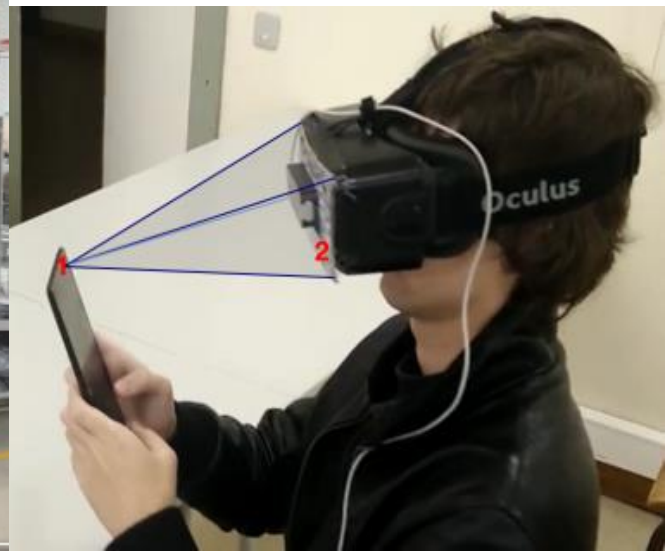
Universidade de Aveiro
Departamento de Electrónica,
Telecomunicações e Informática

An Introduction to Extended Reality



Virtual and Augmented Reality 2023

Beatriz Sousa Santos

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

(starting by VR, but also addressing AR…)

Extended Reality (an umbrella term)

Several “Realities”;

Not stable terminology…

- Virtual Reality
- Augmented Reality
- Mixed Reality
- Altered Reality
- …

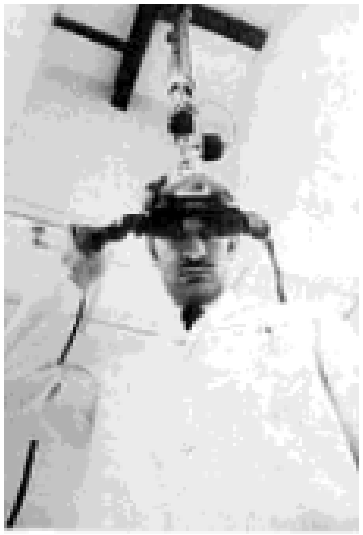
Rick Skarbez, R., Smith, M., Mary Whitton, M., “It Is Time to Let Go of 'Virtual Reality’”. *Communications of the ACM,* vol 66, n. 10, pp. 41–43, 2023. https://doi.org/10.1145/3590959

These ideas are not new:
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?

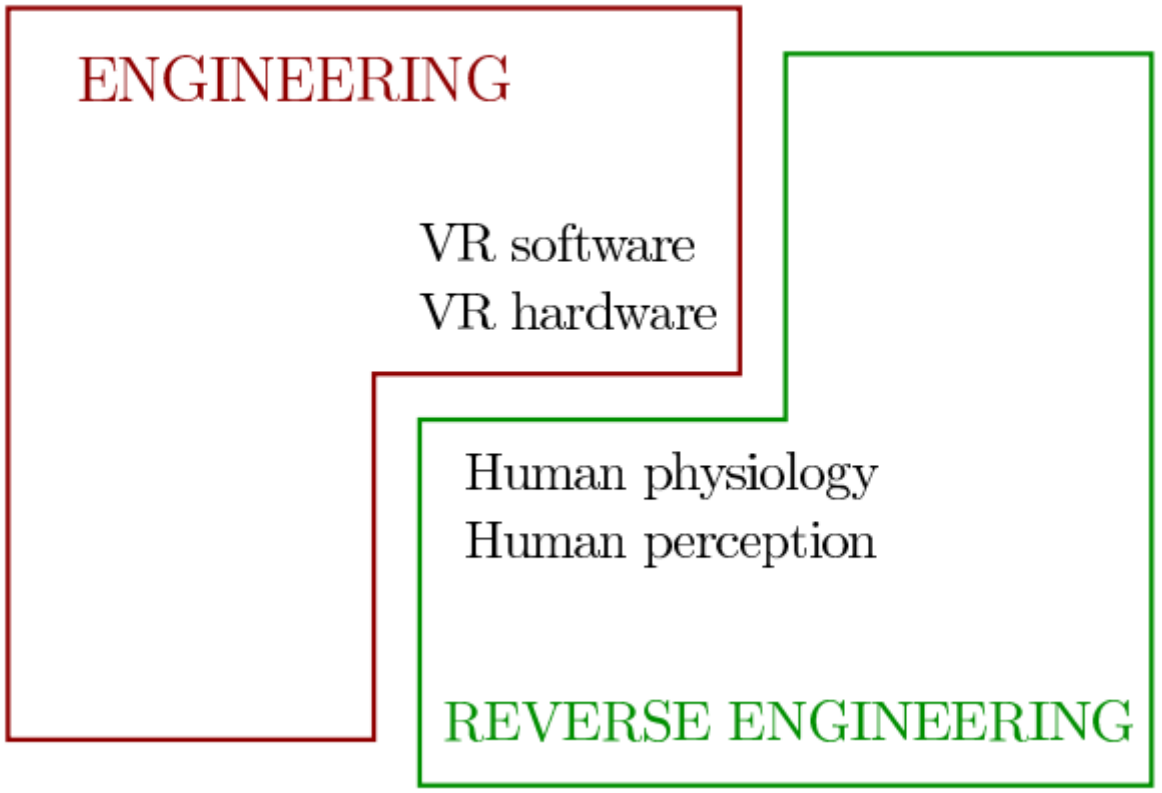
"For better or worse, the label *virtual reality* stuck to this particular branch of computer graphics.

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)

Two important parts of VR:

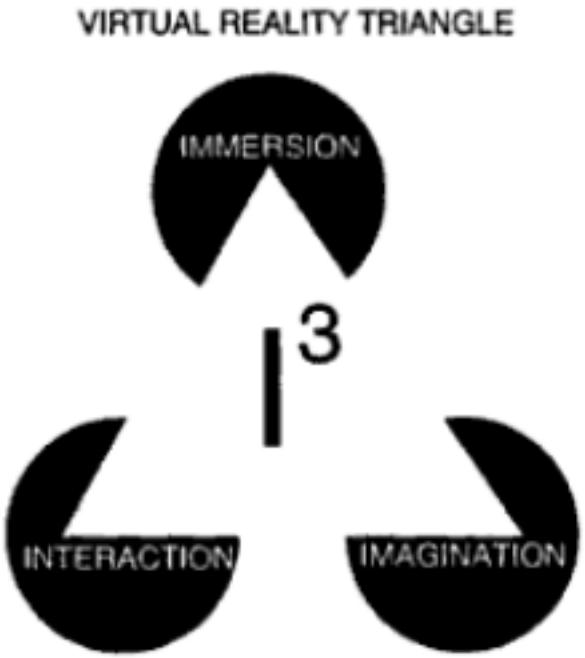


(Lavalle, 2020)

The Virtual Reality Triangle

VR is:

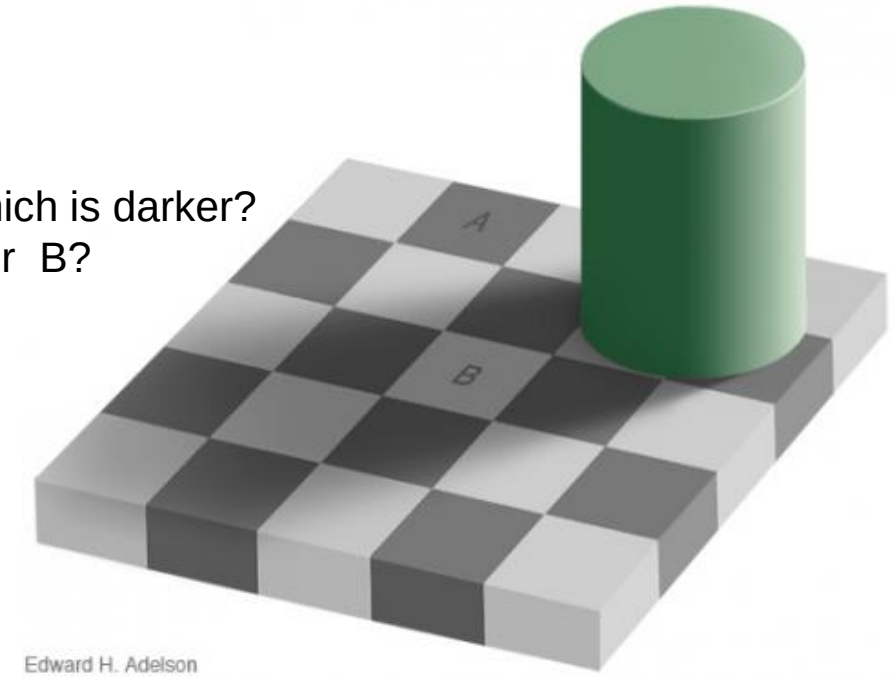
- Immersion
- Interaction
- Imagination
  (to perceive non existing things)

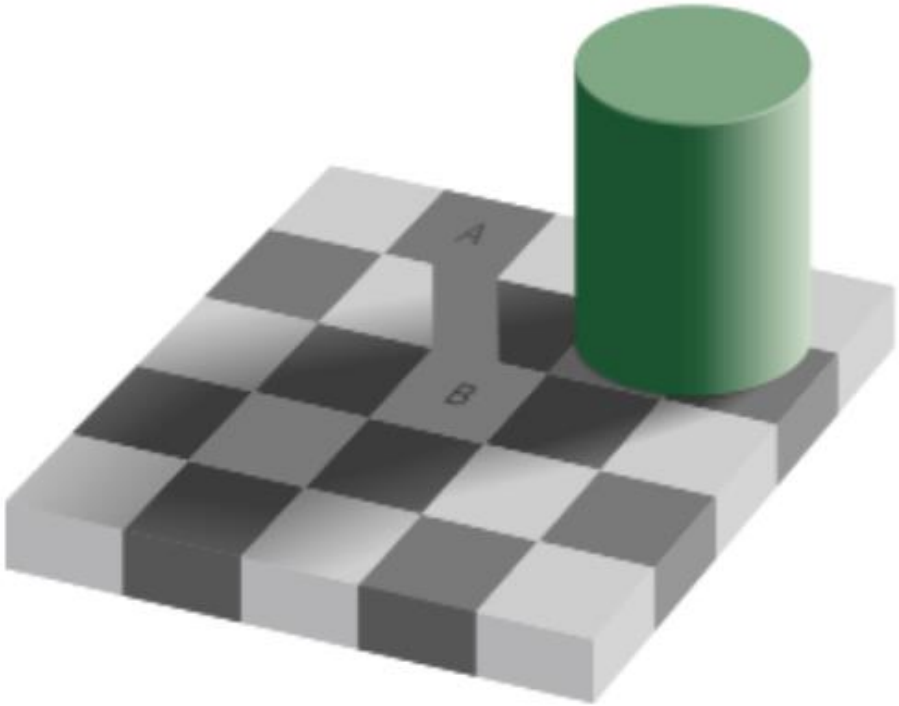


(Burdea et al., 2003)

What we see is more than meets the eye…

Which is darker?
A or B?

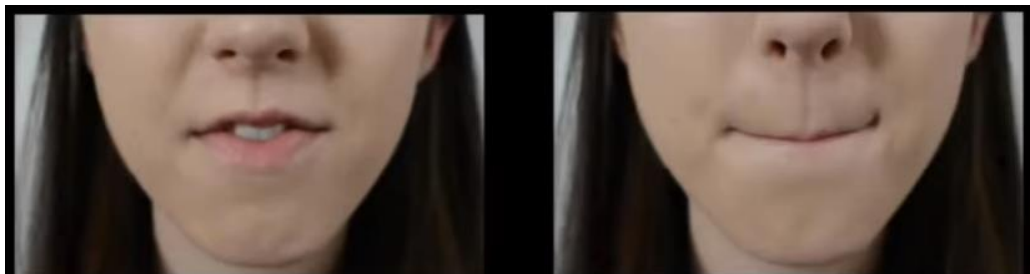




Virtual reality, explained with some illusions:

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

and the ear …

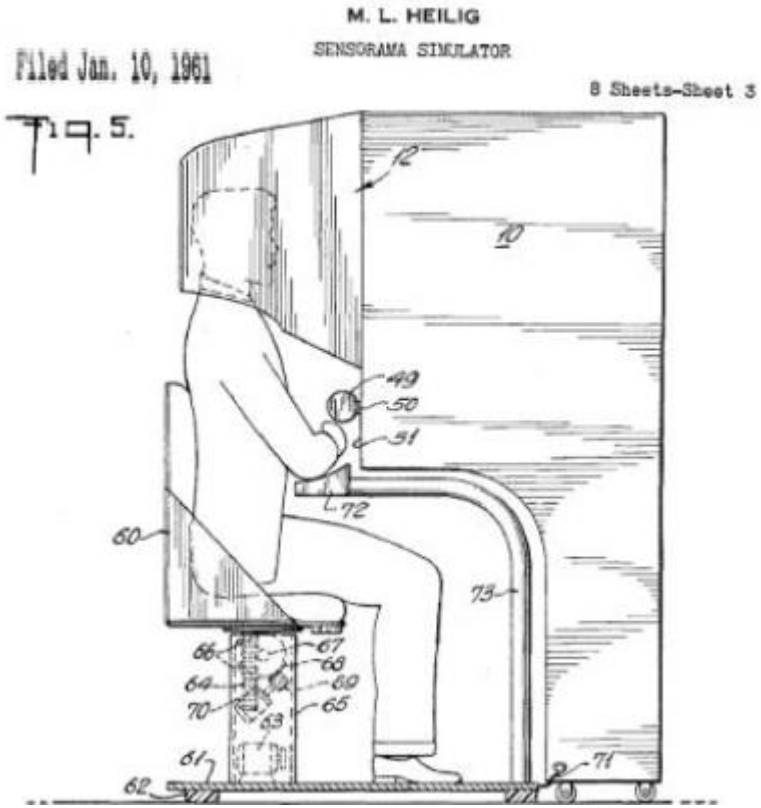


Historical perspective

Sensorama

(Morton Heilig, 1962)

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



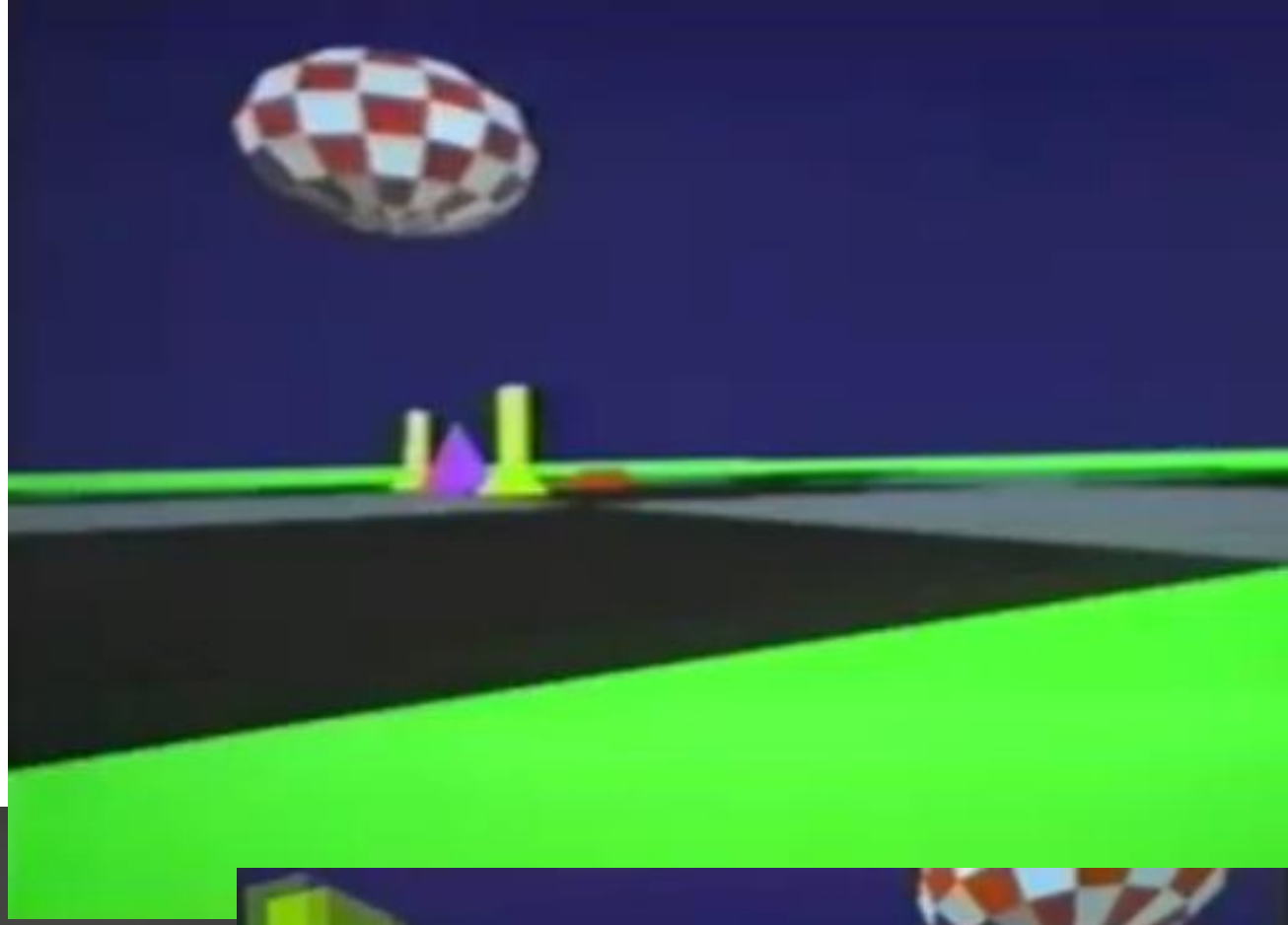
http://en.wikipedia.org/wiki/Sensorama

NASA was pioneer:

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

VIEW - “Virtual Interface Environment Workstation” (1989)

Early VR Demo
by Sense8
(1988)



Early VR Games in the 90's

https://www.youtube.com/watch?v=dji9YiPZ4AM

VR was already much used in the early 2000s:

- Industry
- Medicine
- Culture
- …

But it was very expensive!

What seemed to be the Market Opportunity for Augmented Reality (AR) and Virtual Reality (VR) – 2019
Immersive Experiences at affordable prices

https://www.youtube.com/watch?v=mSWo_CQ2NRM

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 …)
- Data visualization (e.g. science, oil industry)
- Culture, entertainment (museums, games, …)
- Sales and marketing
- …

Virtual Reality in practice - education and training

Google Expeditions: over a million students went on trips to virtually anywhere

https://www.youtube.com/watch?v=JTJSu5H6eGA
https://www.youtube.com/watch?v=3MQ9yG_QfDA

Public speaking anxiety decreases within repeated VR sessions

Tarak, M. et al., “Public speaking anxiety decreases within repeated virtual reality training sessions. PLoS ONE 14(5): e0216288, 2019
https://doi.org/10.1371/journal.pone.0216288

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
Possible high Cost

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

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 time and costs
Fosters innovation …

Design at McLaren

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

Automotive industry: other examples

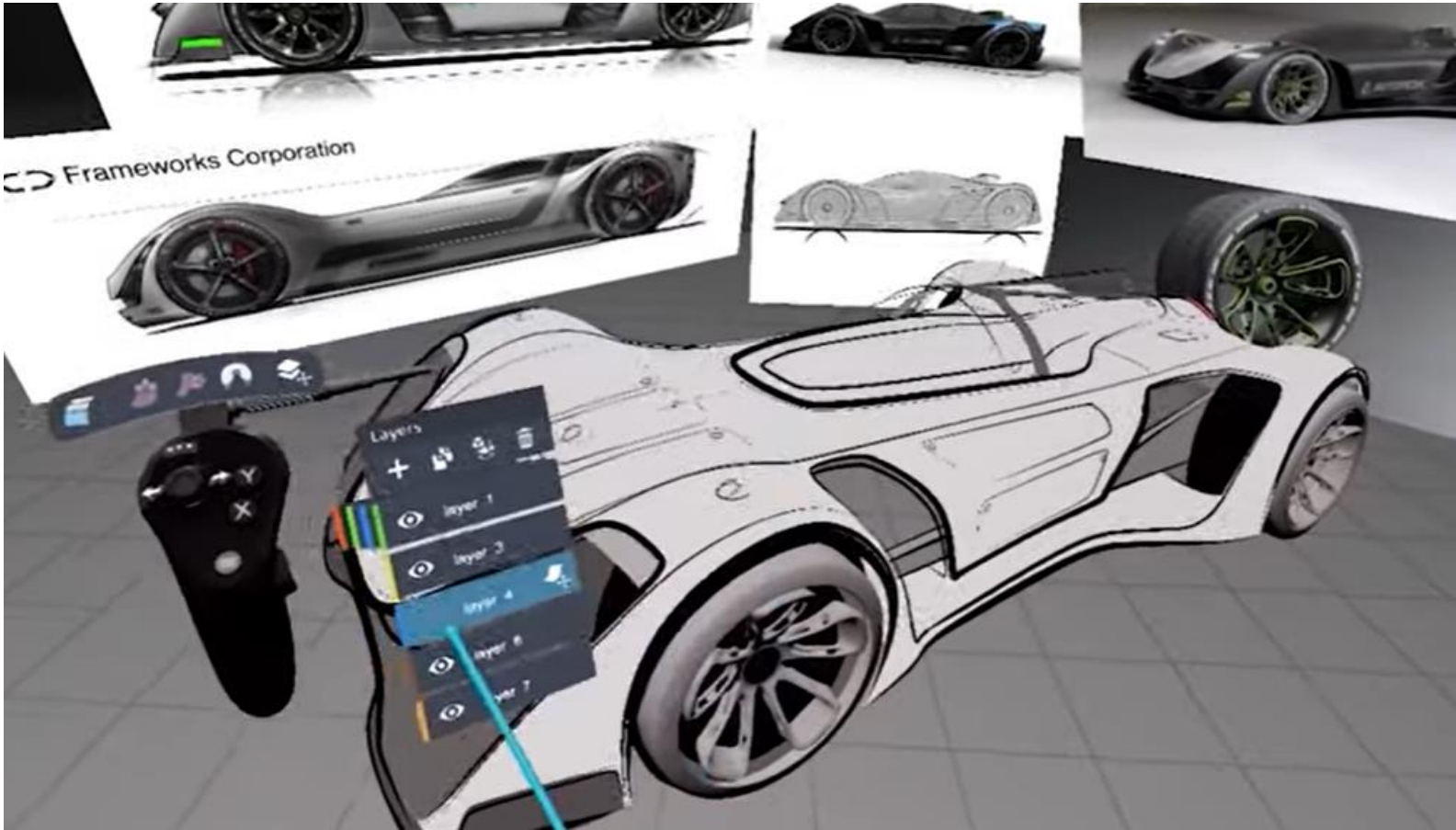
- VR makes possible to:
  - multiply the number of innovative hypotheses studied
  - limit the number of physical mock-ups
  - allow easy collaboration among worldwide located teams
  - cut development time and cost

New models can be analysed even before any physical prototype exists
https://www.youtube.com/watch?v=Xh_Cx_NUO88
https://www.youtube.com/watch?v=pmBuAWQnliM

Automotive industry: other examples

- CAD software adapted to VR: Autodesk Alias

https://www.youtube.com/watch?v=1GfQXG2etTY



A success case for many years at Caterpillar

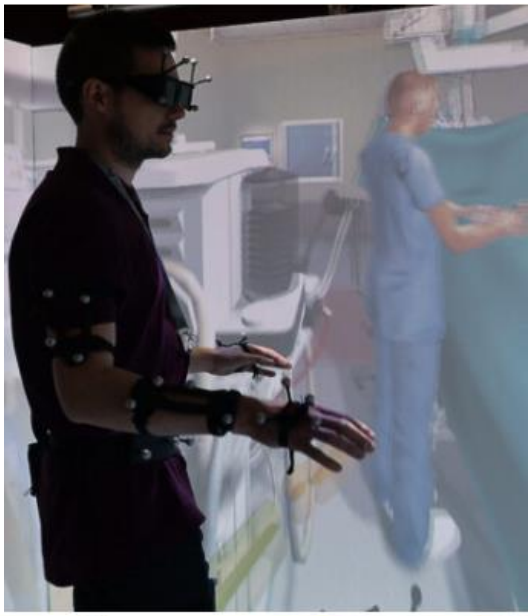
One of the first companies using VR, long ago

Examples:
2016 - Design review
2019 - Training in mining

https://www.youtube.com/watch?v=_438aolqxEA

https://www.youtube.com/watch?v=r9N1w8PmD1E

Virtual Reality in practice
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

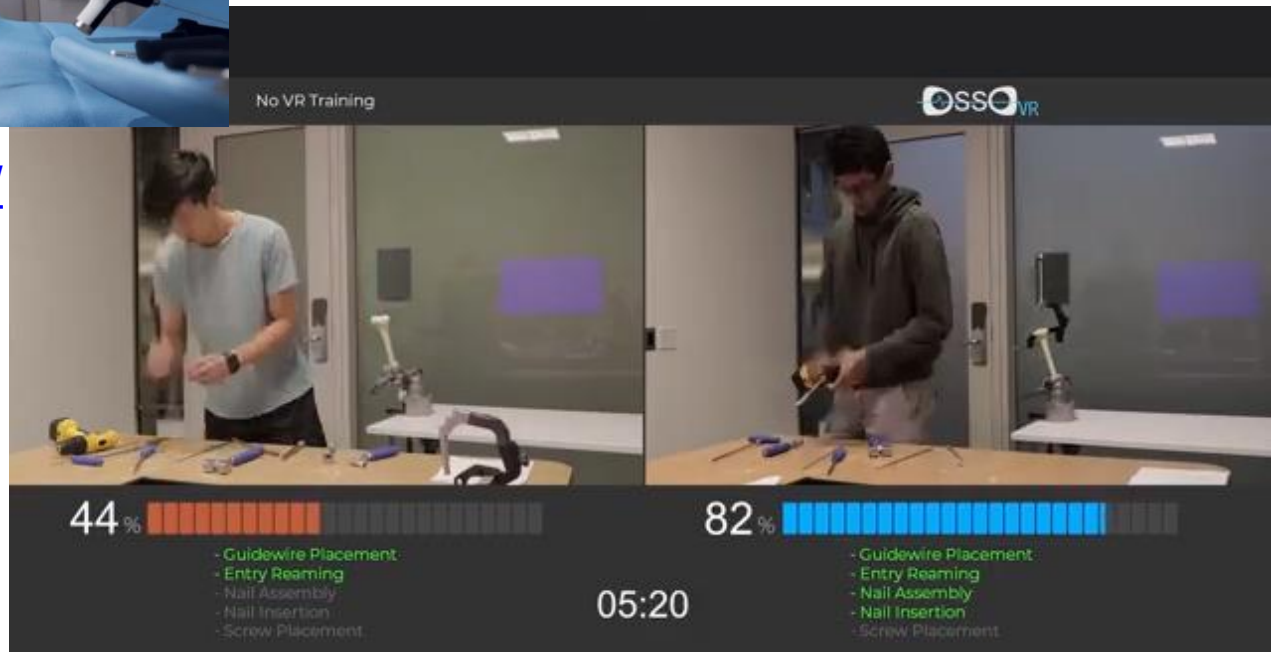
Combining imaging from MRIs, CT scans and angiograms to create a three-dimensional model that physicians and patients can see and manipulate — just like a virtual reality game – Stanford Medicine

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



https://www.healthcareitnews.com/news/how-virtual-reality-turning-surgical-training-upside-down

Dentistry training

Stereoscopic display + glasses

Interaction devices:

- two force feedback devices
- foot pedal

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

Pain control

VR has been used to help:

- distract during painful procedures
(e.g. severe burn victims)

- control chronic pain
(e.g. back pain)

…

https://heal.nih.gov/news/stories/virtual-reality

https://www.stanfordchildrens.org/en/about/news/releases/2017/virtual-reality-alleviates-pain-anxiety

Viderman, D., et al., “Virtual reality for pain management: an umbrella review,” *Frontiers in Medicine,* vol. 10, no. July, 2023
https://www.frontiersin.org/articles/10.3389/fmed.2023.1203670/full

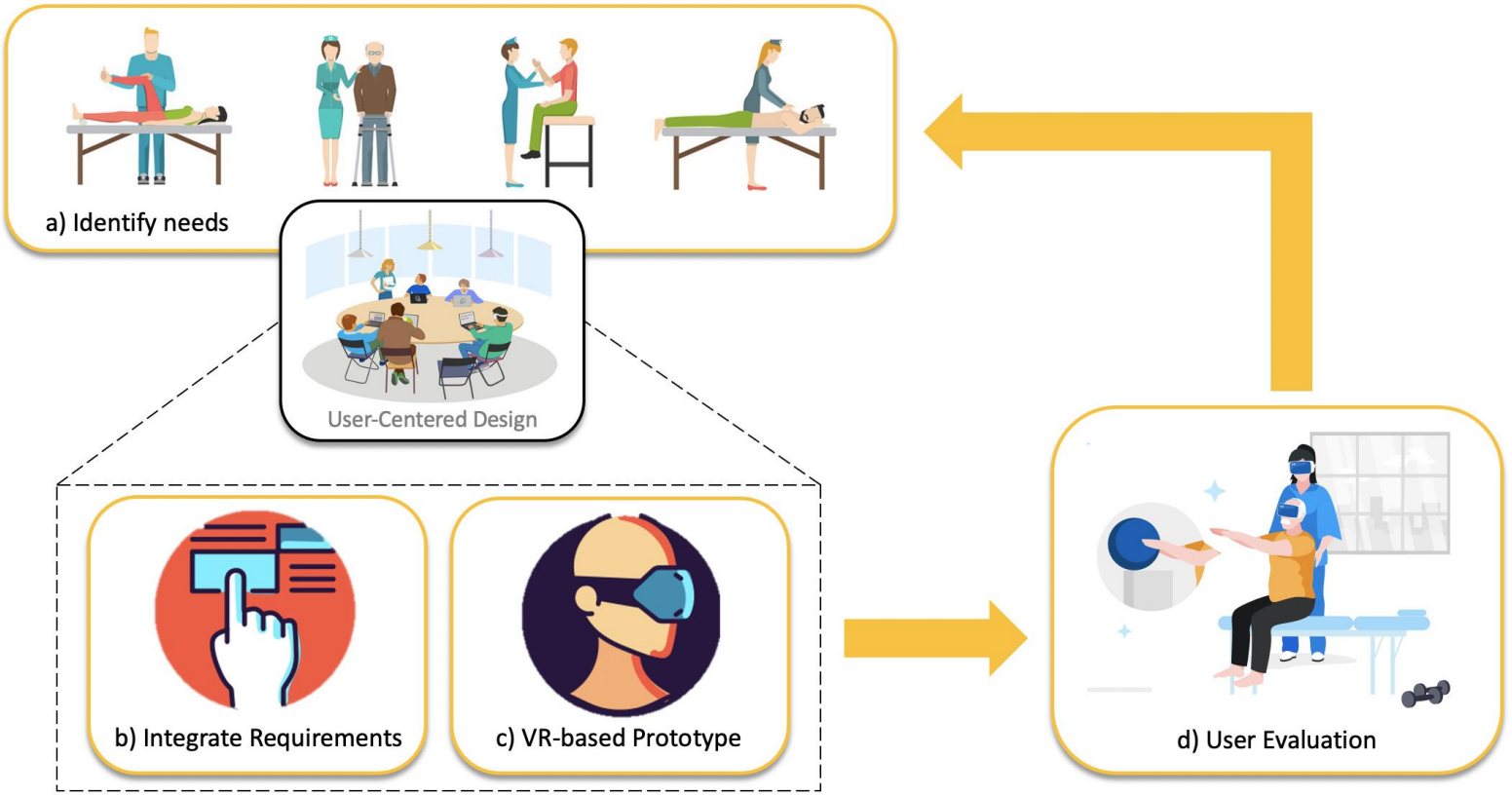
Physical Rehabilitation: an early example

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

DETI/IEETA – VARLab latest work

VR for Stroke rehabilitation

VR for Stroke rehabilitation: Human-Centered Design methodology



Amorim, P., et al., "Chronic stroke survivors' perspective on the use of serious games to motivate upper limb rehabilitation – a qualitative study", *Health Informatics Journal, vol.* 29, n. 2, 2023.
https://journals.sagepub.com/doi/full/10.1177/14604582231171932

Mini-games to help recover arm movement for Stroke patients

DETI/IEETA +
Centro Rovisco Pais

Dias, P., *et al*., "Using Virtual Reality to Increase Motivation in Poststroke Rehabilitation", *IEEE Computer Graphics and Applications,* vol.39, no.1, pp. 65-70, 2019
https://ieeexplore.ieee.org/document/8663653

Mini-games to help recover arm movement for Stroke patients: 2nd version (based on Oculus Quest)

Serra, H. *et at*., "Whac-A-Mole: Exploring Virtual Reality (VR) for Upper-Limb Post-Stroke Physical Rehabilitation based on Participatory Design and Serious Games", *IEEE VR3DUI (VRW)*, pp. 716-717, 2022. https://ieeexplore.ieee.org/document/9757547

VR for Stroke Rehabilitation: serious game to increase therapy adherence simulating a daily activity already used in therapy

Types of immersion

- Semi-immersive VR
- Fully-immersive VR

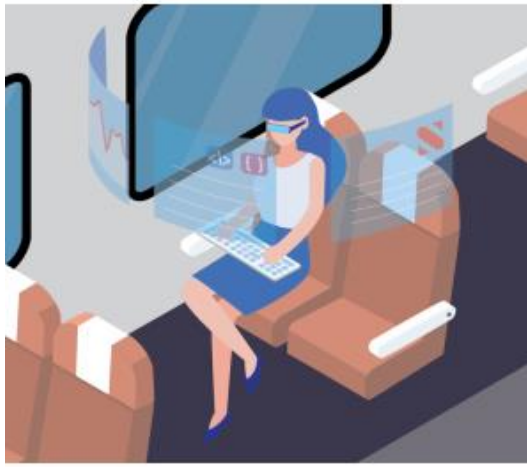
https://sky-real.com/news/the-vr-cave-halfway-between-reality-and-virtuality/

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 desktop information clutter and increase the environment comprehensibility (increased FOV, FOR, and display resolution)



L. Pavanatto, *et al.,* "Do we still need physical monitors? An evaluation of the usability of AR virtual monitors for productivity work," *2021 IEEE Virtual Reality and 3D User Interfaces (VR)*, 2021, pp. 759-767, 2021. https://ieeexplore.ieee.org/document/9417776

Presence

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

- It is difficult to describe;

it is an psychological state

You're somewhere else now

- Is a function of the user and the immersion; 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

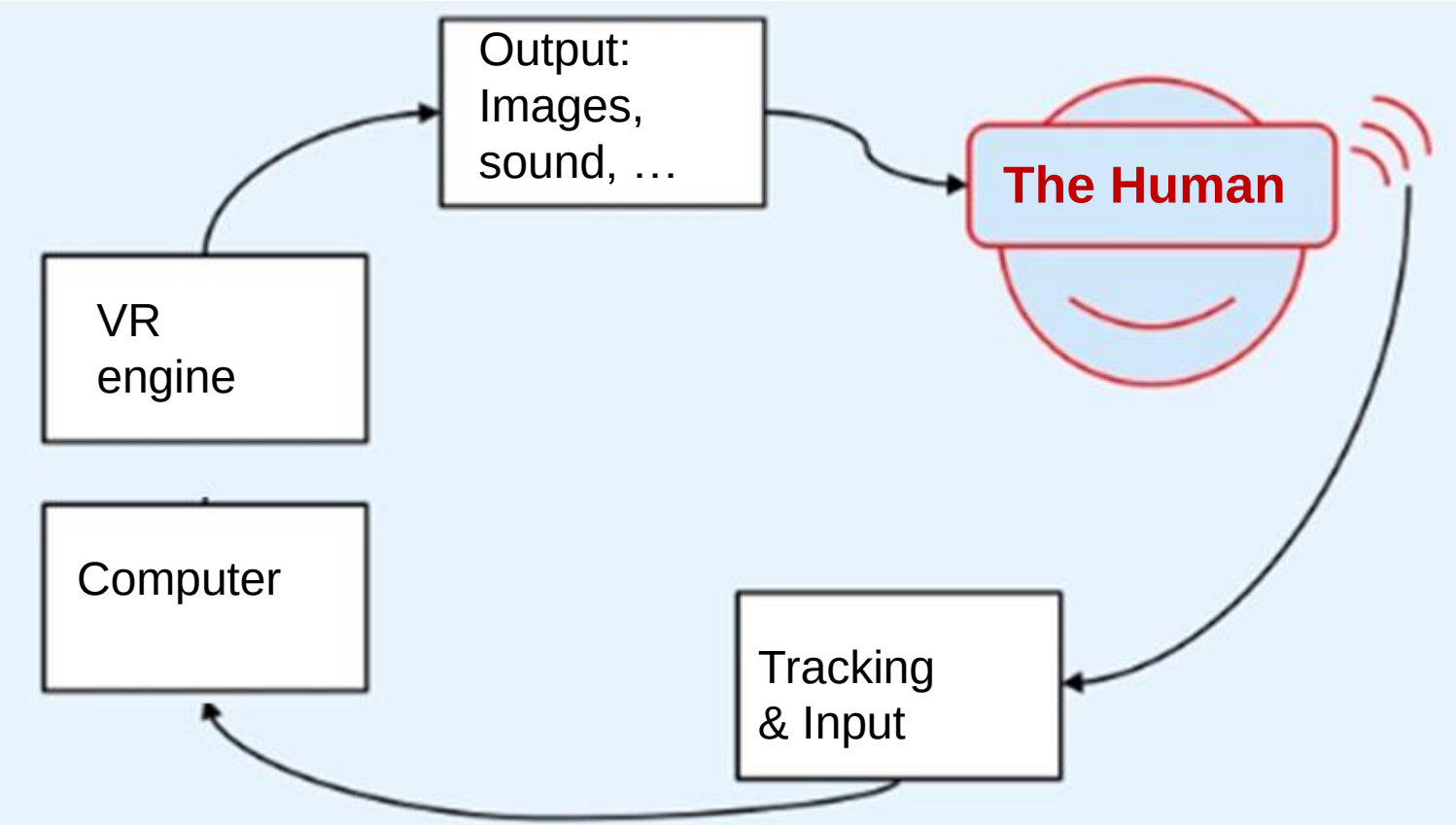
There are several **questionnaires** to measure presence

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.
https://dl.acm.org/doi/10.1145/3290605.3300590

What do we need to have a VR experience?



+ a **properly developed application**!

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

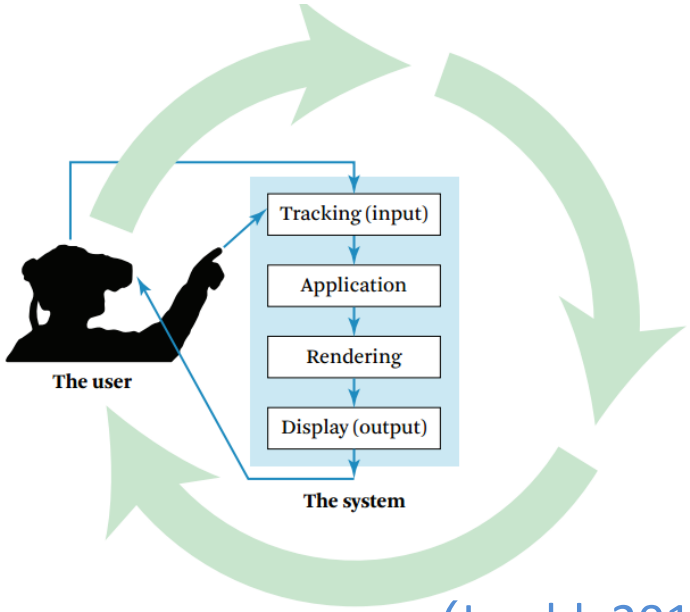
- **Interaction devices** allowing users to interact with virtual objects
- **Interaction techniques** that substitute for the real interactions possible with the physical world
- **Display of synthesized sound** including directional sound and simulated sound fields

(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)



(Jerald, 2016)

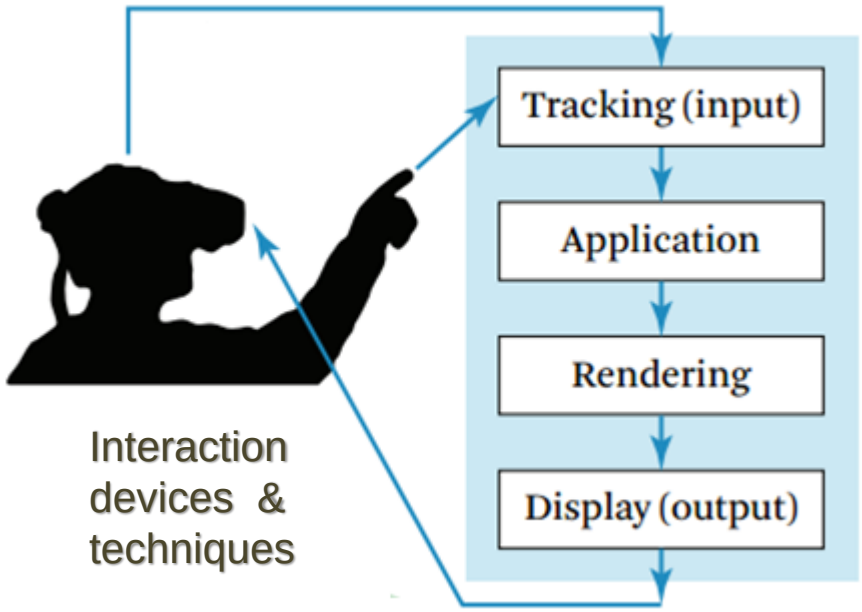
Input devices

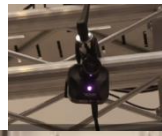
- Trackers:
  - Mechanical
  - Magnetic (AC, DC)
  - Optical
  - Ultrasonic
  - Inertial
  - Hybrid

- Navigation and manipulation interfaces:
  - Tracker-based
  - Controllers...
  - …

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

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





- Navigation and manipulation devices:
  - Tracker-based
  - Controllers
  - Cameras, ...

- Gesture interfaces:
  - Gloves
  - …

https://www.senseglove.com/
http://www.cyberglovesystems.com/
https://www.youtube.com/@senseglove4021
https://www.youtube.com/watch?v=EXqQlQmcGlY

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
    (mice, gloves, ...)
  - Force feedback interfaces
    (force-feedback joysticks, haptic arms, ...)

Graphics Displays

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

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

Oculus Rift
2014; ~300 USD

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

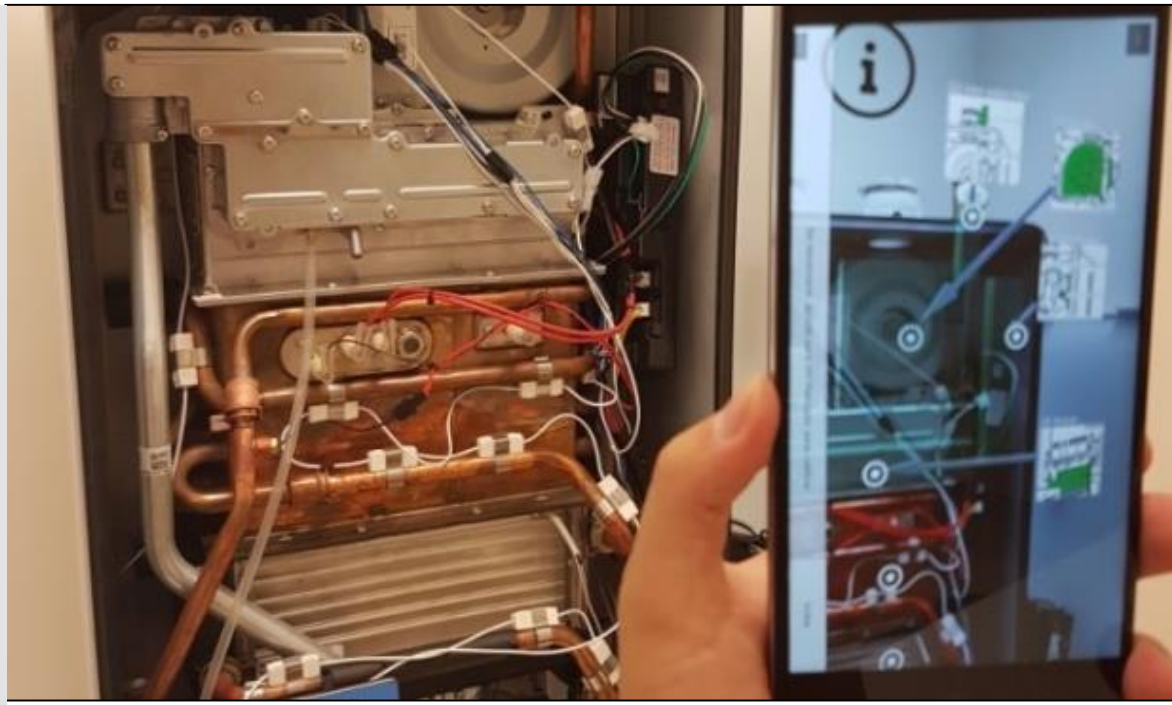
Made VR economically viable in many more situations!!

Was widely used in research and many applications

Best VR headset 2023?
https://www.youtube.com/watch?v=9SFddaeRDmA

AR- Several types of displays

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



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, to 120Hz
- Internal cameras
- Qualcomm Snapdragon XR2
- 128GB.
- Lithium-ion battery with 2-3 hours playtime, depending on what is played
- 6 DOF head and hand tracking.
- Two touch controllers.
- ~300USD – Sep/2023

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

HMD for professional purposes

~9000 USD

https://vrgineers.com/xtal/
https://www.xtal.pro/product/xtal-3-vr

HMD for professional purposes

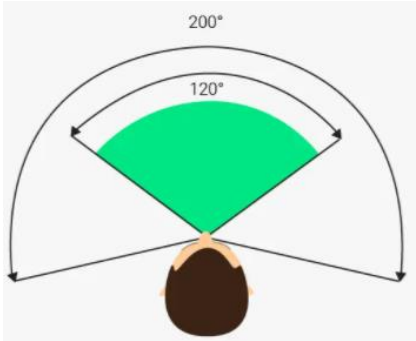
RESOLUTION	3840×2160 per eye
DISPLAYS	Two fast-switching 4K LCD displays for virtual reality
REFRESH RATE	75 Hz @ 4K per eye, 120 Hz @ QHD per eye
FIELD OF VIEW	180° horizontal, 120° vertical (maximum experimental values) 140° horizontal, 90° vertical (default values)
ADVANCED FEATURES	Foveated Rendering, Timewarp
EYE TRACKING	Gaze analyses, heatmap visualization, running native 120 Hz (up to 210 Hz)
POSITIONAL TRACKING	Lighthouse (SteamVR)/ART/Optitrack/Polhemus/Vicon or custom
HAND TRACKING	embedded Ultraleap sensor
IPD	Auto IPD – range 56-74 mm
HEADSET CONNECTIVITY	VirtualLink (5m / 16.40 ft) cable or DisplayPort 1.4 , USB 3.2 gen 2, Power 12V, 3A (5m / 16.40 ft)

https://vrgineers.com/xtal/
https://www.xtal.pro/product/xtal-3-vr

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 systems)

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

  - wide, surrounding field of view
  - shared experience to a small group

  - cost of multiple image-generation
  - space requirements
  - brightness limitations
  - corner and edge effects

http://www.antycipsimulation.com/
VR Collaboration | ST Engineering Antycip (steantycip.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 ->

Using binaural sound …

wear your headphones!!

The turning forest
Virtual reality Binaural sound demo - BBC Click
https://www.youtube.com/watch?v=51za5u3LtEc

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=EHJBZzeubAI

ISMAR2021 keynote: "Wearable Haptics for Virtual and Augmented Reality"

Haptic devices

- Tactile feedback interfaces
  (mice, gloves, ...)

The new SenseGlove Nova 2 | SenseGlove

- Force feedback interfaces
  (force-feedback joysticks, CyberGrasp...)

- Vests…

https://www.cnet.com/tech/computing/haptic-gloves-for-quest-2-are-a-small-step-towards-vr-you-can-touch/

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

Haptic PIVOT, an on-demand controller, simulates physical forces such as momentum and gravity

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. *https://doi.org/10.1145/3379337.3415854*

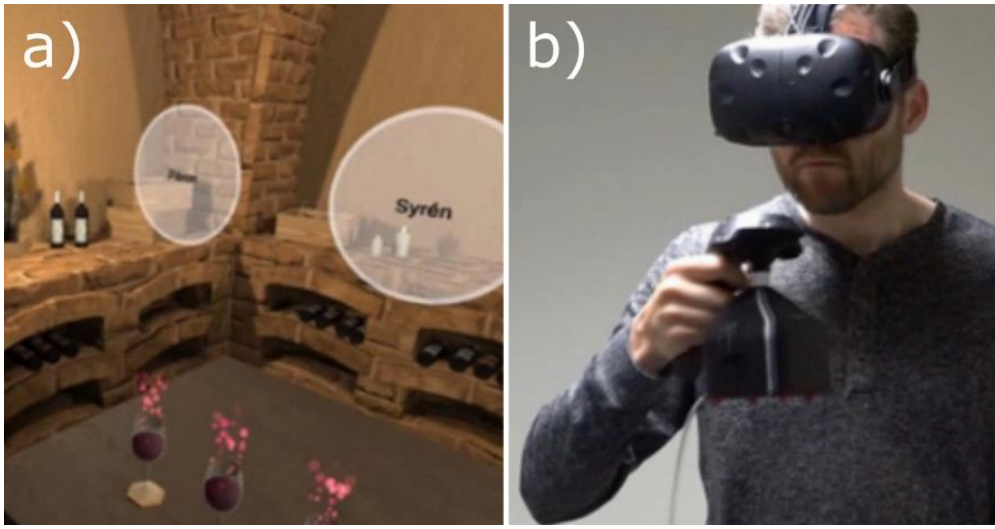
https://www.microsoft.com/en-us/research/blog/physics-matters-haptic-pivot-an-on-demand-controller-simulates-physical-forces-such-as-momentum-and-gravity/?OCID=msr_blog_pivot_uist_tw

Displays for other senses

Research on smell has years

Some startups are working on devices

But olfactory stimuli are difficult …



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

Taste is even more difficult and “invasive” …

Displays for other senses

"What we wanted to do was, as accurately as possible, recreate how we experience smell in the real world in the virtual world,"

https://www.wbur.org/news/2022/03/14/virtual-reality-smell-ovr-technology

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**
- Needs to be **more usable**
- It still has **human factors challenges and ethical, societal**
- It may suffer from **cybersecurity and privacy issues …**

Virtual vs Augmented Reality

- VR **replaces** reality

- AR **enhances** reality

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

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 …

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.
https://dl.acm.org/doi/10.1145/3290605.3300767

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

Specific HMDs

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

Recent umbrella term - **Extended Reality (XR)**

What is Mixed Reality?

(Speicher, et al., 2019)

- Interviews with ten AR/VR experts from academia and industry
- Survey of 68 papers

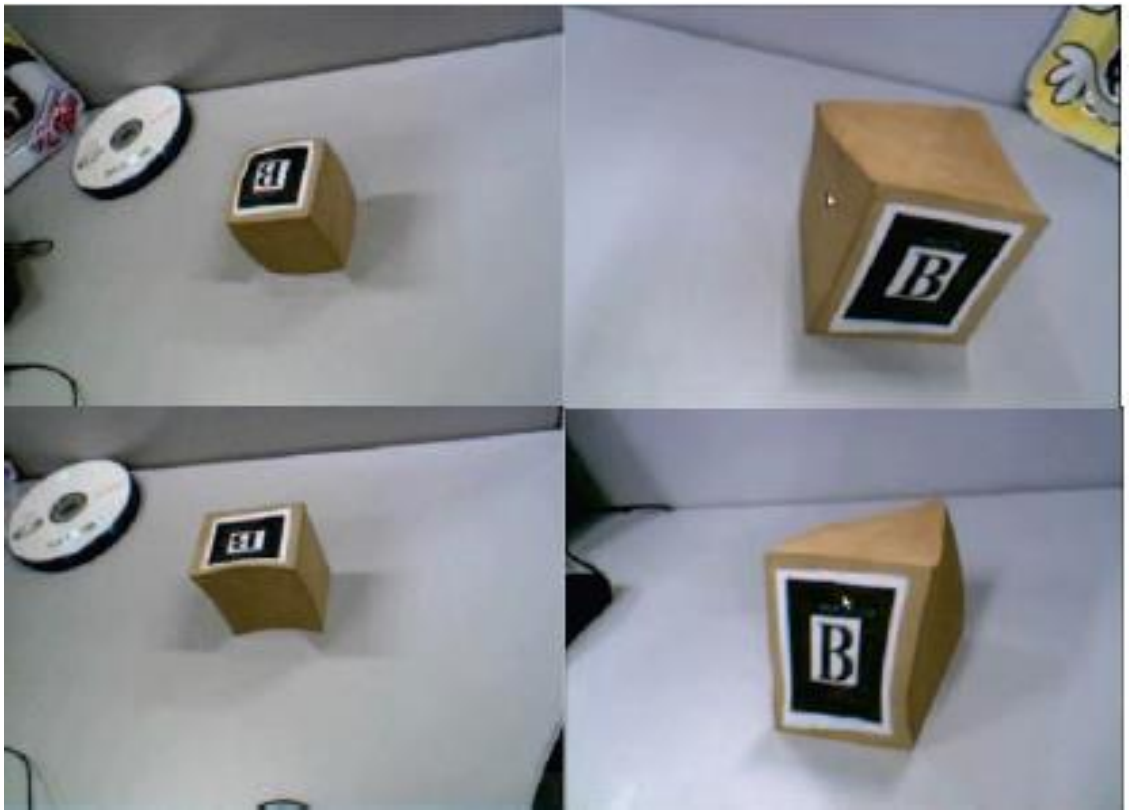
- Six partially competing notions

- Model with 7 aspects:
  number of environments and users,
  level of immersion and virtuality,
  degree of interaction,
  input, and output

Yet Other Realities: Altered Reality
(Augmented + Diminished)

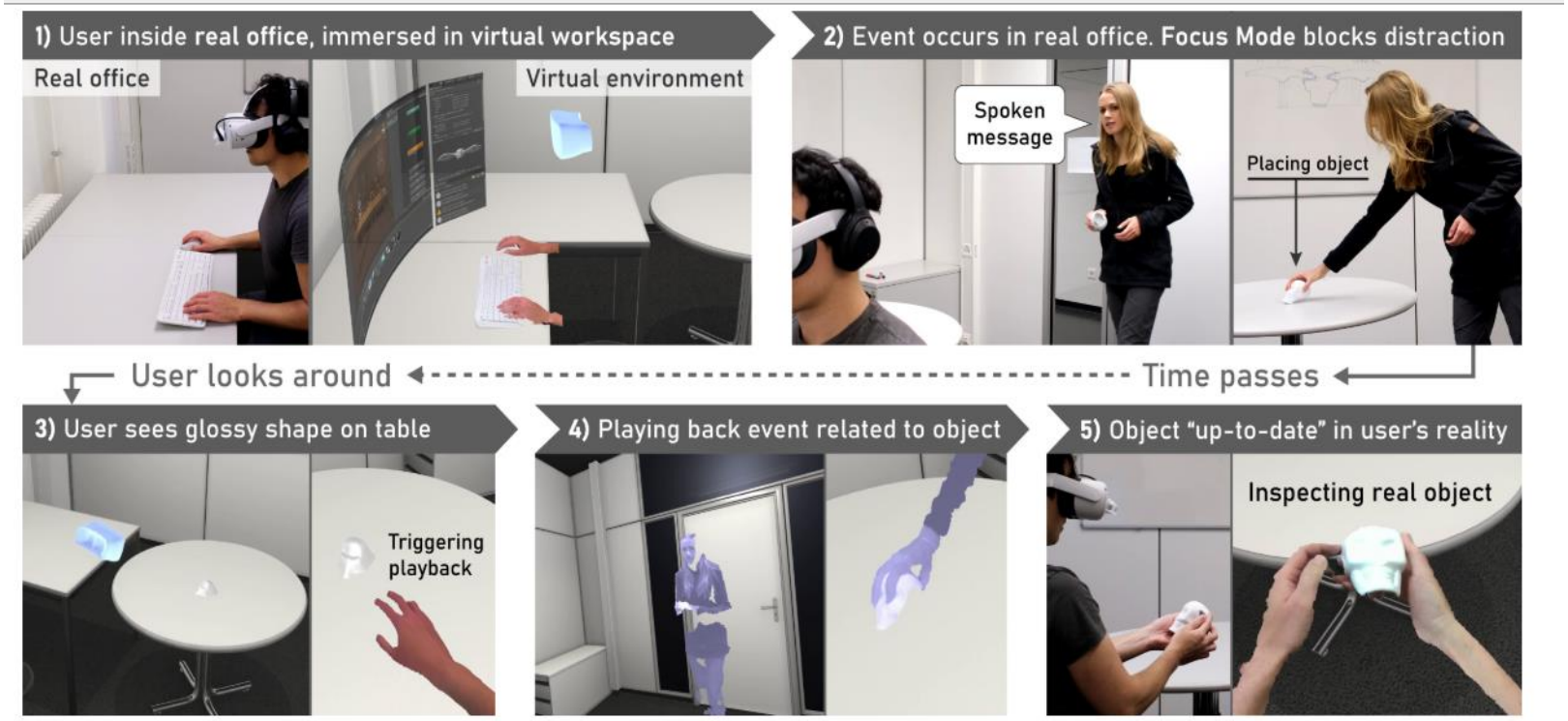
Leao, C., el al., "Demo — Altered reality: Augmenting and diminishing reality in real time," *IEEE Virtual Reality Conference, 2011,* pp.259-260

https://ieeexplore.ieee.org/document/5759497



Yet Other Realities: Asynchronous Reality

A. R. Fender and C. Holz, “Causality-preserving Asynchronous Reality,” *CHI 22 Conf. Hum. Factors Comput. Syst. - Proc.*, 2022
https://dl.acm.org/doi/10.1145/3491102.3501836



Relevant issues in AR

- Registration
- Displays
- Latency
- Calibration
- Interaction
- Human factors
- Security and privacy…
- Ethics …

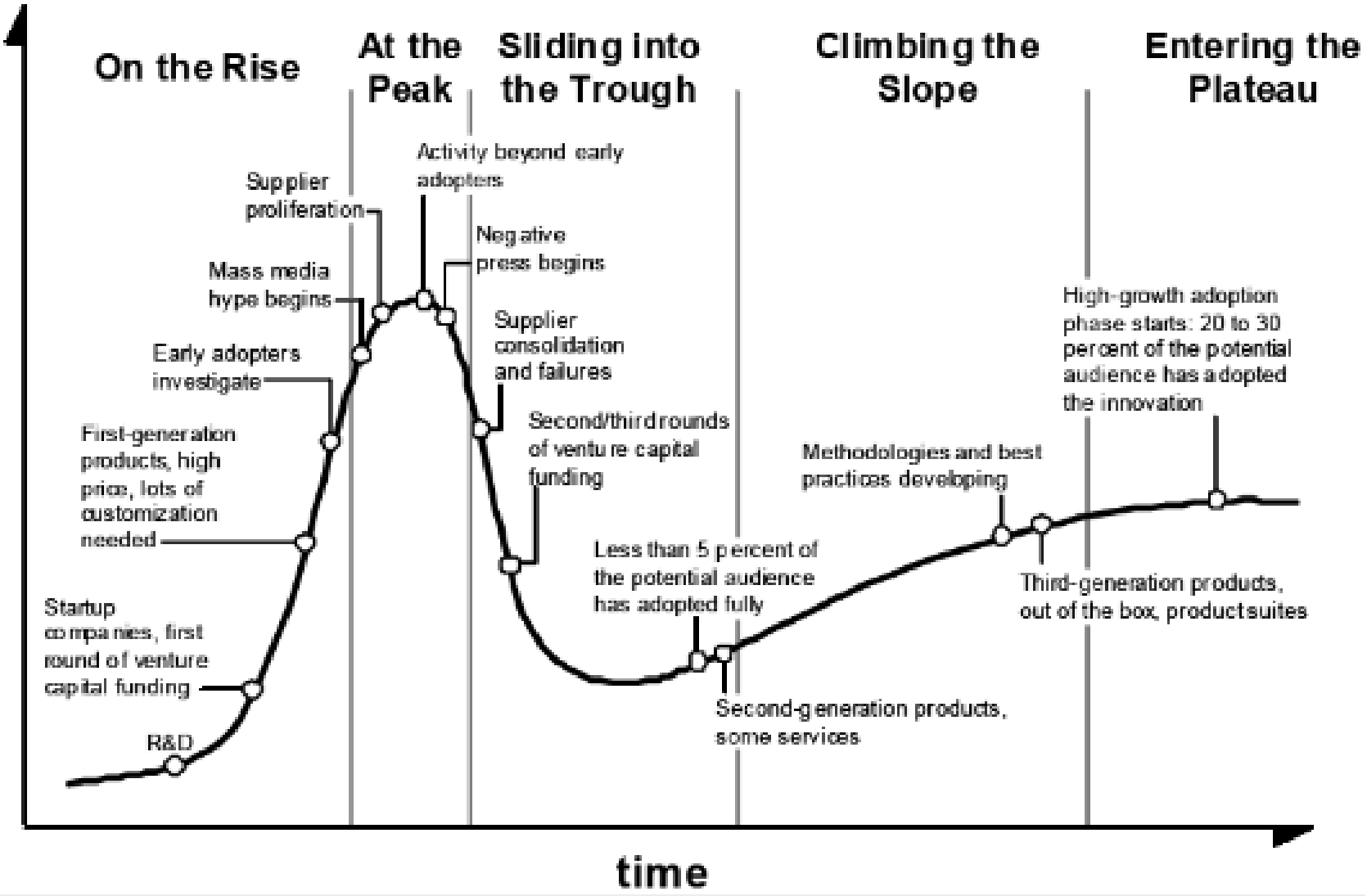
The Industry perspective

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

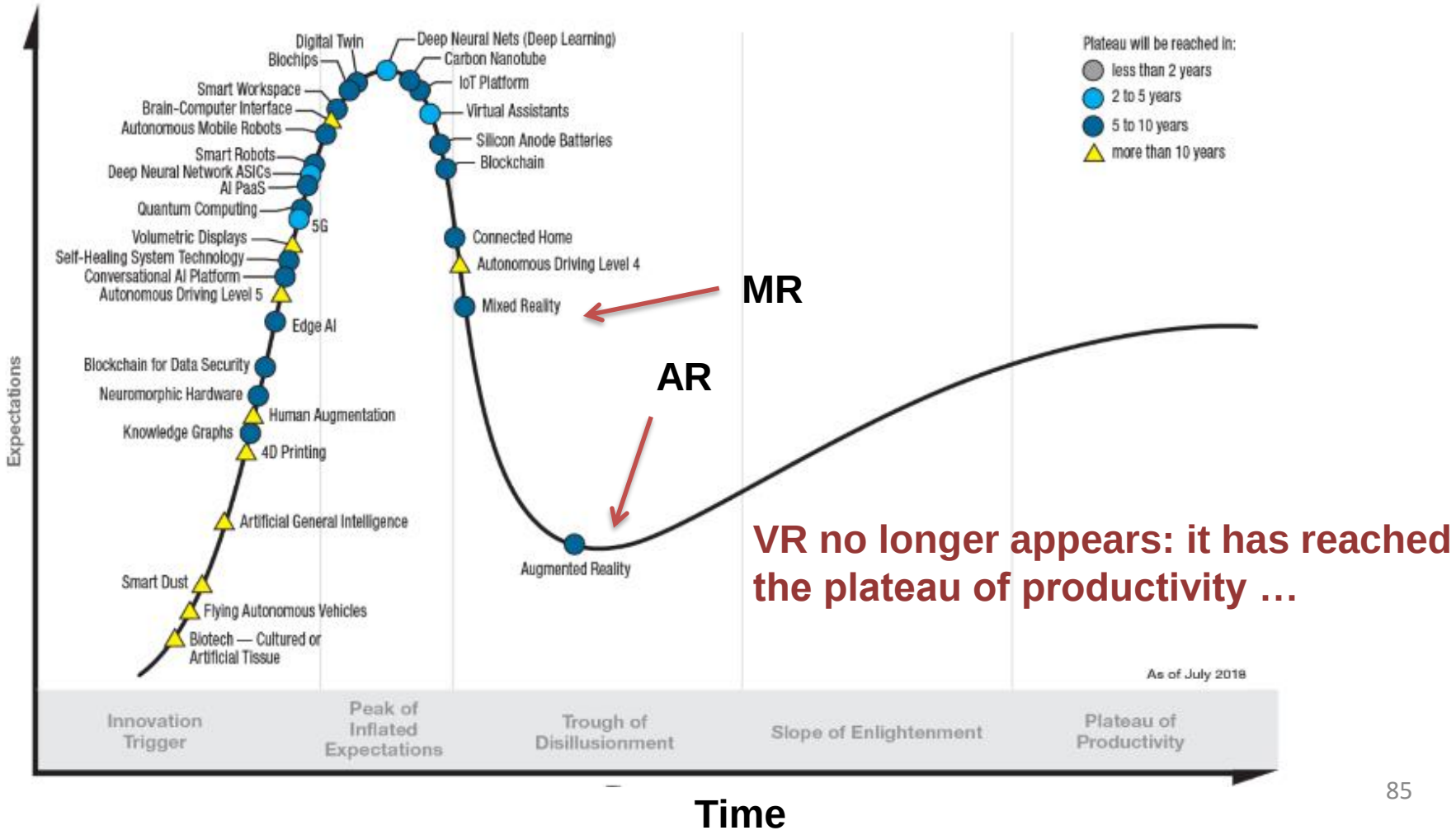
https://www.gartner.com/smarterwithgartner/5-trends-appear-on-the-gartner-hype-cycle-for-emerging-technologies-2019/
https://www.gartner.com/en/articles/what-s-new-in-the-2022-gartner-hype-cycle-for-emerging-technologies

Gartner's Hype Cycle



Gartner's Hype cycle - AR Last appearance

2018

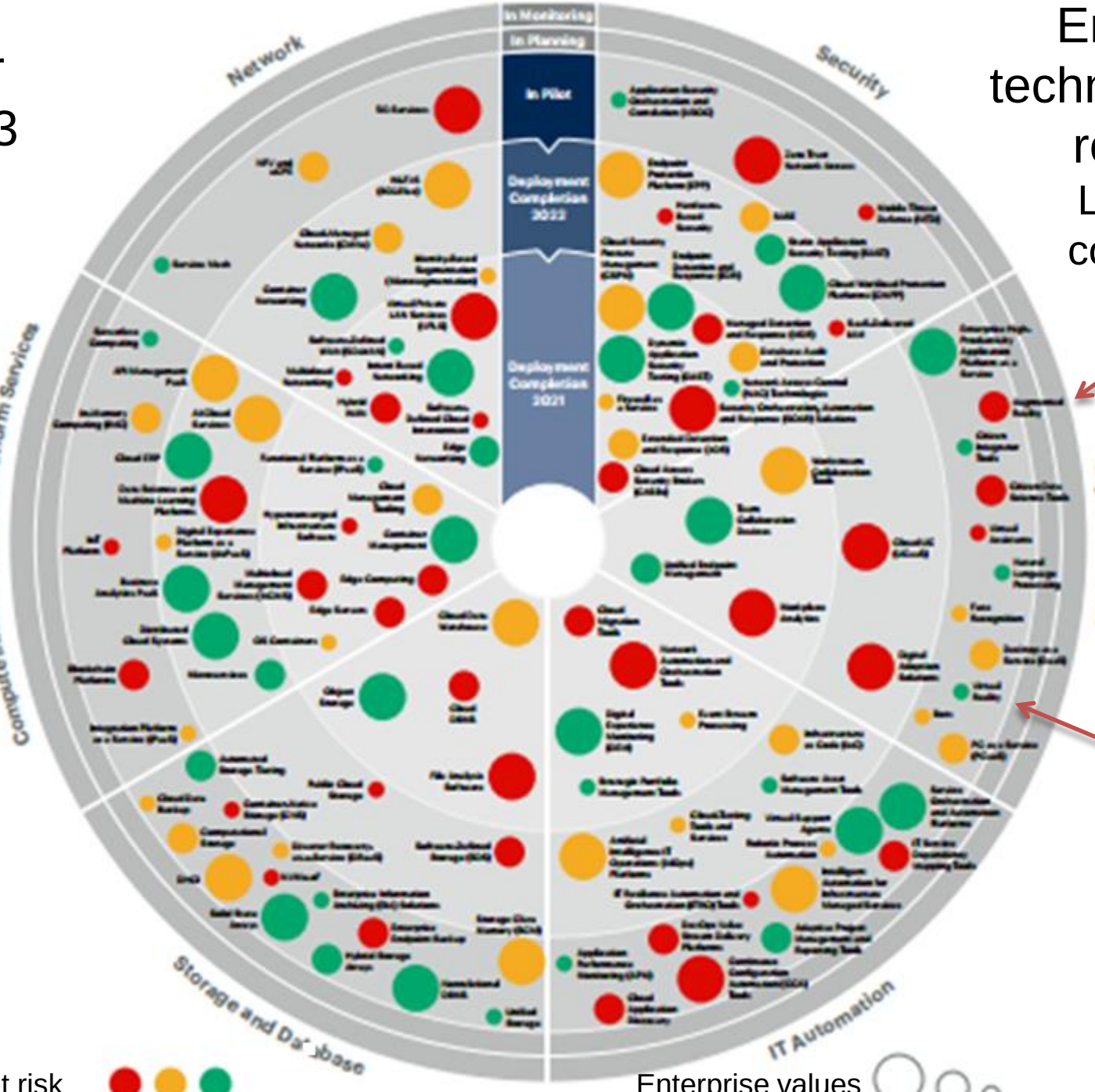


VR no longer appears: it has reached the plateau of productivity …

Gartner
2021-23

Emerging technologies roadmap

Large size companies

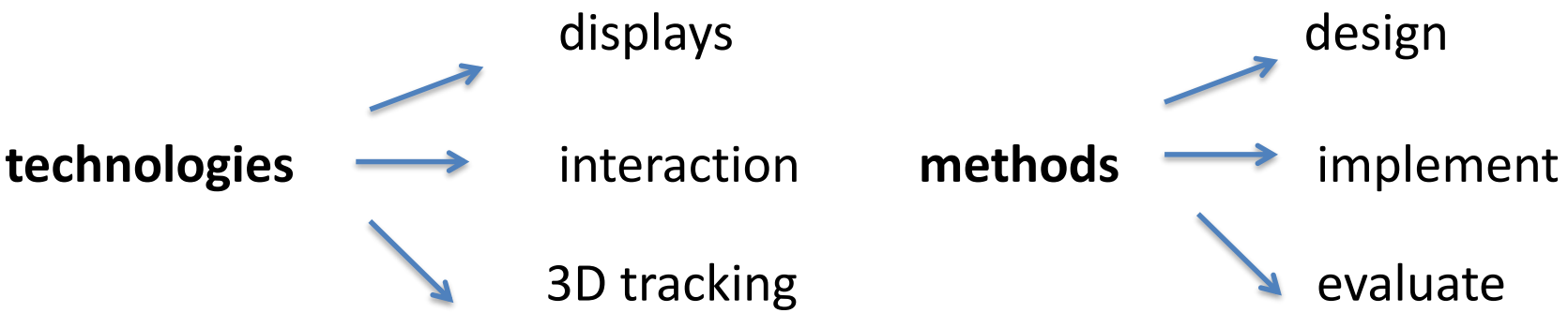


Deployment risk

Enterprise values

AR and VR have evolved a lot

important research goals to be addressed:



security, privacy, acceptability and other social issues

Mobile AR provides an accessible entry

but 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)

Evolving, but still far from the “ultimate display”…

Pro-level AR and XR headsets

Evolving, but still far from the “ultimate display”…

Google Glass Enterprise 2
Best AR glasses overall

Microsoft HoloLens 2
Best AR glasses for collaboration

Lenovo ThinkReality A3
Best wired AR glasses

Vuzix Blade Upgraded
Best AR glasses for remote access

https://www.zdnet.com/article/best-ar-glasses/

Tracking technologies

Vision- based

Magnetic

Inertial

GPS-based

…

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

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

But improving…

Interaction

3D User Interfaces

Tangible User Interfaces (TUIs)

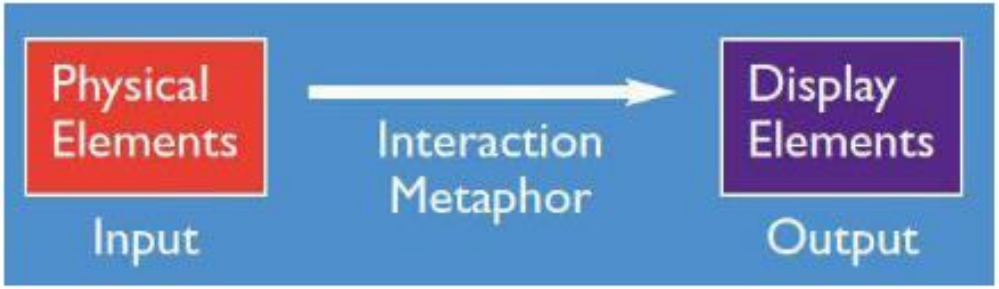
Natural User Interfaces (NUIs)

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

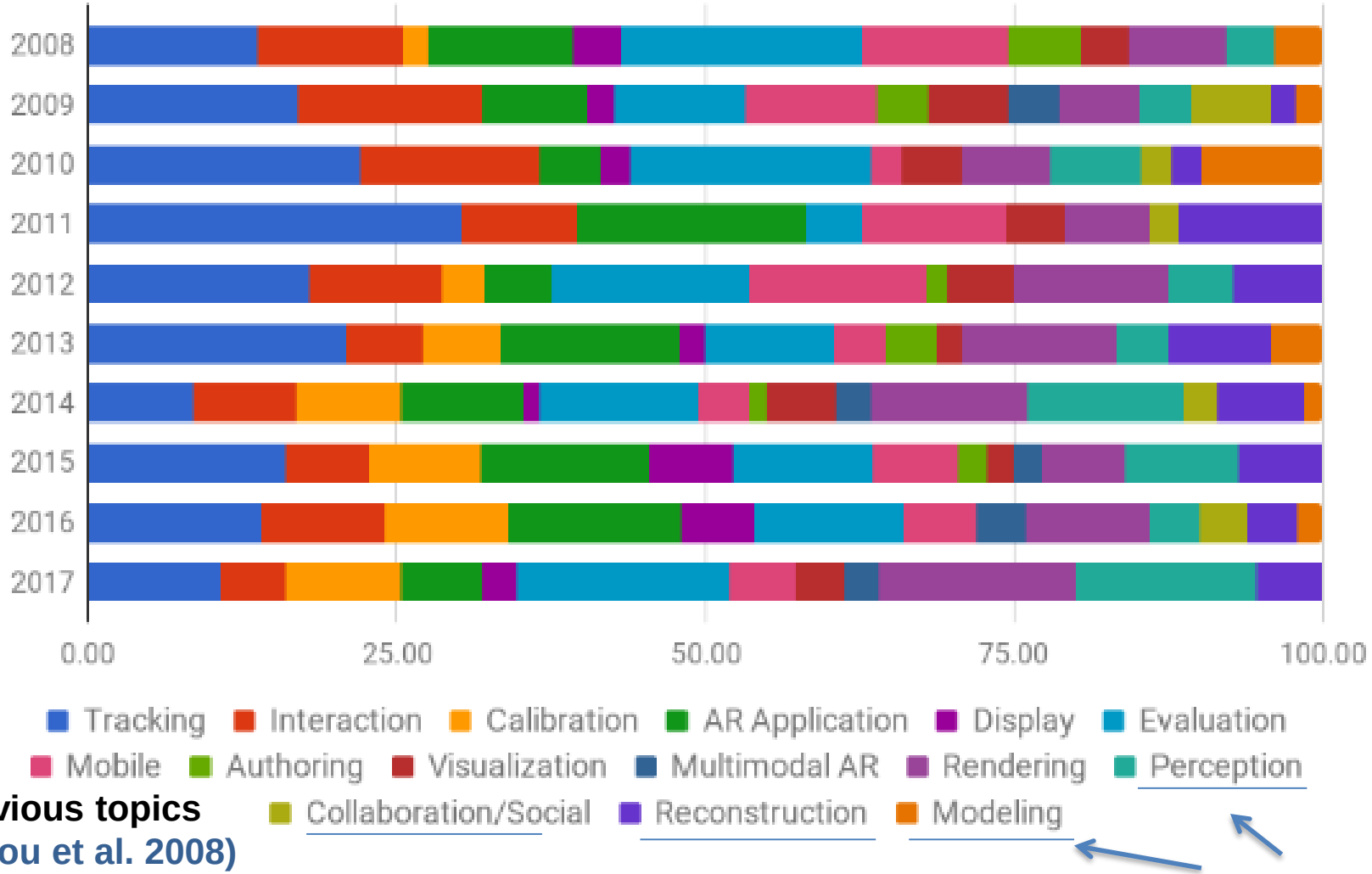


Design patterns may be used …

(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 (2016)

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

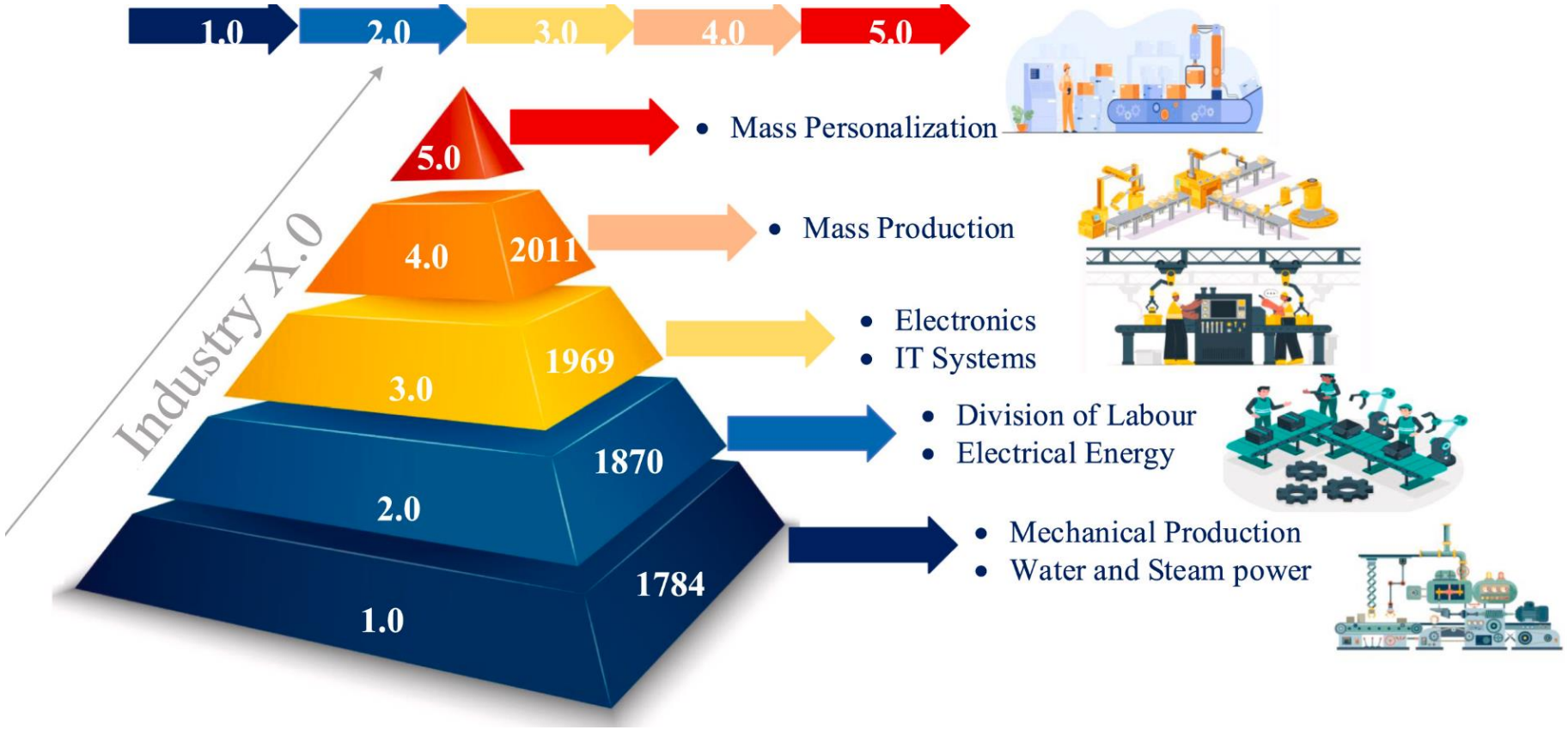
Industry 4.0 offers many opportunities and challenges for XR/VR/AR/MR

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

Masood, T., J. Egger, "Adopting augmented reality in the age of industrial digitalisation," *Computers in Industry*, vol. 115, 103112, 2020

Industry 5.0 offers even more opportunities and challenges…

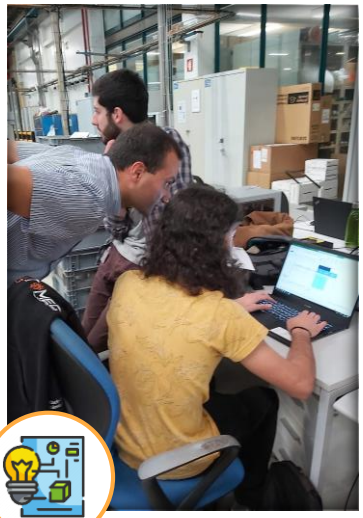
leveraging the creativity of human experts in collaboration with efficient, intelligent and accurate machines

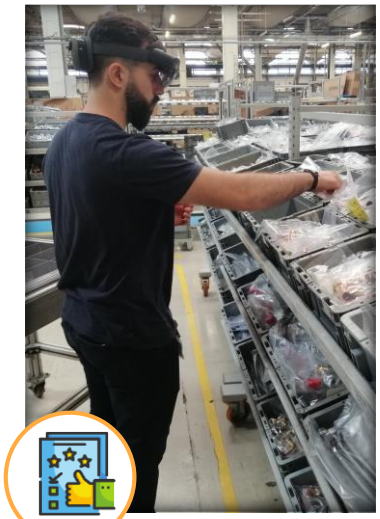


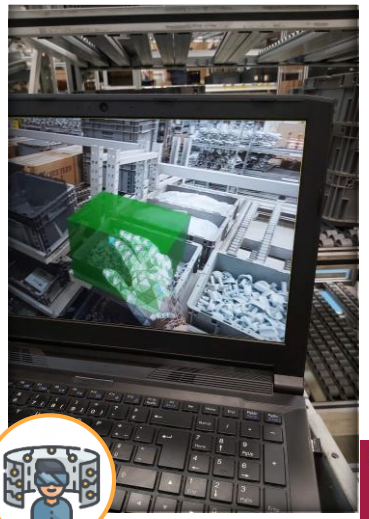
Kumar, P. et al., Industry 5.0: A survey on enabling technologies and potential applications, *Journal of Industrial Information Integration*, vol. 26, 2022 https://doi.org/10.1016/j.jii.2021.100257.

DETI/IEETA VARLab + Bosch latest work

MR for manufacturing: Human-Centered Design methodology







Analysis → Design → Evaluation → Development

BOSCH

MR for manufacturing

Picking scenario - a worker may be supported by an MR application while gathering parts from a set of shelfs (known as “supermarket”),

Picking: Content Configuration

Content Visualization

Picking: Evaluation with End-Users – a fundamental step to obtaining a useful solution!

Latest hype: Metaverse

Collective virtual space, virtually enhanced physical and digital reality

device-independent, not owned by a single vendor
independent virtual economy
enabled by digital currencies and nonfungible tokens (NFTs)

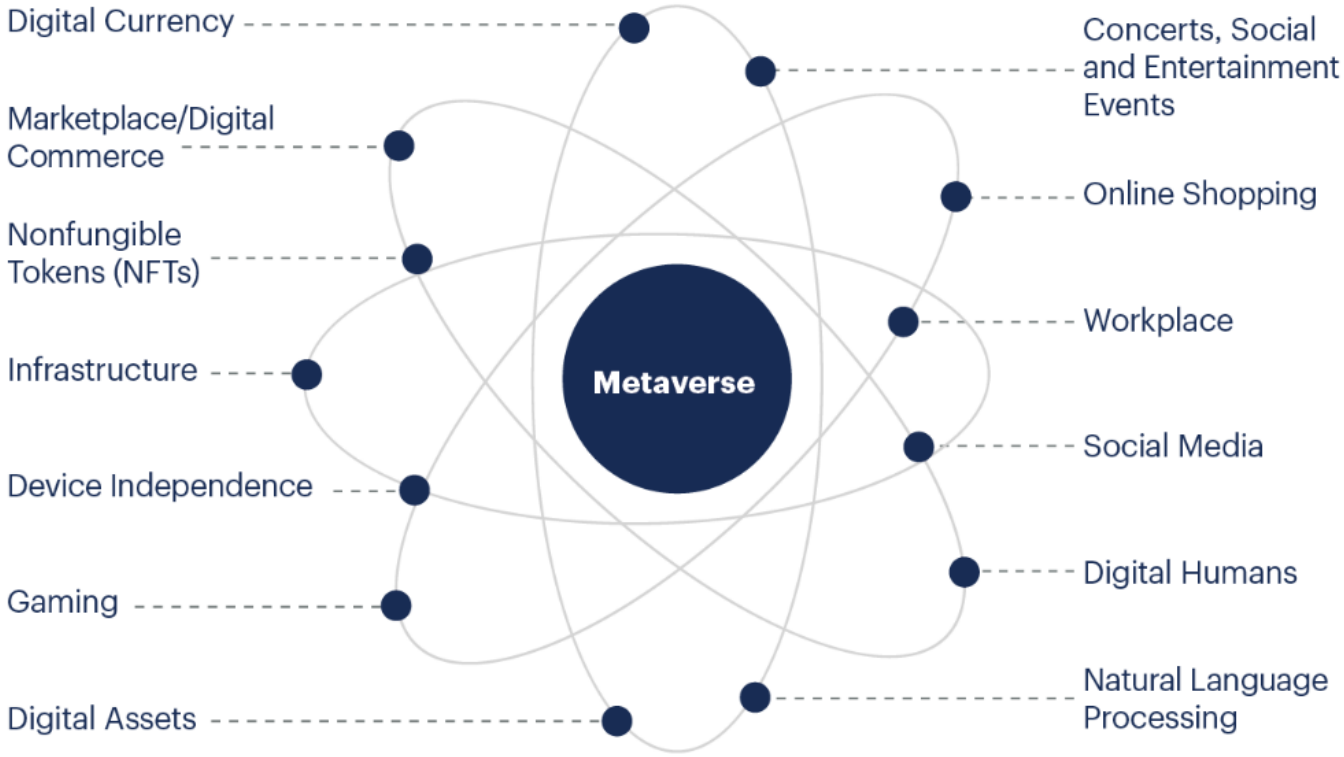
Gartner expects that by 2026, 25% of people will spend at least one hour a day in the Metaverse for work, shopping, education, social media and/or entertainment

Contributing tech capabilities include:
augmented reality (AR), AR cloud
head-mounted displays (HMDs)
Internet of Things (IoT), 5G
artificial intelligence
spatial technologies

next version of the Internet?

https://www.gartner.com/en/articles/what-is-a-metaverse

Elements of a Metaverse



Source: Gartner

https://www.gartner.com/en/articles/what-is-a-metaverse

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

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- La Valle, S., *Virtual Reality*, Cambridge University Press, 2020 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

Introductory books for the general public:

- Marr, B., *Extended Reality in Practice*, Wiley, 2021
- Greengard, S., *Virtual Reality*, MIT Press, 2019

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- - 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

Interesting papers

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