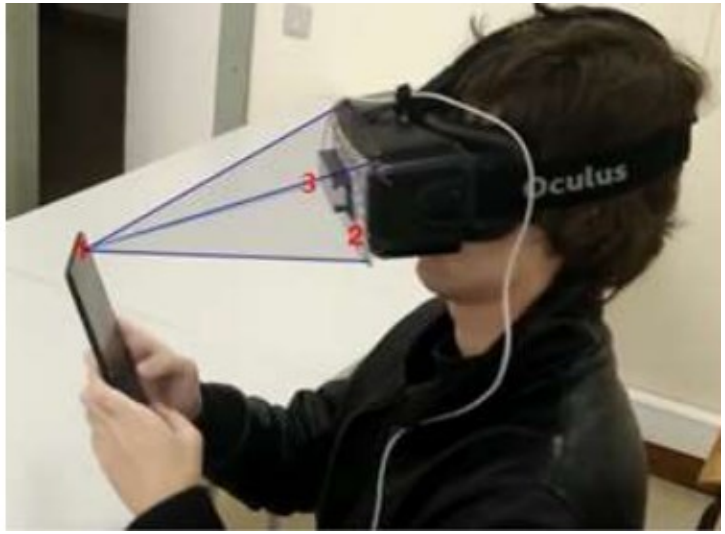
An example of a typical usability study:
**Mobile devices for interaction in a VR system**

# Why Mobile Devices for Interaction in Immersive Virtual Environments?

- Mobile devices are widespread, familiar and affordable
- Have a configurable touch screen and onboard sensors
- Give passive haptic feedback
- Can they be interesting input devices?
- In immersive IVEs?
- e.g.  for selection and navigation tasks?

# The System



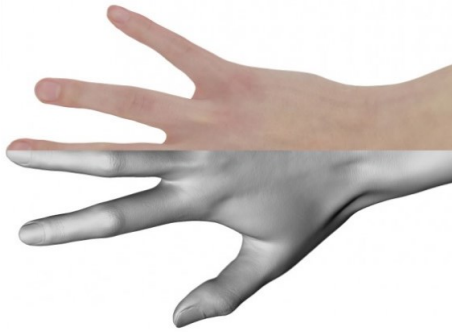




- The mobile device camera tracks the HMD location
- A virtual representation of the device screen is shown in the VE
- A sensor tracks the user's hands; how to represent them?

**P. Dias, L. Afonso, S. Eliseu, B. Sousa Santos, "Mobile Devices for Interaction in Immersive Virtual Environments", *AVI'18, International Confer.. on Advanced Visual Interfaces*, 2018**

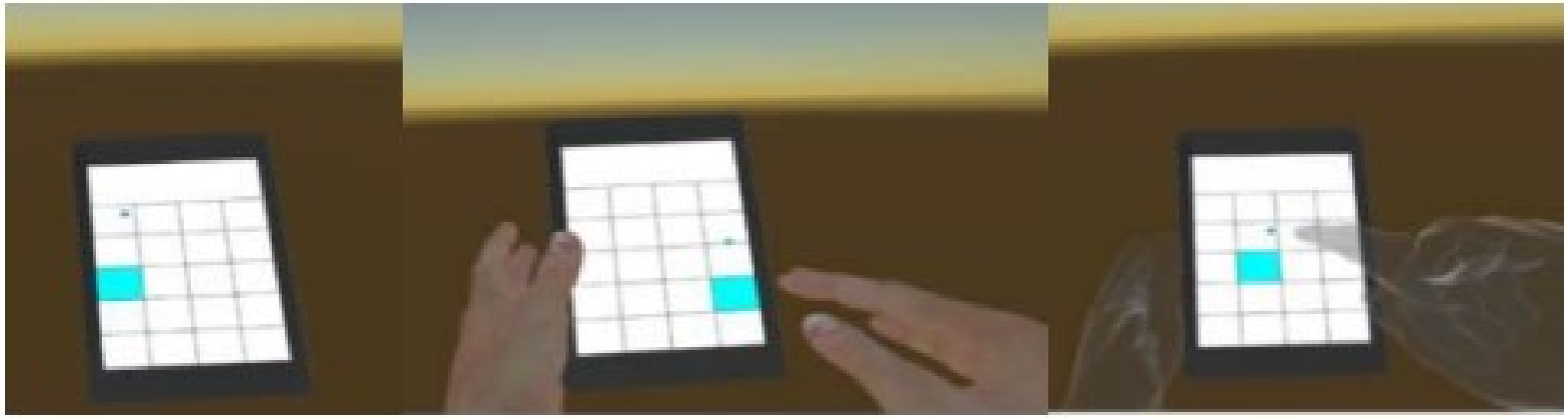
# User Representation in Immersive Virtual Environments (IVEs)

- User representation in the IVE is relevant
- There is literature, but we could not find specific guidelines
- Are hand avatars useful in IVEs?
- e.g.  for interaction tasks with mobile devices ?
- How realistic should they be?
- How will their appearance affect usability?



# Effect of Hand-Avatar when using a tablet as Input Device in IVEs

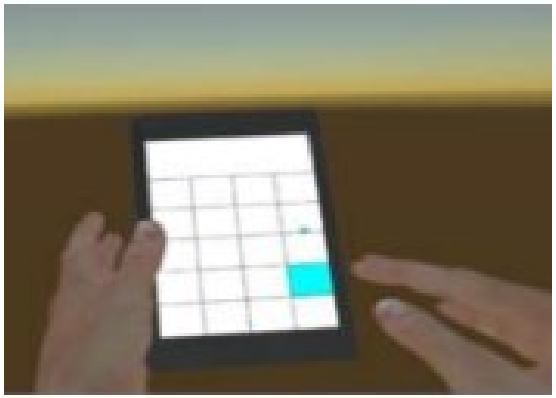
- How does the virtual representation of the user's hands influence the performance on a tablet based interaction in IVEs?
- It is still an open research question
- We could not find any guidelines for this new situation
- Performed a controlled experiment with three conditions:



No-avatar Realistic avatar Translucent avatar

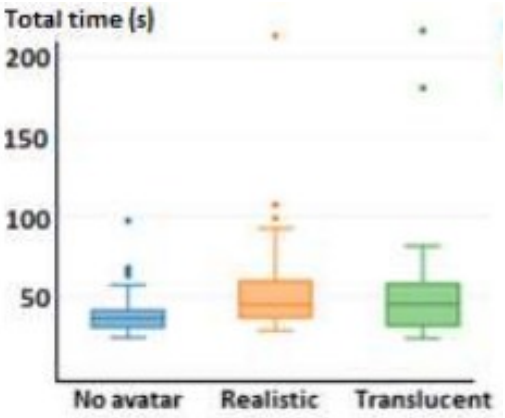
## The user study

- $H_0$: All methods are equally usable
- Input variable: avatar appearance (no /realistic/ translucent avatar)
- Output variables: times, errors, preferences, …
- Within-groups experimental design
- Task: selection
- 52 participants were observed and answered a questionnaire



**L. Afonso, P. Dias, C. Ferreira and B. Sousa Santos, "Effect of hand-avatar in a selection task using a tablet as input device in an immersive virtual environment," *3DUI'17, IEEE Symp. on 3D User Interfaces*, Los Angeles, 2017**

# Main results:




**Performance:** Participants were faster (statistically significant) without avatar
But made less errors with the translucent avatar

**Preferences:** Translucent avatar was preferred by most participants

**Difficulty:** Participants found easier (statistically significant) to perform the task with the translucent avatar

**Main issues:** Hand tracking

**Results suggest:**

- virtual representation of the hands may **improve the user experience**
- the avatar does **not need to be completely realistic**
- which may alleviate the implementation

## Directions in VR -> useful, usable, affordable

- Processing power, image resolution, communication bandwidth
- Latency and motion sickness
- Interaction (NUI, tangible interfaces …)
- Multimodal (voice, haptic, smell…)
- Evaluation methods
- Displays (autostereoscopic, holographic)
- Blending VR and AR …

# Research Directions in AR

- Tracking
- Interaction Techniques and User Interfaces
- Displays (FOV, resolution, focus distance, filtering light)
- Applications
- Evaluation
- Rendering and Visualization

**Kim, K. *et al.*, Revisiting Trends in Augmented Reality Research: A Review of the 2nd Decade of ISMAR (2008–2017), *IEEE Trans. Visualization and Computer vol. 24, n. 11*, 2018, pp. 2947 - 2962**

## Human Centered VR Design
## Five Essentials Every Engineer Needs to Know

"We don´t know all the answers about VR design, nor will we ever. However, five essential concepts discussed here can help you iterate toward building impactful VR experiences"

- Design for Multimodal Input and Output
- Be aware of Adverse Health Effects
- Don't assume Intuitiveness
- You are not your users
- Iteration is required

**J. Jerald, Human Centered VR Design Five Essentials Every Engineer Needs to Know, *IEEE Computer Graphics and Applications*, March/April, 2018, pp. 15-20**

# 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, 2017 http://vr.cs.uiuc.edu
- Schmalstieg, D., Hollerer, T., Augmented Reality: Principles and Practice, Addison Wesley Professional, 2016
- LaViola, J., Kruijff, E., McMahan, R., Bowman, D., Poupyrev, I., *3D User Interfaces: Theory and Practice*, 2nd ed. Addison Wesley Professional, 2017
- Furht, B. (ed.), *Handbook of Augmented Reality*, Springer, 2011
- Craig, A., Sherman, W., Will, J., Developing Virtual Reality Applications: Foundations of Effective Design, Morgan Kaufmann, 2009
- Kim, K., Billinghurst, M., Bruder, G., Duh, H., and Welch, G., "Revisiting Trends in Augmented Reality Research: A Review of the 2nd Decade of ISMAR (2008–2017)," *IEEE Trans. Vis. Comput. Graph*., vol. 24, no. 11, pp. 2947 - 2962, 2018.

**I believe**

the MR community will eventually master the science and art of developing **useful**, **usable** and **affordable** MR applications

Even if it is going to be a
"long and winding road"
it will be exciting!