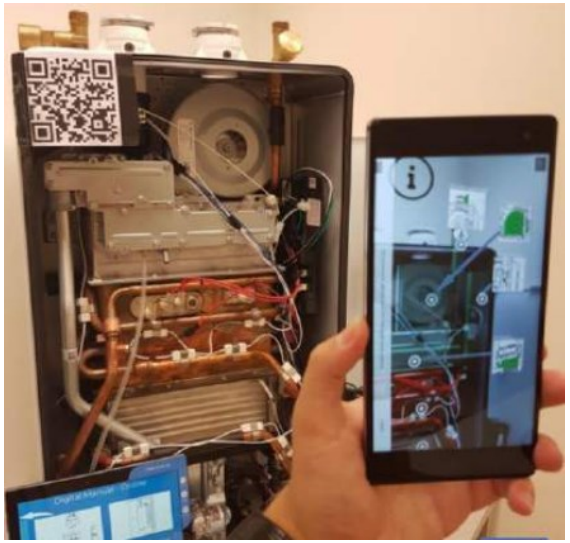
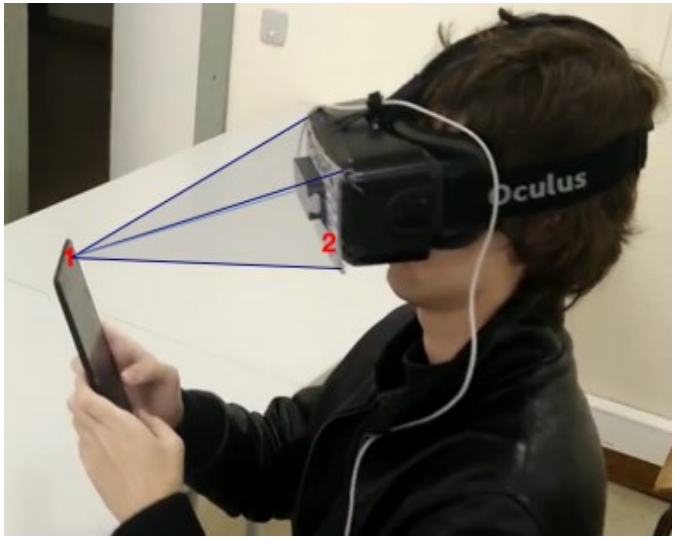
Universidade de Aveiro
Departamento de Electrónica,
Telecomunicações e Informática

An Introduction to Virtual (and other) Realities





Virtual and Augmented Reality 2021

Beatriz Sousa Santos

- What is?
- Historical perspective
- Important aspects
- Applications (old and new examples)
- VR Systems
- Industry perspective

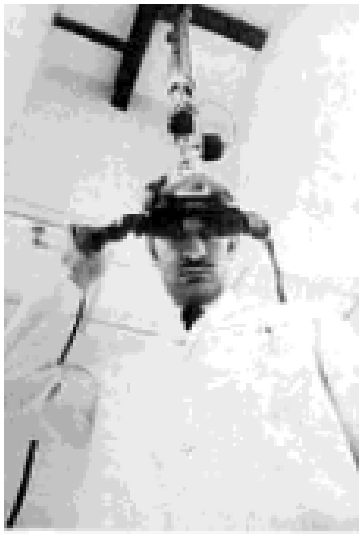
(focused on VR, but also addressing AR…)

Ivan Sutherland's 1965 Vision

"**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 to computer graphics is to make that virtual world look real, sound real, move and respond to interaction in real time, and even feel real."

Ivan Sutherland's 1965 Vision



"**Display as a *window* into a *virtual world***

Improve image generation until the picture *looks real*

Computer maintains world model in *real time*

User *directly manipulates* virtual objects

Manipulated objects *move realistically*

Immersion in virtual world via *head-mounted display*

Virtual world also *sounds real, feels real*"

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

What is VR?

"For better or worse, the label *virtual reality* stuck to this particular branch of computer graphics.

I define a *virtual reality experience* as any in which the user is effectively immersed in a responsive virtual world. This implies user dynamic control of viewpoint." (Fred Brooks, 1999)

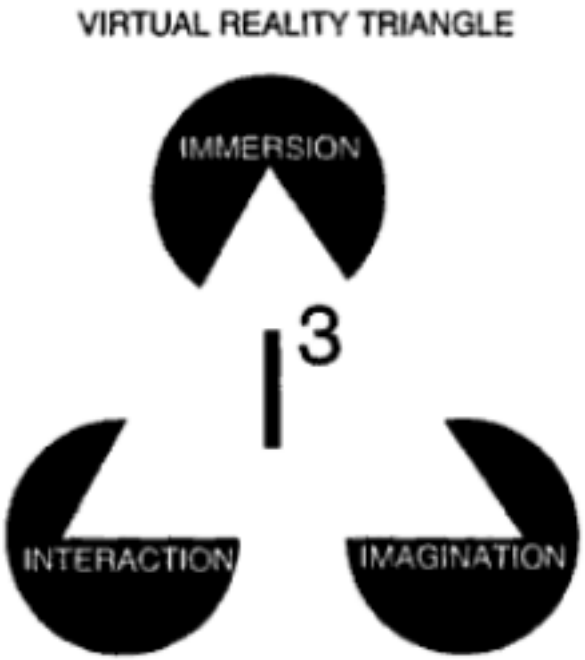
"A high-end user-computer interface that involves real-time simulation and interaction through multiple sensorial channels (vision, sound, touch, smell, taste)". (Burdea et al., 2003)

" A computer generated digital environment that can be experienced and interacted with as if the environment were real" (Jerald, 2015)

The Virtual Reality Triangle

VR is:

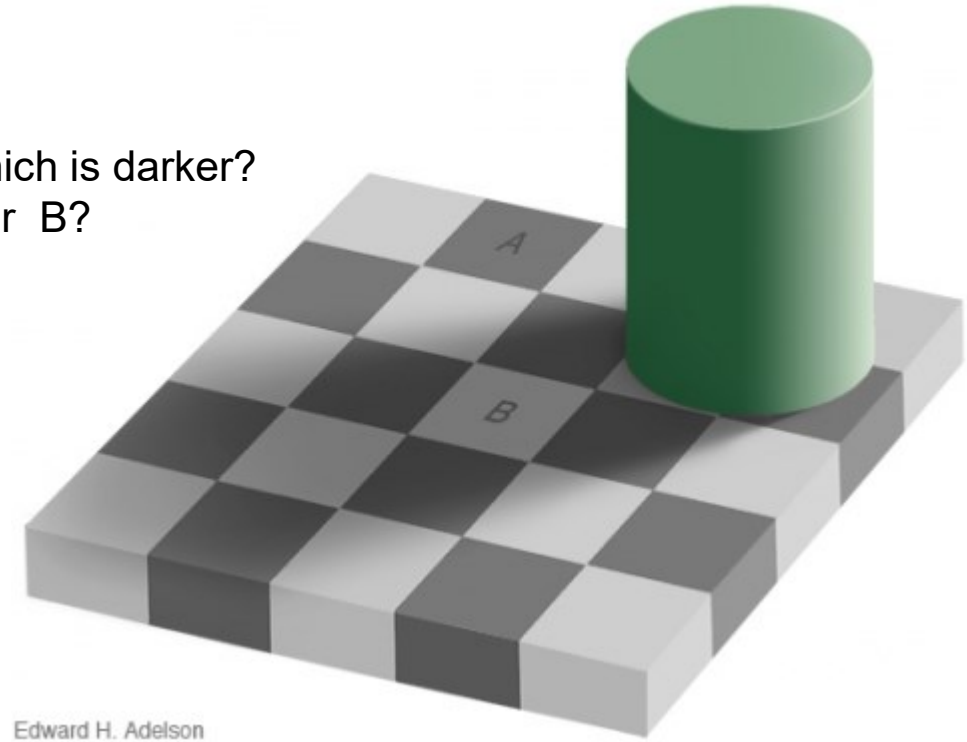
- Immersion
- Interaction
- Imagination
  (to perceive non existing things)



(Burdea et al., 2003)

What we see is more than meets the eye…

Which is darker?
A or B?

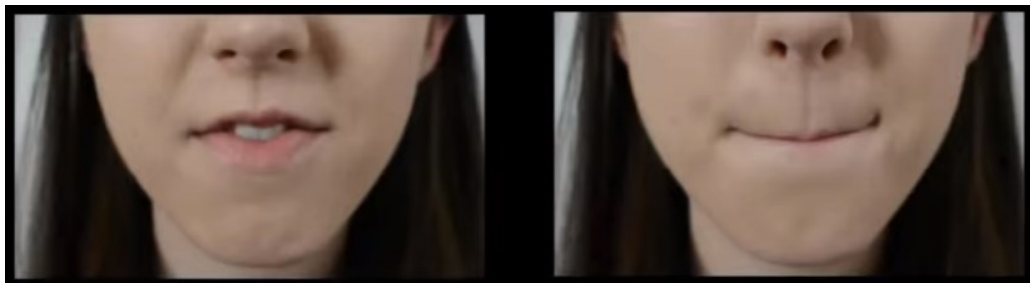


Edward H. Adelson

Virtual reality, explained with some illusions:

https://www.youtube.com/watch?v=qD3w3cAhEYU

and the ear …

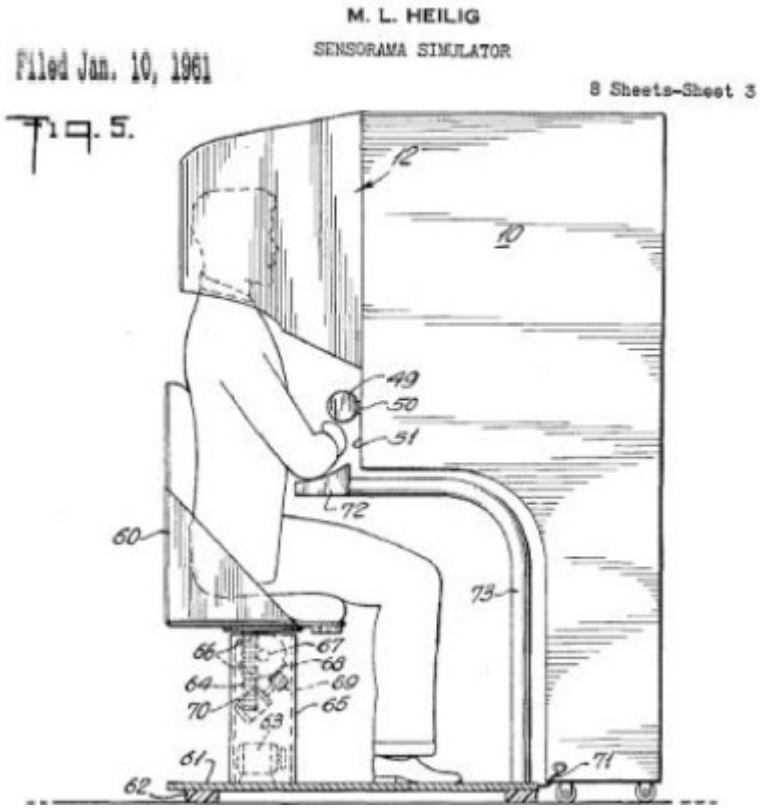


Historical perspective

Sensorama

(Morton Heilig, 1962)

- 3D, wide vision, motion, color, stereo sound, aromas, wind, vibrations
- Lacked interaction…



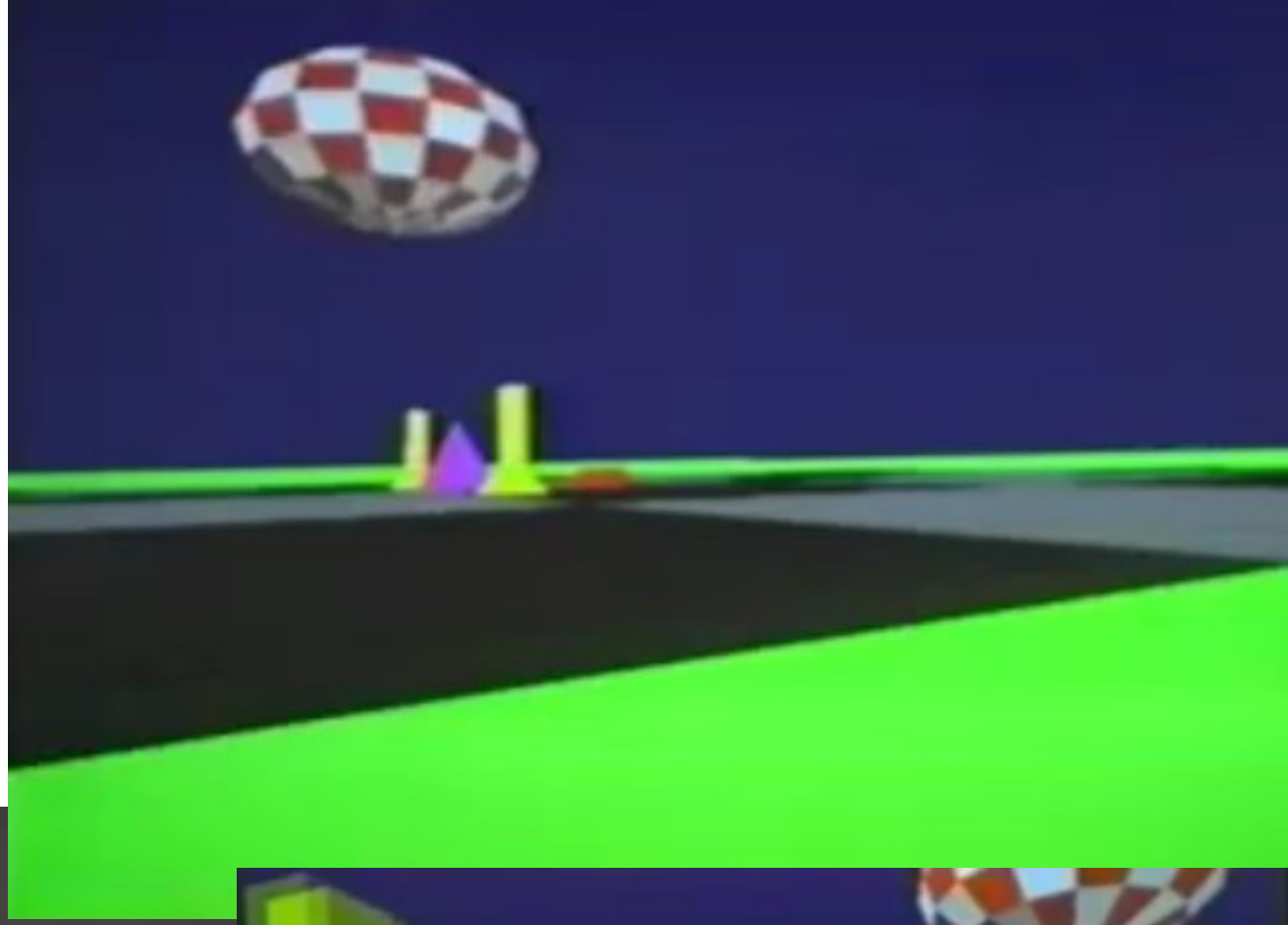
http://en.wikipedia.org/wiki/Sensorama

NASA was pioneer:

VIVED - “Virtual Visual Environmental Display” (early 80s)

VIEW - “Virtual Interface Environment Workstation” (1989)

Early VR Demo
by Sense8
(1988)



VR was already much used in the early 2000s:

- Industry
- Medicine
- Culture
- …

But it was very expensive!

Applications

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

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

Used in :
Design, Project review,
Ergonomic studies,
Production, Marketing

Accelerates the process
Decreases costs
Fosters innovation …

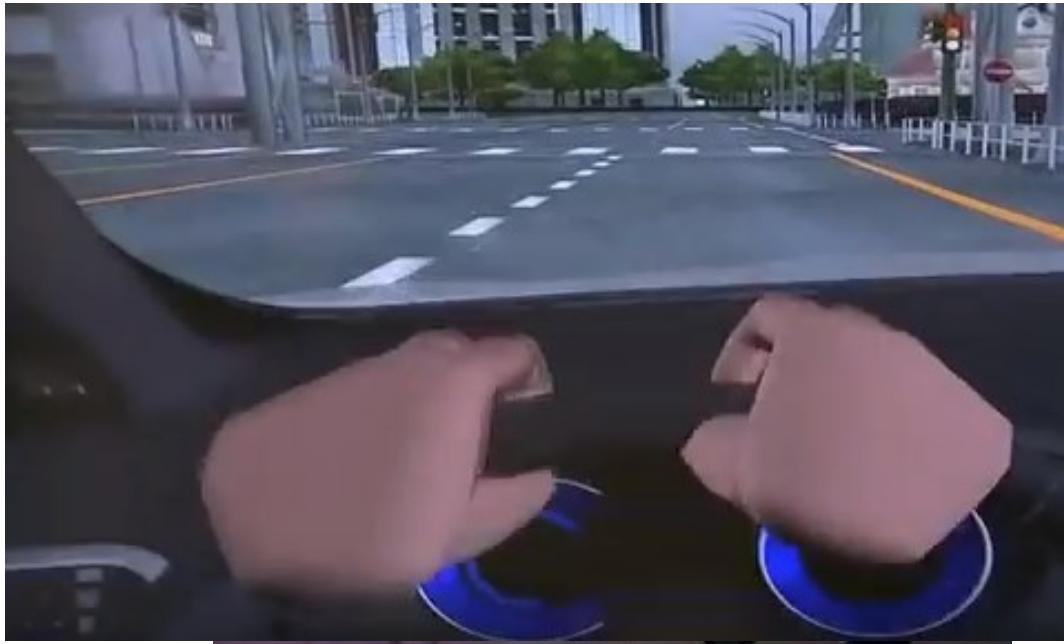
Design at McLaren
https://www.youtube.com/watch?v=mWaQfjEJIMQ

Automotive industry: other examples

- 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

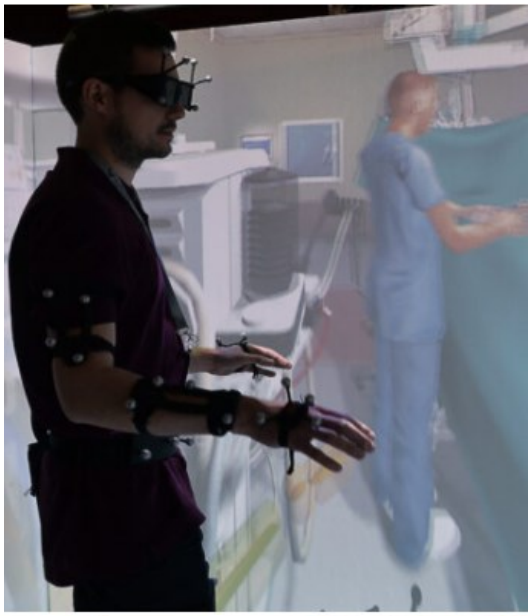
https://www.youtube.com/watch?v=BEFfp2QhHZU



Applications in Medicine

- Application areas that went beyond the prototype phase:
  - Radiation Treatment, Planning and Control
  - Interactive 3D Diagnostic Imaging
  - Rehabilitation and Sports Medicine
  - Psychiatric and Behavioral Healthcare
  - Neurological Evaluation
  - Pre-Surgical Planning
  - Pain Mitigation
  - Medical Education
  - Surgical Training
  - ...

https://www.youtube.com/watch?v=YNq4uGfR0lM

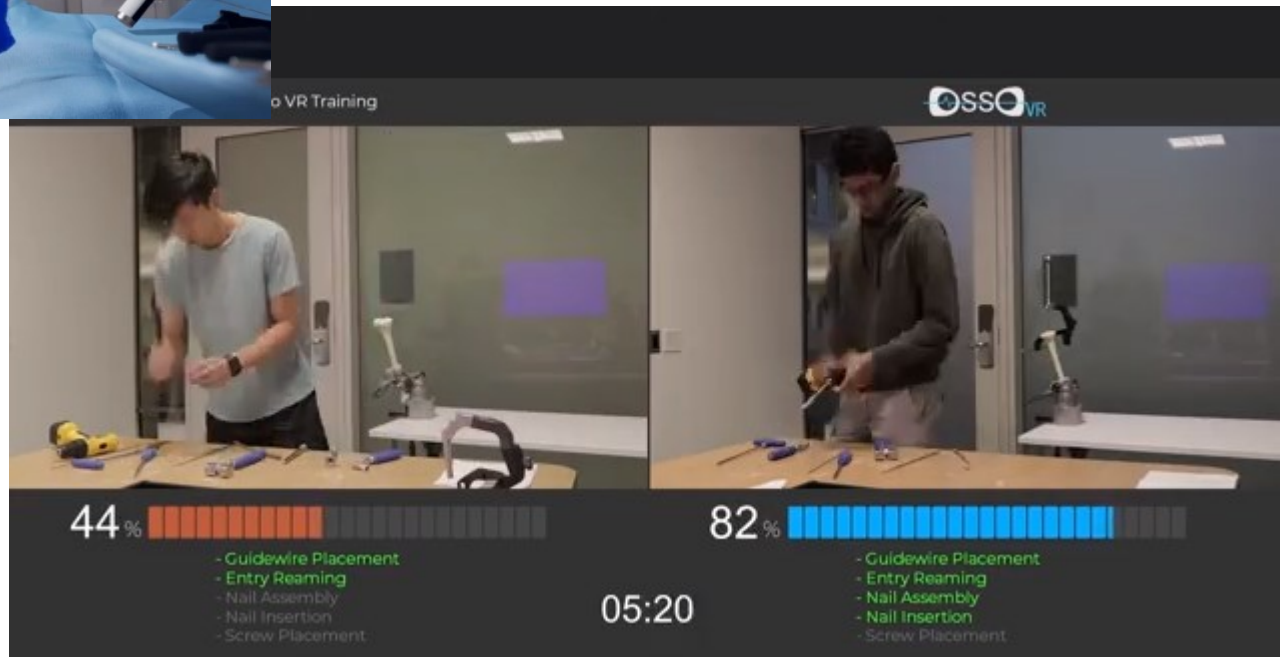


Combining imaging from MRIs, CT scans and angiograms to create a three-dimensional model that physicians and patients can see and manipulate — just like a virtual reality game – Stanford Medicine

https://medicalgiving.stanford.edu/news/virtual-reality-system-helps-surgeons-reassures-patients.html
https://www.statnews.com/2019/08/16/virtual-reality-improve-surgeon-training/

Surgeons new to complex procedures can may practice through spaced-repetition, and then measure skill through an **Assessment Analytics™** reports.

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



https://ossovr.com/
https://www.youtube.com/watch?v=jM615O59rqo

Dentistry training

Stereoscopic display + glasses

Interaction devices:

- two force feedback devices
- foot pedal

https://www.voxel-man.com/simulators/dental/

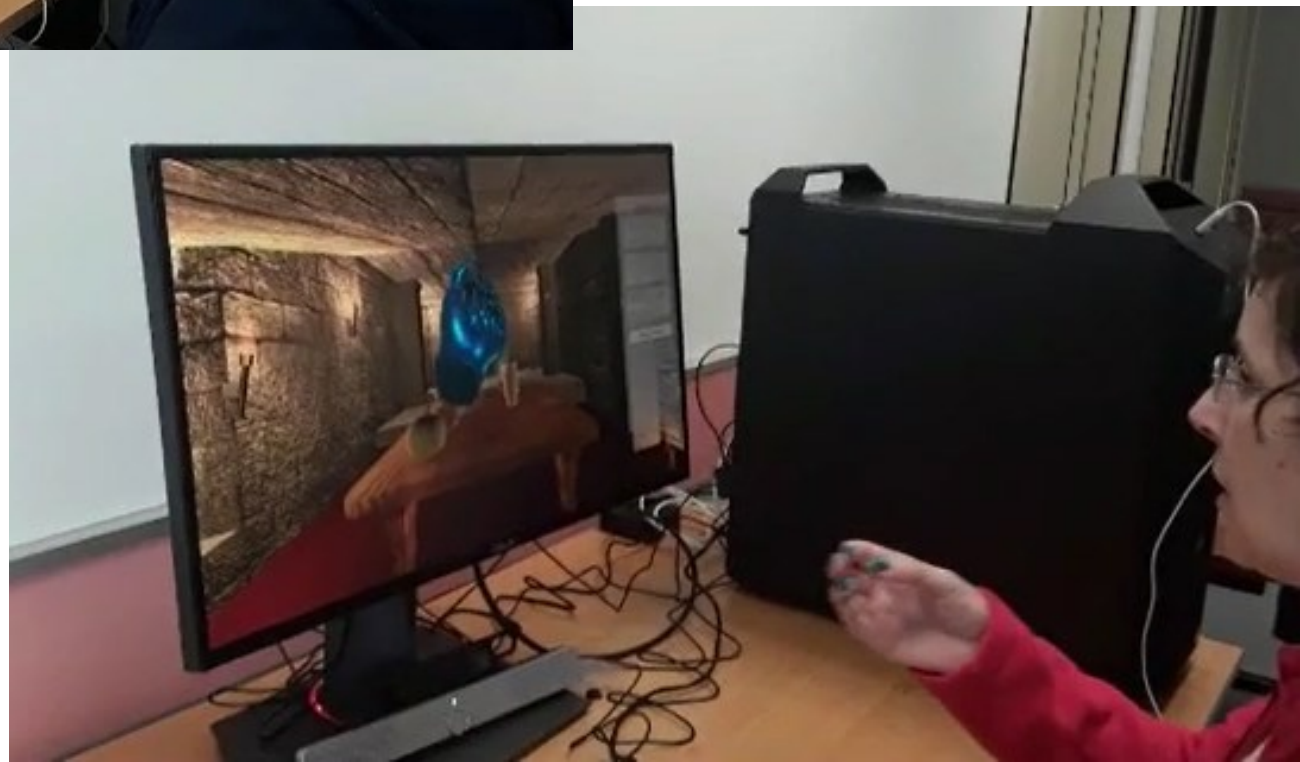
https://www.youtube.com/watch?v=CB_vdW6K42o

Physical Rehabilitation

A stroke patient interacts with a virtual reality environment using an electronic glove to "pour tea" during a therapy session
University of Chicago

Mini-games to help recover arm movement for Stroke patients

DETI/IEETA +
Centro Rovisco Pais



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

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

Product Design Process

Using the HTC Vive Virtual Reality (VR) system in the product design process for an Industrial Designer creating an exterior for a industrial laser cutter.

https://www.youtube.com/watch?v=TiY45xUaml0

VR in training - Pros and Cons

Pros:
Creates a Safe Learning Environment
Exciting and Engaging
Realistic Technical Skills Practice
Collects Key Training Metrics

Cons:
Physical Side Effects
Technology Developments and Updates
High Cost

https://www.youtube.com/watch?v=o647rbB6ubY

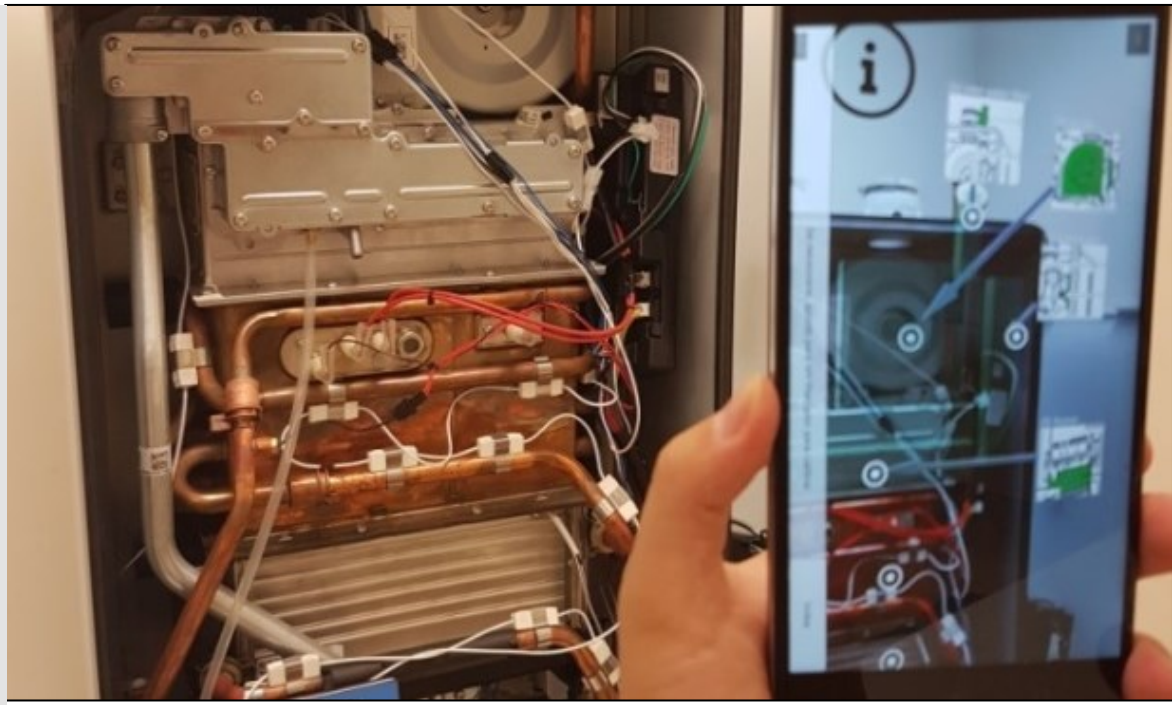
Several degrees of immersion

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

(S.H. Choi and H.H. Cheun, 2008)

AR- Several types of displays

- Hand Held display
- Head Mounted Display
  - Video see-through
  - Optical see-through
- Spatial projector



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

Oculus Rift
2014; ~300 USD

Made VR economically viable
in many more situations!!

Was widely used in research
and many applications

http://www.oculusvr.com/

Potential benefits of Immersion

- Immersion can offer benefits beyond a realistic experience:

- Spatial understanding can result in greater effectiveness in:
  - scientific visualization,
  - design review,
  - virtual prototyping
  - etc.

- Decrease in information clutter and increase the environment's comprehensibility (increased FOV, FOR, and display resolution)

Presence

- " A sense of "being there" inside a space even when physically located in a different location" (Jerald, 2016)

- It is difficult to describe as it is an psychological state

- Is a function of the user and the immersion; it is an illusion

- Definition by the International Society for Presence Research (2000) :

"is a psychological state or subjective perception in which even though part or all of an individual's current experience is generated by and/or filtered through human made technology, part or all of the individual's perception fails to accurately acknowledge the role of the technology in the experience"

Presence

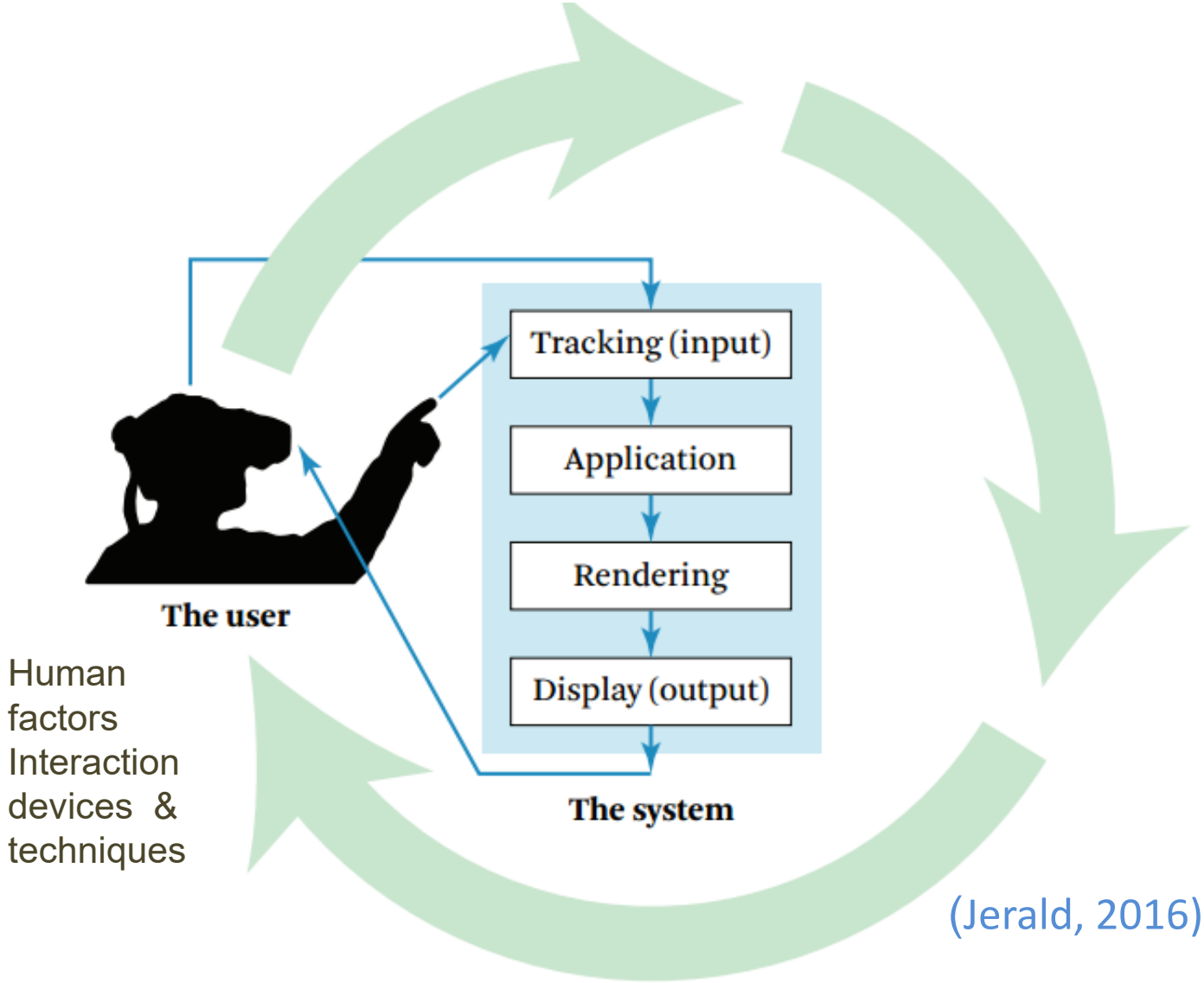
There are several questionnaires to measure presence

Carefully designed and refined over more than two decades

There have been vigorous debates over measuring presence

V. Schwind, P. Knierim, N. Haas, and N. Henze, “Using Presence Questionnaires in Virtual Reality,” in *CHI ’19 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2019.

Virtual Reality Systems



(Jerald, 2016)

Crucial technologies for VR

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

- **Interaction devices** allowing users to interact with virtual objects

- **Interaction techniques** that substitute for the real interactions possible with the physical world

- **Display of synthesized sound** including directional sound and simulated sound fields

(if possible)

- **Display of synthesized forces** and other haptic sensations

VR System

- I/O devices:
  - trackers, interaction devices, ...
  - displays (visual, sound, haptic,…)

- Virtual Reality engine (architecture)

- Software for virtual object modeling:
  - geometry, texture,
  - intelligent behavior
  - physical modeling (inertia, hardness,...)

- Users and their tasks (human factors)

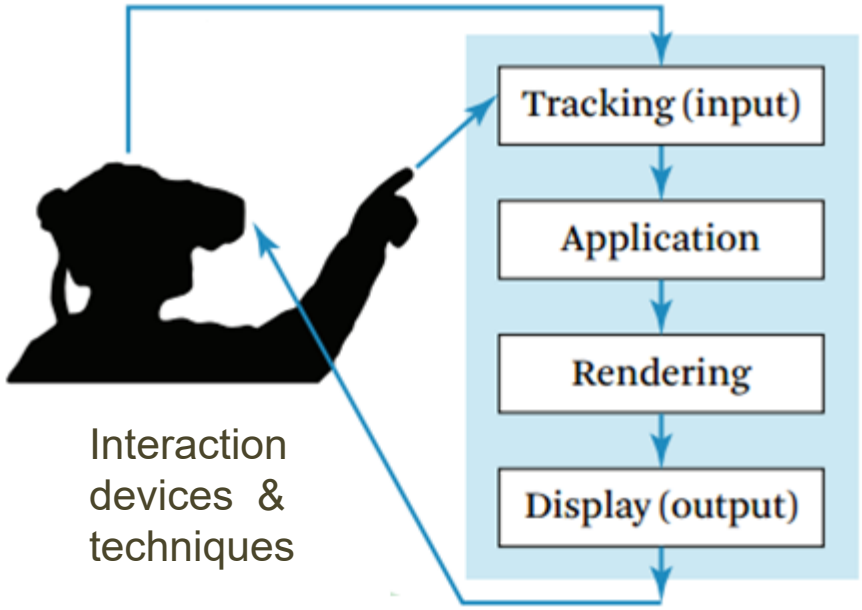
Input devices

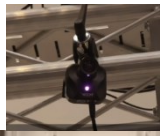
- Trackers:
  - Mechanical
  - Magnetic (AC, DC)
  - Optical
  - Ultrasonic
  - Inertial
  - Hybrid

- Navigation and manipulation interfaces:
  - Tracker-based
  - Trackballs
  - 3D probes …

- Gesture interfaces:
  - Gloves
  - Various sensors and controlers ...

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





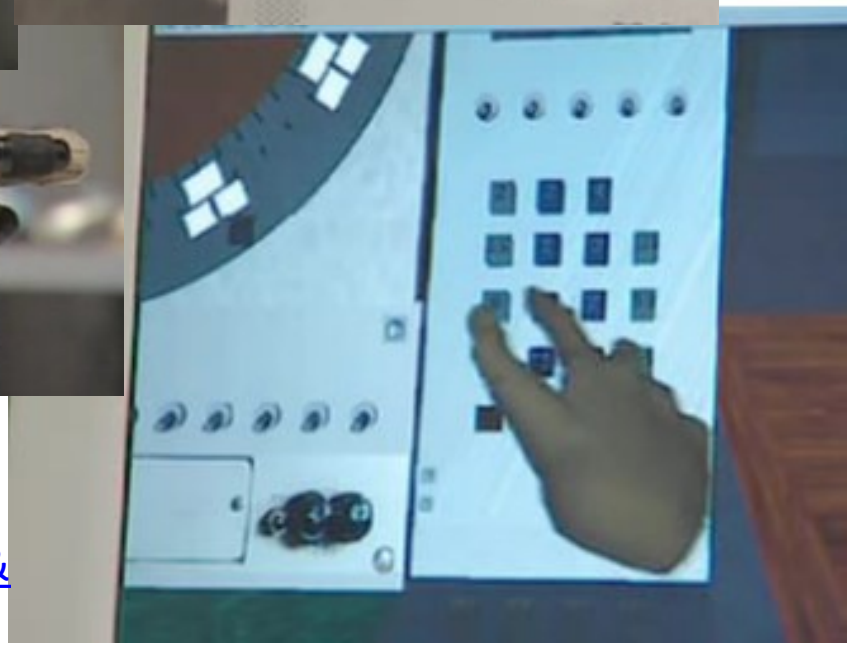
- Navigation and manipulation devices:
  - Tracker-based
  - Trackballs
  - 3D probes, ...

- Gesture interfaces:
  - Gloves

http://www.cyberglovesystems.com/
https://www.senseglove.com/

https://www.youtube.com/watch?v=32f2UxKjydI
https://www.youtube.com/watch?v=EXqQlQmcGIY

Very sophisticated and expensive I/O devices



http://www.cyberglovesystems.com/
http://www.cyberglovesystems.com/cybertouch/
https://www.youtube.com/watch?time_continue=4&v=OiNQfxvV4sM&feature=emb_logo

And other affordable input devices you know from other contexts:

- Wiimote

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

- Kinect

Item is no longer available

Output devices

- Graphics displays:
  - Personal
    (HMDs, HSD, DSD, ...)
  - Large volume displays
    (monitor-based, projector-based)

- Sound displays:
  - Speaker-based 3D sound

- Haptic displays:
  - Tactile feedback interfaces
    (mouses, gloves, ...)
  - Force feedback interfaces
    (force-feedback joysticks, haptic arms, ...)

Speech and brain interfaces?

Graphics Displays

https://www.inition.co.uk/extraordinary-technology/head-mounted-displays/

- HMDs
  - single user; very immersive
  - small field-of-view
  - may have poor ergonomics
    (weight, cables)

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/2021

https://www.oculus.com/quest-2/
https://www.telegraph.co.uk/gaming/features/oculus-quest-2-review-facebooks-new-headset-breaks-virtual-reality/

Device	Oculus Quest 2	Oculus Quest	Valve Index	HTC Vive Cosmos	HP Reverb G2
Starting Price	$299	$399	$999	$699	$599
Pixels per eye	1832 x 1920	1440 x 1600	1440 x 1600	1440 x 1700	2160 x 2160
Screen refresh rate	72Hz at launch, 90Hz to come	72Hz	80Hz to 144Hz	90Hz	90Hz
Weight	503 grams	571 grams	809 grams	645 grams	550 grams
Tracking	Internal cameras	Internal cameras	External SteamVR towers	Internal cameras (SteamVR with upgrade)	Internal cameras
Battery capacity	Two to three hours	Two to three hours	N/A	N/A	N/A
Processor	Qualcomm Snapdragon XR2	Qualcomm Snapdragon 835	N/A	N/A	N/A
RAM	6GB	4GB	N/A	N/A	N/A
Storage	64GB or 256GB	64GB or 128GB	N/A	N/A	N/A
Color	White	Black	Black	Turquoise	Black
Facebook required?	Yes	No	No	No	No
Controller charging	AA batteries (2)	AA batteries (2)	Rechargeable	AA batteries (4)	AA batteries (4)

https://www.theverge.com/21433030/oculus-quest-2-vr-headset-specs-comparison-htc-valve-microsoft

HMD for professional purposes as of 2020

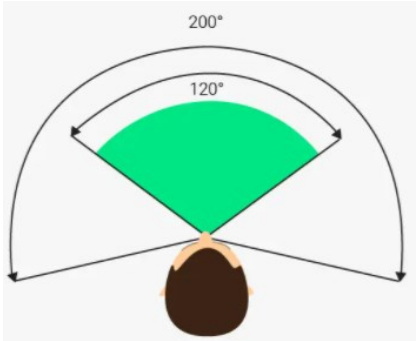
~6000 USD

https://vrgineers.com/xtal/

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°**

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.



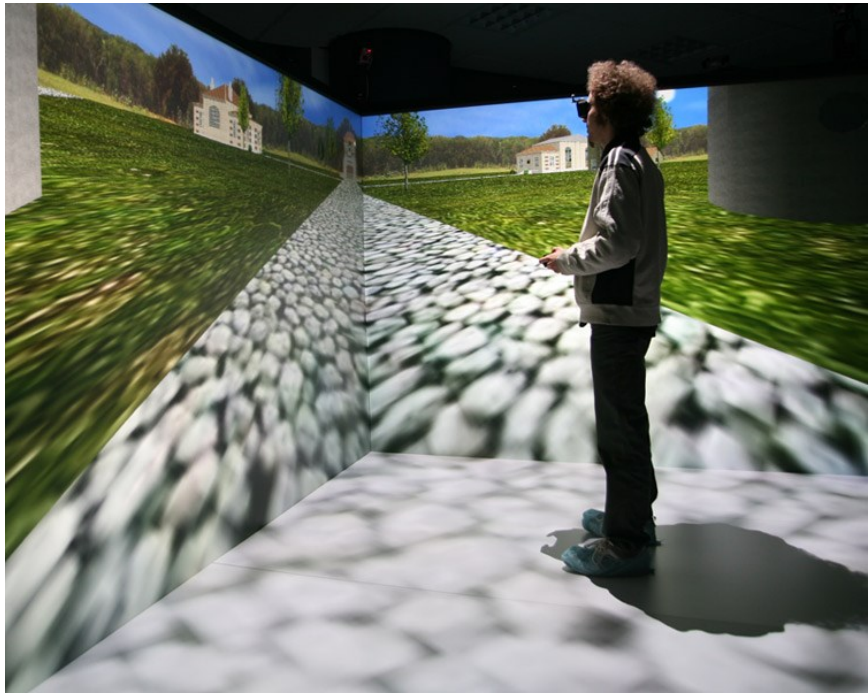
Human FOV is ~ 210°×150°.
https://uploadvr.com/field-of-view-tool-database/

Graphics Displays

- Projection systems (CAVE like sysmems)
  - wide, surrounding field of view
  - shared experience to a small group

  - cost of multiple image-generation
  - space requirements
  - reduced contrast and color saturation
  - brightness limitations
  - corner and edge effects

http://www.antycipsimulation.com/

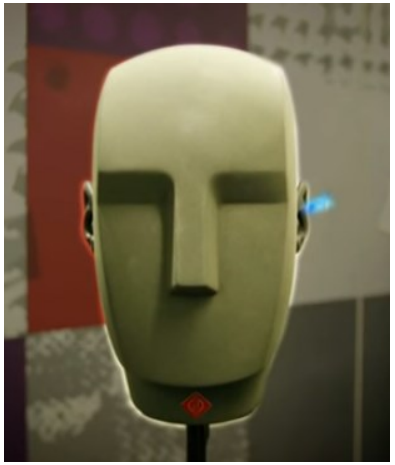


Auditory displays

- In addition to the visual and tactile displays, sound:
  - enhances the presence
  - enhances the display of spatial information
  - can convey simulated properties of elements of the environment (e.g. mass, force of impact...)
  - can be useful in designing systems where users monitor several communication channels (selective attention)

Auralization

- Produces a 3D sound space by digital means based on binaural human hearing principles (psycho-acoustic)
- From the two signals that reach our ears we extract information about the location of sound sources
- The types of displaying audio differ in:
  - size of the listening area (sweet spot)
  - amount of tonal changes
  - …



Virtual reality for your ears - Binaural sound demo ->

https://www.youtube.com/watch?v=51za5u3LtEc

Haptic interfaces

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

Coming devices in 2020:
gloves and vests…

https://www.youtube.com/watch?v=AX-Oz5hocyI

Haptic interfaces

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

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

I

ISMAR keynote: "Wearable Haptics for Virtual and Augmented Reality"

Haptic devices

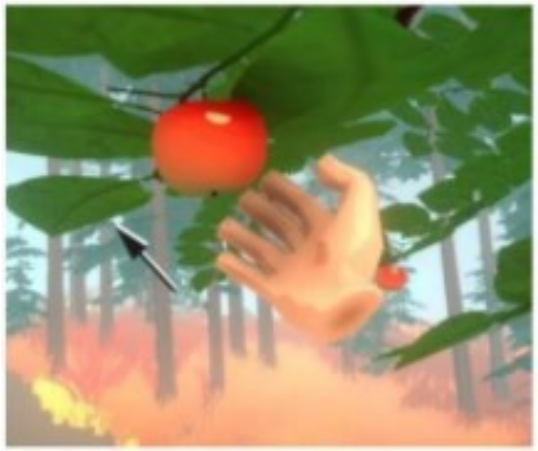
- Tactile feedback interfaces
  (mice, gloves, ...)
- Force feedback interfaces
  (force-feedback joysticks, PHANTOM, CyberGrasp...)
- Suits…

https://www.inition.co.uk/product/haption-virtuose/?%3E

http://www.sensable.com/haptic-phantom-omni.htm

http://www.cyberglovesystems.com/cybergrasp/






R. Kovacs, et al., "Haptic PIVOT: On-Demand Handhelds in VR". In Proceedings of the 33rd ACM Symposium on User Interface Software and Technology (UIST '20) ACM, 1046–1059. DOI:https://doi.org/10.1145/3379337.3415854

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

Displays for other senses

Research on smell has years

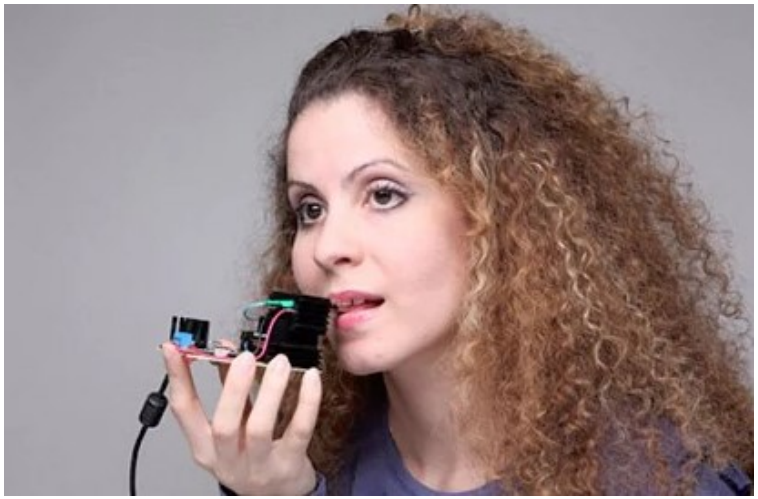
Some startups are working on devices

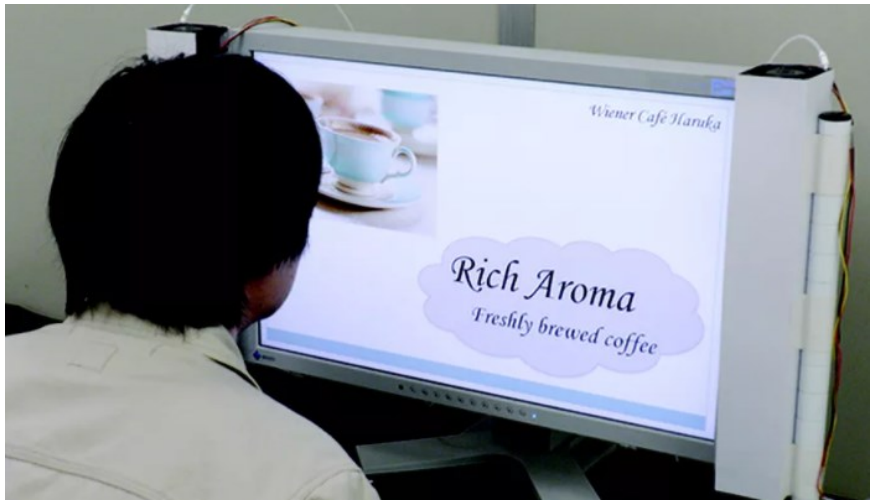
But olfactory stimuli are difficult …

Taste is even more difficult and “invasive” …

https://www.pcmag.com/news/can-smell-o-vision-save-vr

https://feelreal.com/





Main challenges to wide adoption of VR

Design and technology…

- 3D user interfaces

- Convenience and control (easy to use and affordable)

"The biggest barrier to wide adoption of immersive technologies is the lack of good user experience design"

(https://www.gartner.com/smarterwithgartner/3-reasons-why-vr-and-ar-are-slow-to-take-off/

What about VR currently? In my opinion:

- There is a continuum of realities **Don't forget AR, MR!**
- It is more consolidated and **more affordable**
- It has passed the "hype and disappointment phases"
- **It works and is useful in specific applications**
- **There is a range of VR settings with very different costs**
- It is still not easy to integrate a complete solution
- Needs to be more usable
- It still has **human factors challenges and ethical, societal**
- It may suffer from **cybersecurity issues …**

Augmented *versus* Virtual Reality

- AR is a natural evolution from VR technology
- The major limitation of VR is that it is not easy to fully and accurately model the actual environment
- Does not need to model the entire real world
- AR enhances an existing environment rather than replacing, reduces the high cost of fully immersive VR environments and avoids time-consuming remodeling of complex real objects

Virtual vs Augmented Reality

- VR **replace** reality

- AR **enhances** reality

Augmented Reality

- "Augmented reality (AR) is a live, direct or indirect, view of a physical, real-world environment whose elements are augmented by computer-generated sensory input such as sound, video, graphics or GPS data." (Wikipedia)

- *"Augmented Reality* (AR) is a variation Virtual Reality …
  VR completely immerse a user inside a synthetic environment, … While immersed, the user cannot see the real world around him.

  … AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world.

  …AR supplements reality, rather than completely replacing it. "

  (Azuma, 1997)

Reality Virtuality “Continuum”

“Augmenting natural feedback to the operator with simulated cues”

(Milgram & Kishino, 1994)

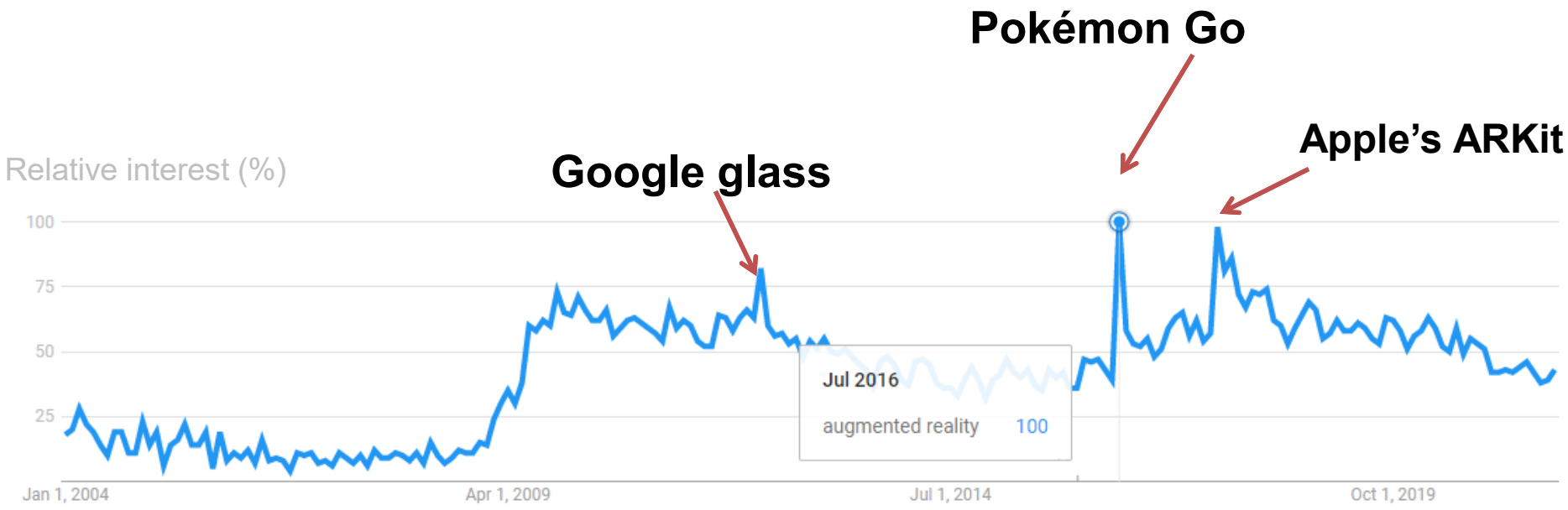
Mixed Reality (MR)

Real Environment | Augmented Reality | Augmented Virtuality | Virtual Environment

(Steinicke et a., 2009)

- **Azuma (1997)** defines AR as systems that has the following three characteristics:
  - 1) Combines real and virtual
  - 2) Interactive in real time
  - 3) Registered in 3-D
- But terminology is not yet completely stable…

Awareness, interest and adoption of AR



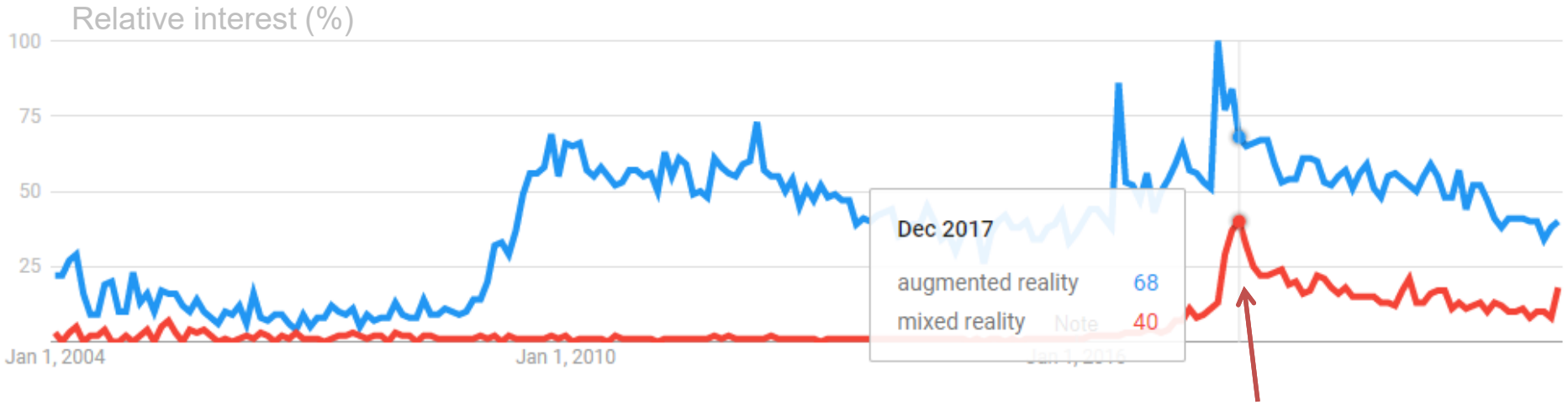
(Google trends – Augmented reality, Worldwide)

Pokémon Go demonstrated AR's potential to be adopted by mainstream culture

The global AR services market is expected grow 5x until 2025

Several terms and definitions

M. Speicher, B. D. Hall, and M. Nebeling, “What is Mixed Reality ?,” *CHI ’19 Proc. SIGCHI Conf. Hum. Factors Comput. Syst.*, 2019.



(Google trends – Augmented reality)
(Google trends – Mixed reality)

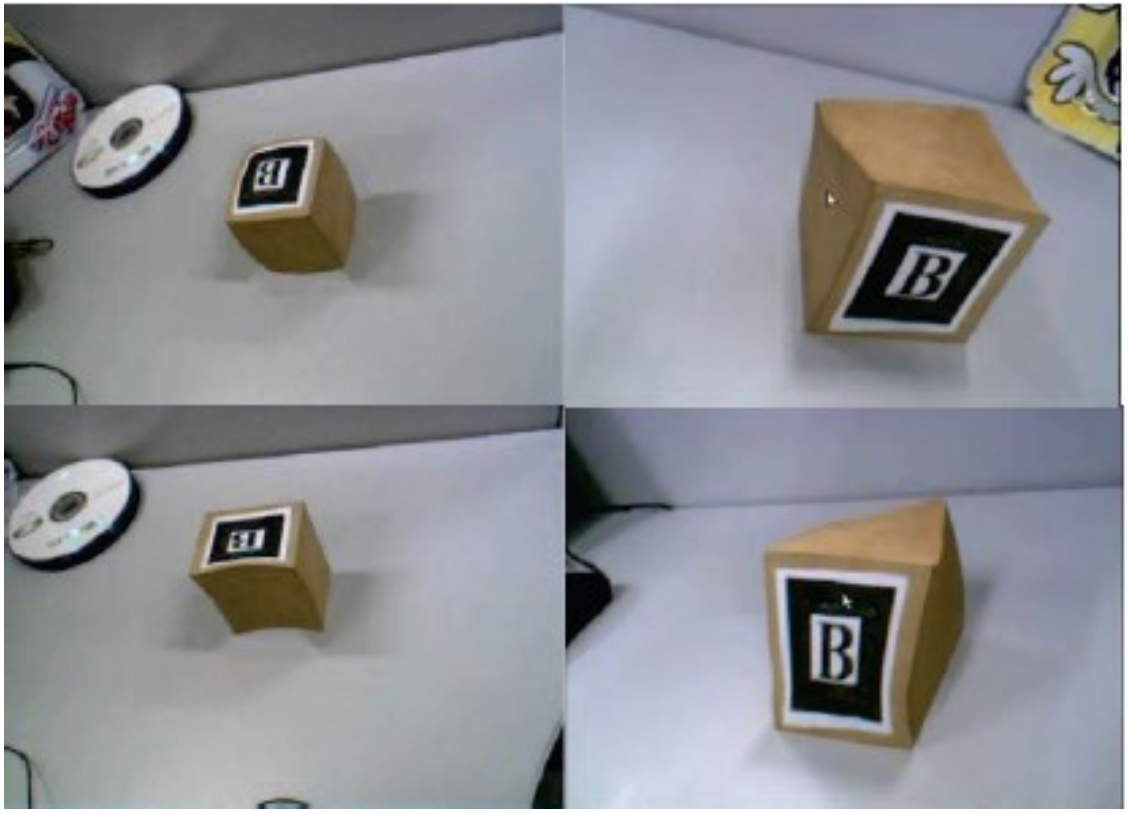
Specific HMDs

AR *vs* MR: branding strategy, interaction, believability?

Recent umbrella term - Extended Reality (XR)

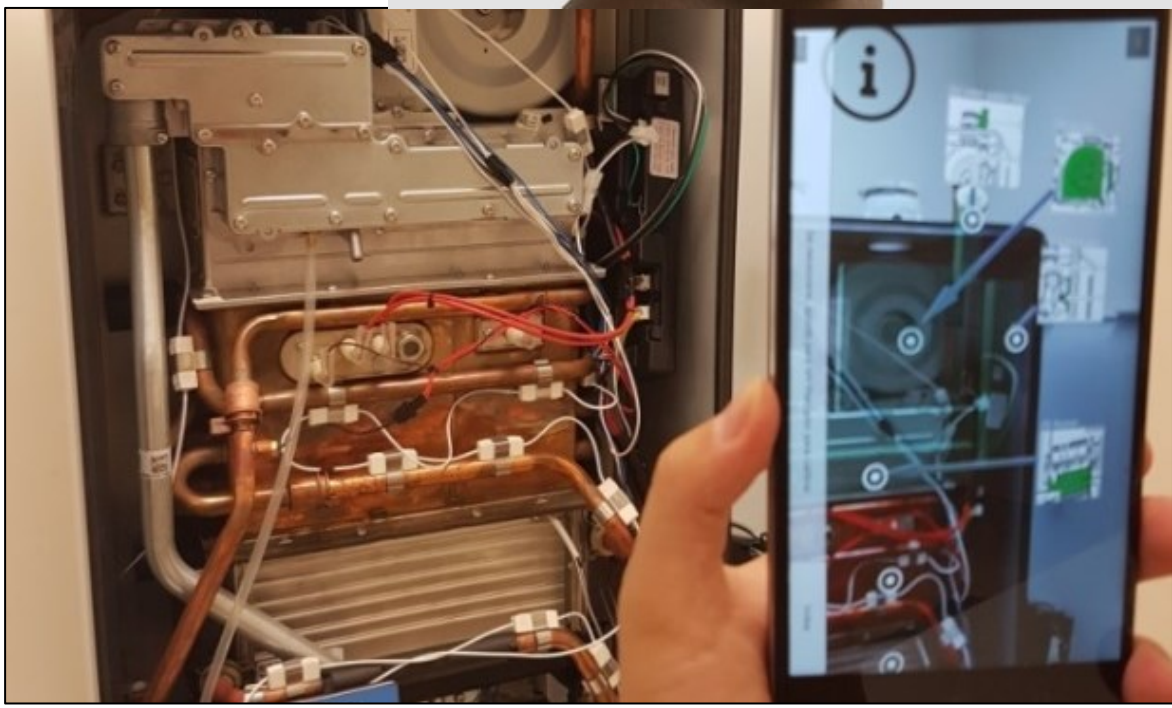
Yet Other Realities: Altered Reality
(Augmented + Diminished)

- Leao, C.W.M. Lima, J.P. Teichrieb, V., Albuquerque, E.S., Kelner, J. , "Demo — Altered reality: Augmenting and diminishing reality in real time," *IEEE Virtual Reality Conference, 2011,* pp.259-260



Relevant issues in AR

- Registration
- Displays
- Latency
- Calibration
- Interaction
- Human factors …



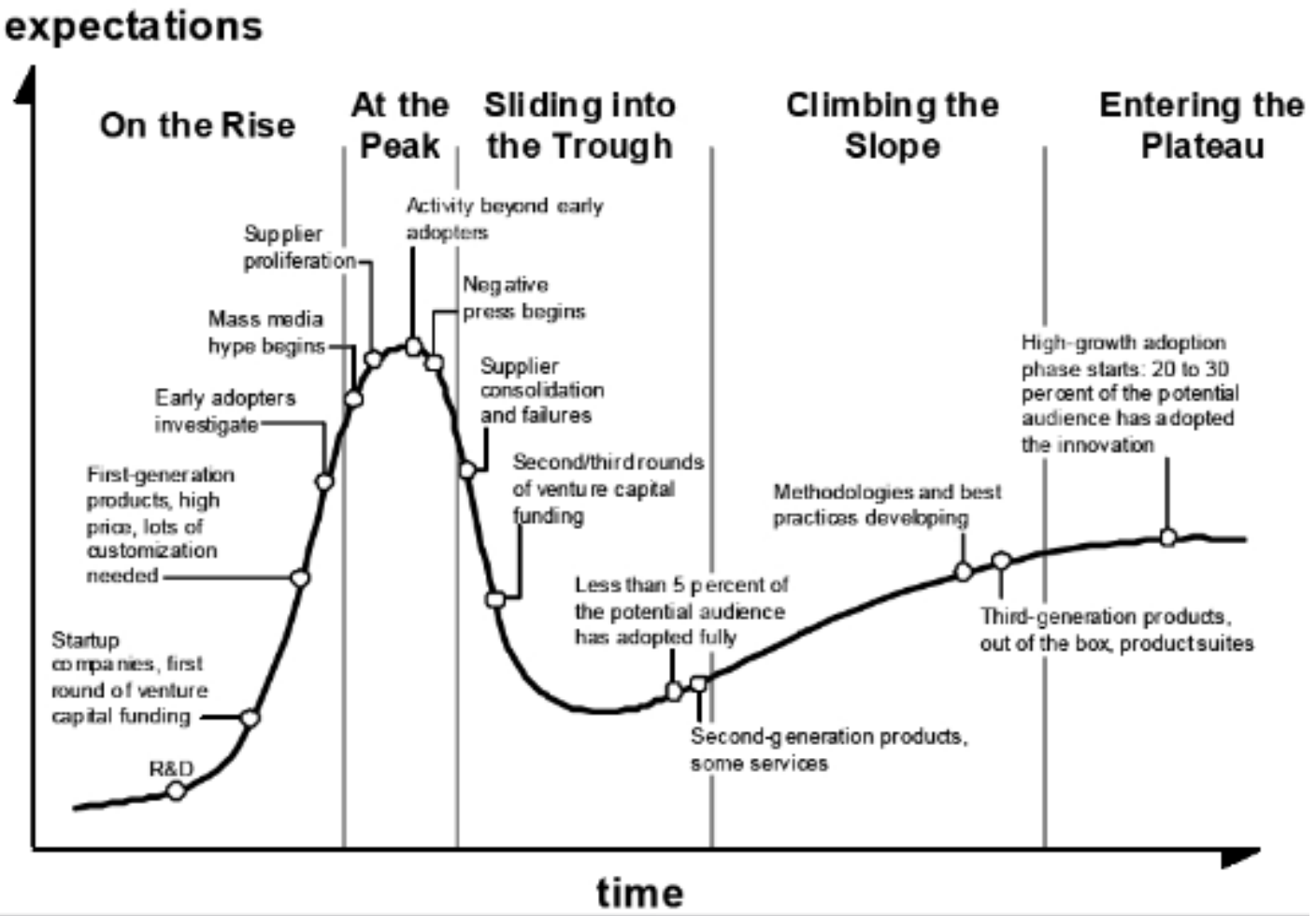
The Industry perspective

Gartner's Hype cycle:

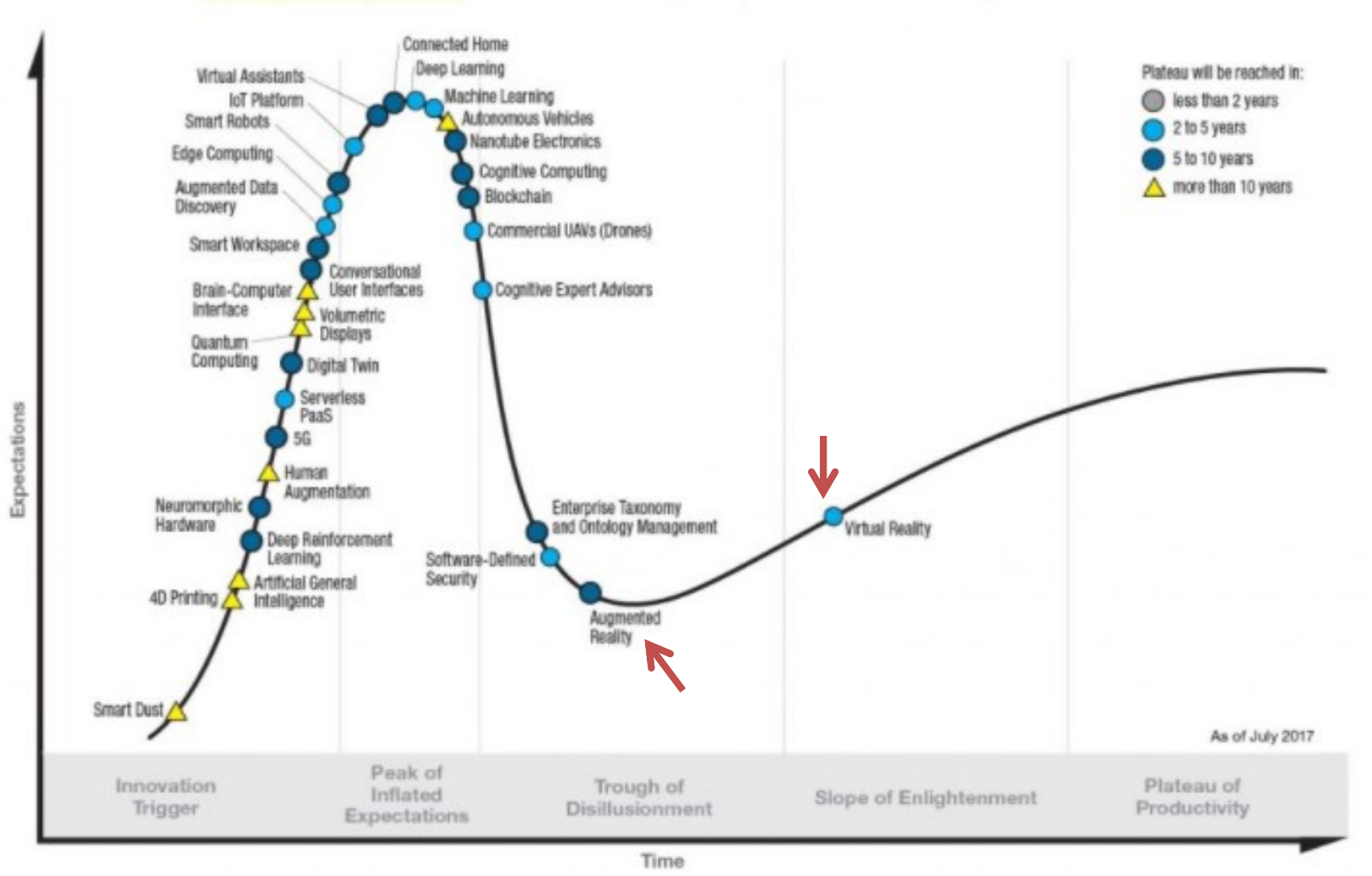
- 1. A new technology creates expectations; it is investigated and its potential explained
- 2. Expectations peak; the technology becomes overestimated
- 3. Failures and high cost lead to disappointment
- 4. Technology is consolidated and expectations rise again
- 5. Mainstream productivity is attained

https://www.gartner.com/smarterwithgartner/5-trends-appear-on-the-gartner-hype-cycle-for-emerging-technologies-2019/
/

Gartner's Hype Cycle



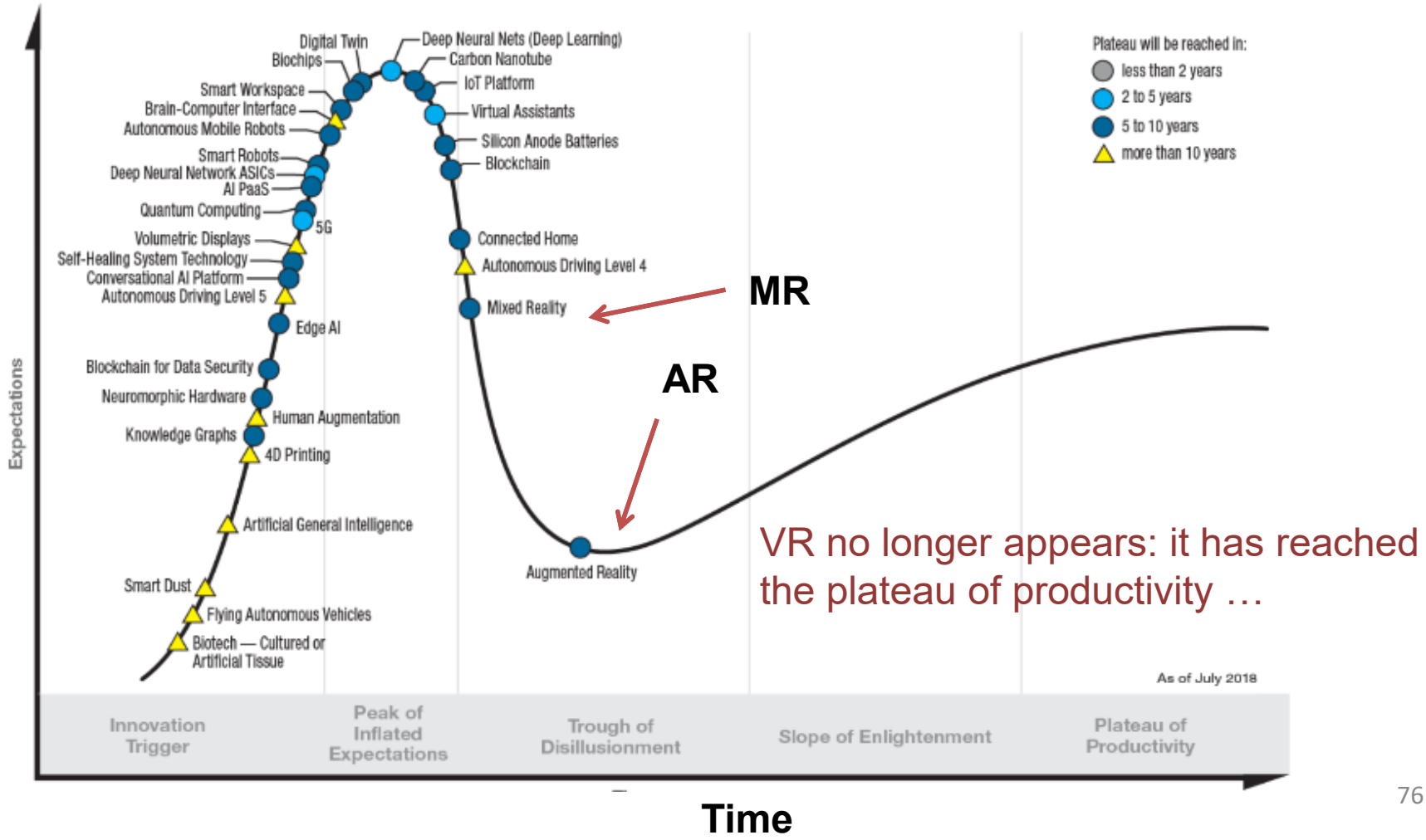
2017



http://www.gartner.com/smarterwithgartner/top-trends-in-the-gartner-hype-cycle-for-emerging-technologies-2017/

Gartner's Hype cycle - AR Last appearance

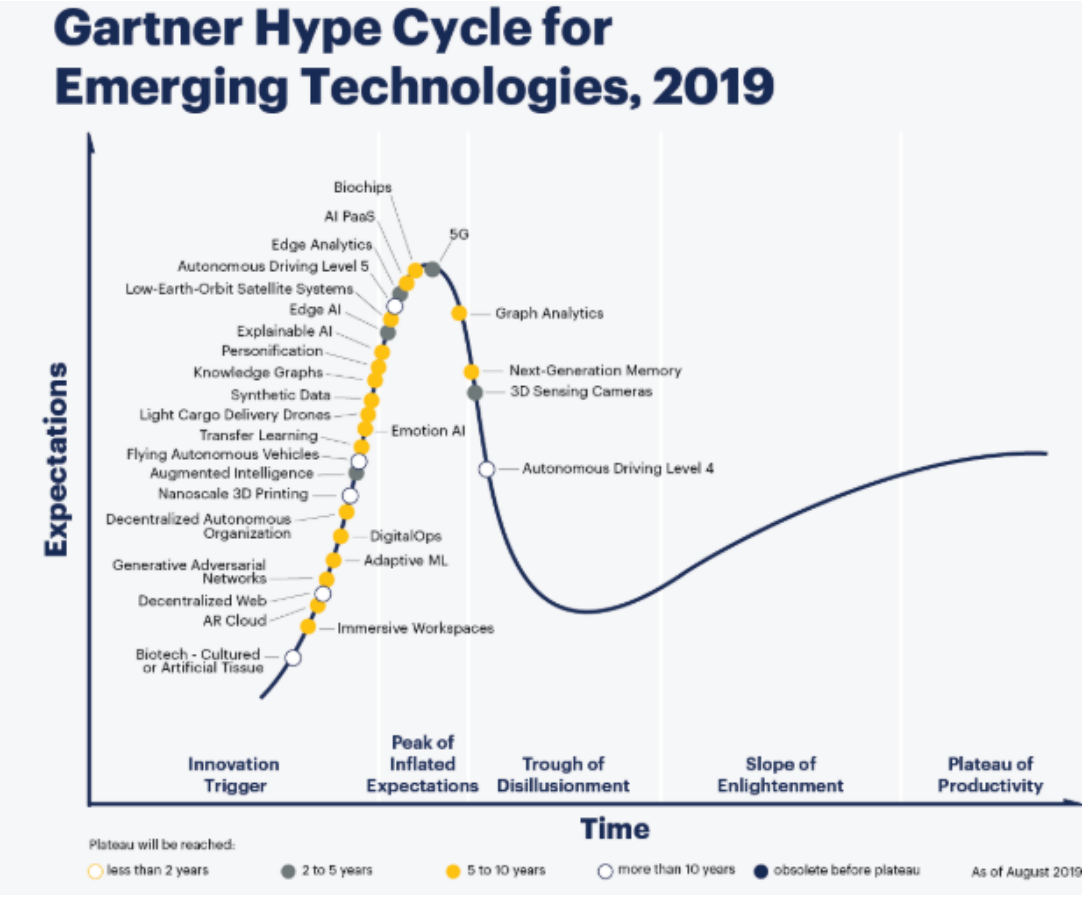
2018



VR no longer appears: it has reached the plateau of productivity …

What is the current state of VR/AR? Industry perspective

Expanding from a research field into commercially viable technologies

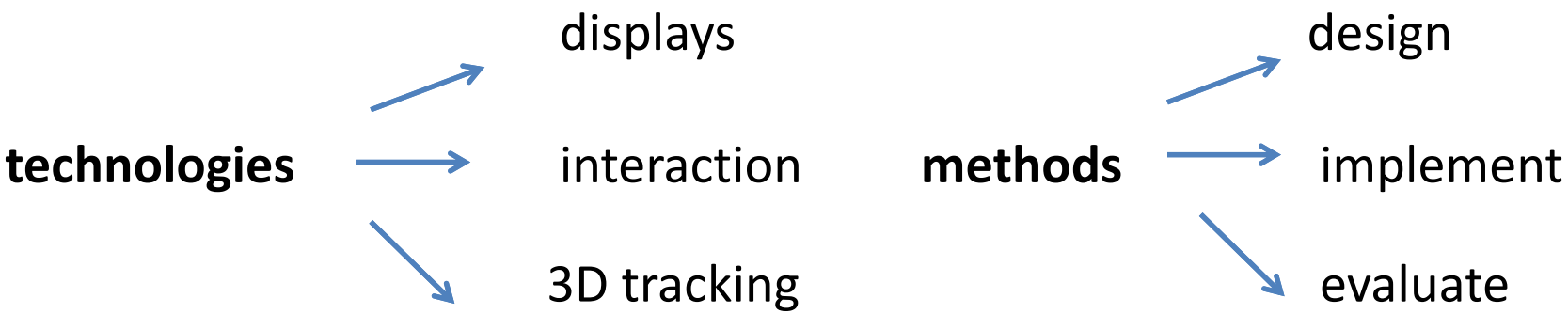


In 2019 VR and AR no longer appear, they have reached the plateau of productivity

https://www.gartner.com/smarterwithgartner/5-trends-drive-the-gartner-hype-cycle-for-emerging-technologies-2020/#:~:text=The%20Gartner%20Hype%20Cycle%20for%20Emerging%20Technologies%2C%202020%20highlights%2030,next%20five%20to%20ten%20years.

Has evolved a lot

important research goals to be addressed



acceptability and other social issues

Mobile AR provides an easily accessible entry point

the true potential is achieved through

- HMDs,
- a richer interaction,
- better tracking

In some niche situations,
projection AR (SAR) may be
Interesting

AR Display technologies

Video see-through

Optical see-through

Projection (spatial)

Still far from the “ultimate display”…

Tracking technologies

Vision- based

Magnetic

Inertial

GPS-based

…

not yet at the "anywhere augmentation“ **(Höllerer, 2007)**

Nor “pervasive AR” **(Grubert, 2017)**

Interaction

3D User Interfaces

Tangible User Interfaces (TUIs)

Natural User Interfaces (NUIs)

Multimodal User Interfaces

...

Components that must be designed in an AR application UI

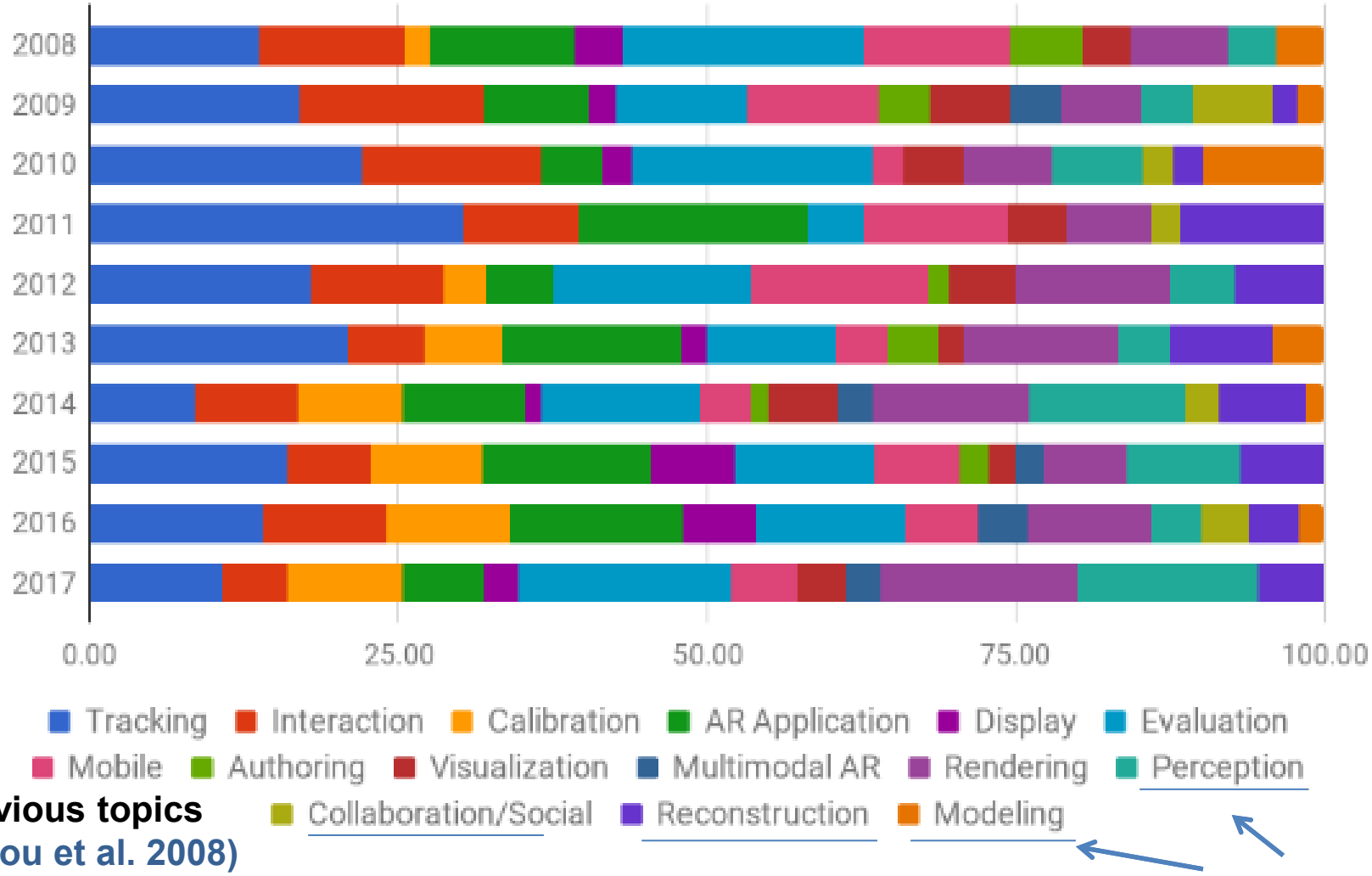
- real physical objects,
- virtual elements to be displayed,
- the interaction metaphor that links the real and virtual

Design patterns may be used …

(Billinghurst et al., 2015)

Research on Augmented Reality (2008-2017)

(Kim et al., 2018)



Previous topics (Zhou et al. 2008)

+ 4 emerging topics

Trends of ISMAR research topics within ISMAR 2008–2017

Needed Research on Augmented Reality

(Kim et al., 2018)

1) Tracking,

2) Rendering and Visualization,

3) Displays,

4) Applications,

5) Evaluation,

6) Rendering and Visualization

Needed Research on Augmented Reality

(Billinghurst, 2021)

1) Displays,

2) Interaction,

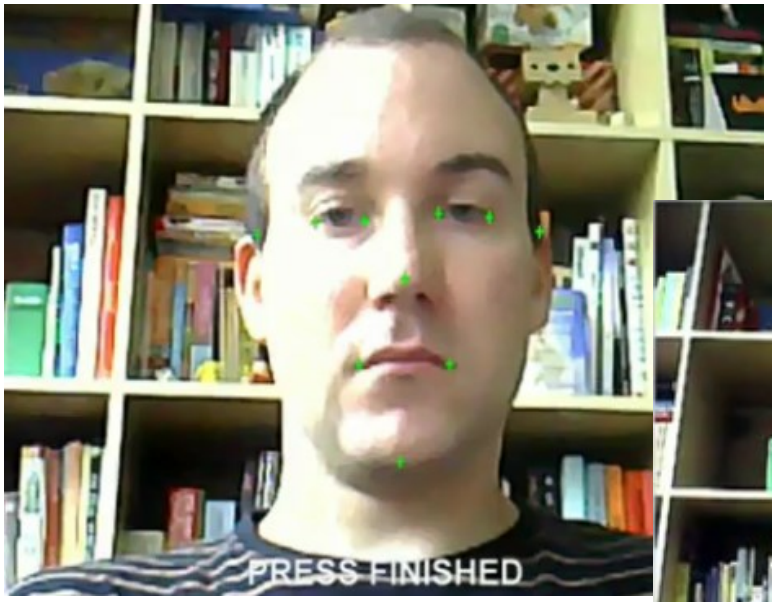
3) Tracking,

4) Collaboration,

5) Perception and Neuroscience,

6) Social and Ethical issues + Evaluation

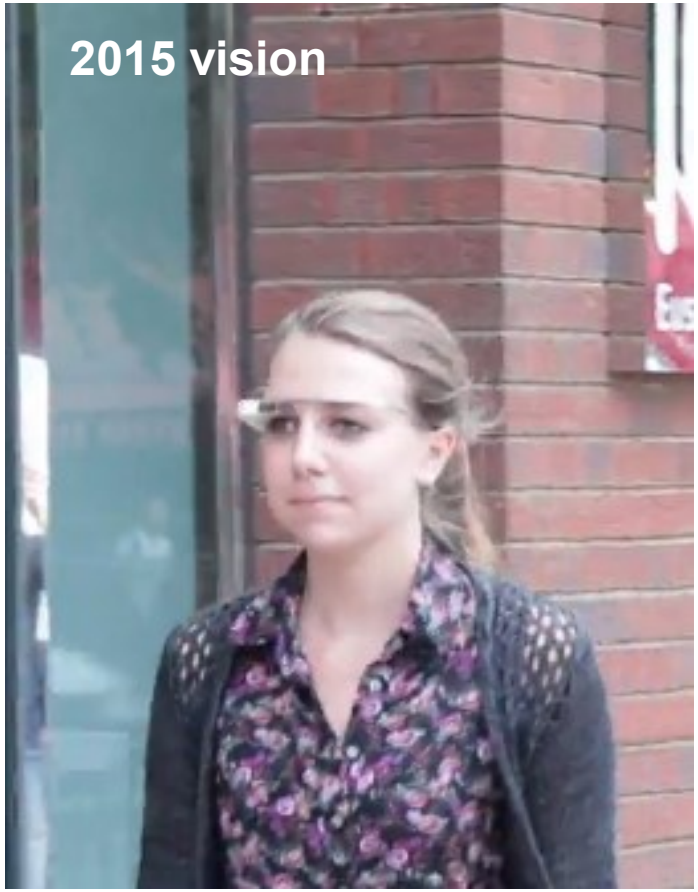
Past examples of AR



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

Google glass (2015)
Google Glass Enterprise Edition (2019)

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



http://www.wareable.com/google-glass/enterprise-edition-images-price-release-date-2092

https://edition.cnn.com/2019/05/20/tech/google-glass-enterprise-edition-2/index.html

Hololens

http://www.digitaltrends.com/virtual-reality/thyssen-krupp-hololens-partnership/

What future ? ?
Augmented reality is headed to the windshield …

… “the Retina-grade display of the automotive world,”

“devices work at three to four times the resolution of the human eye … to tens of thousands of candelas of brightness, which enables you to see this in the most extreme environments.”

https://www.digitaltrends.com/features/envisics-ar-windshield-technology/

To keep up with the latest developments: Conferences

- IEEE Virtual Reality (VR) (since 1993)
- ACM Symposium on Virtual Reality Software and Technology (VRST) (since 1994)
- Eurographics Workshop on Virtual Environments (since 1995)
- IEEE International Symposium on Mixed and Augmented Reality (ISMAR) (since 2002)
- IEEE World Haptics Conference (WHC) (since 2005)

- IEEE 3D User Interfaces (3DUI) (since 2006)
- IS&T/SPIE Electronic Imaging
- SIGGRAPH Emerging Technologies
- …
- http://www.wikicfp.com/cfp/call?conference=virtual%20reality

Bibliography – Books

- 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

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

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

References - papers

- - M. Billinghurst, “Grand Challenges for Augmented Reality,” Front. Virtual Real., vol. 2, March, pp. 1–4, 2021.
- - M. Billinghurst, A. Clark, and G. Lee, “A Survey of Augmented Reality,” Found. Trends Human-Computer Interact., vol. 8, no. 2, pp. 73–272, 2015.
- - P. Milgram, F. Kishino, “A Taxonomy of Mixed Reality Visual Displays”, IEICE Transactions on Information Systems, E77-D, no. 12, pp. 1321–1329, 1994.
- - K. Kim, M. Billinghurst, G. Bruder, H. Duh, and G. Welch, “Revisiting Trends in Augmented Reality Research: A Review of the 2nd Decade of ISMAR (2008–2017),” IEEE Trans. Vis. Comp. Graph., vol. 24, no. 11, pp. 2947–2962, 2018.
- - M. Speicher, B. D. Hall, and M. Nebeling, “What is Mixed Reality ?,” CHI ’19 Proc. SIGCHI Conf. Hum. Factors Comput. Syst., 2019.
- - F. Zhou, H. B. L. Duh, and M. Billinghurst, “Trends in augmented reality tracking, interaction and display: A review of ten years of ISMAR”, 7th IEEE Int. Symp. on Mixed and Augmented Reality, pp. 193–202, 2008
- .