ESILV
ENGINEERING SCHOOL
DE VINCI PARIS

IHM & Extended Reality (xR)

Pr Ahmed Azough
ahmed.azough@devinci.fr

… - …
2022/2023

SUMMARY

02. Extended Realities

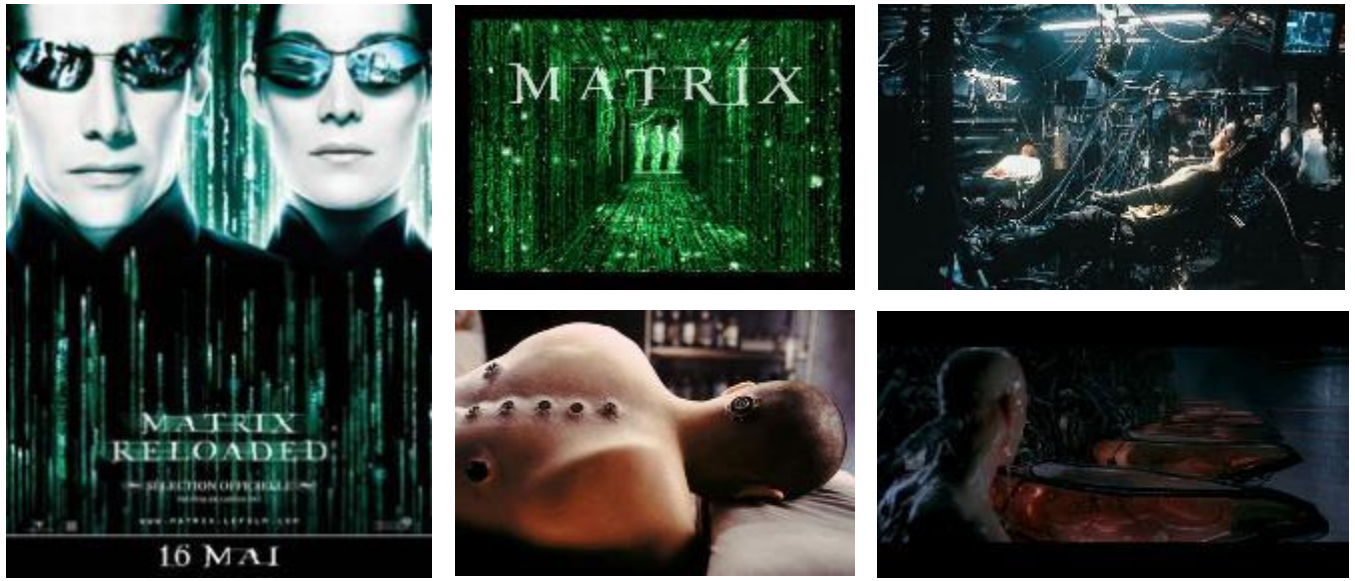
01. Introduction
02. Augmented reality
03. Virtual Reality
04. Mixed Reality

Introduction

From science fiction to reality

- Film **The Matrix** 1999, 2003
  - An imaginary future in which the reality perceived by most humans is in fact a **virtual simulation** called the "Matrix", created by intelligent machines to subjugate and use the human population.

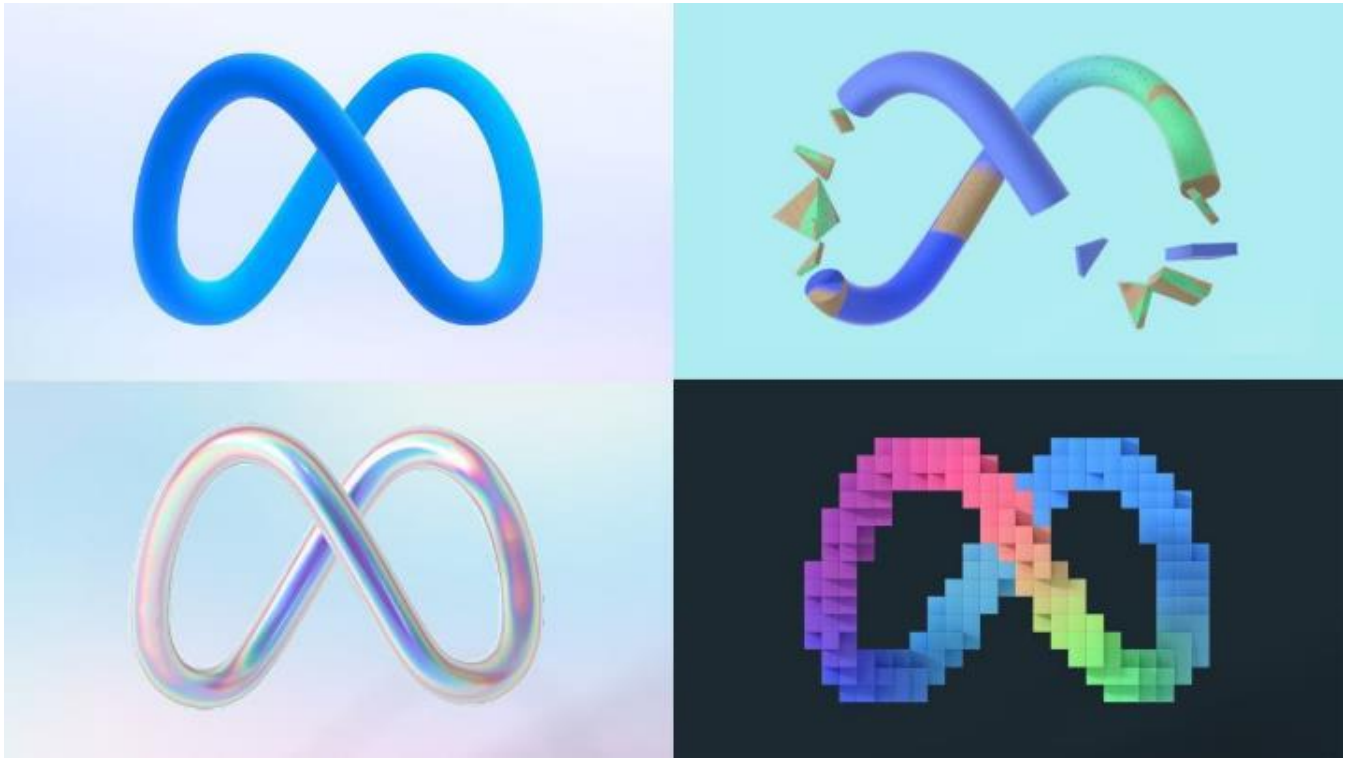
  - "The Matrix" (1999) -- 'Construct' Scenes : https://www.youtube.com/watch?v=AGZiLMGdCE0
  - The Matrix - Battery: https://www.youtube.com/watch?v=IojqOMWTgv8



From science fiction to reality

- Facebook goes meta
  - **Metaverse** : https://www.youtube.com/watch?v=gElfIo6uw4g
  - **Horizon World :** https://www.youtube.com/watch?v=02kCEurWkqU&t=3s

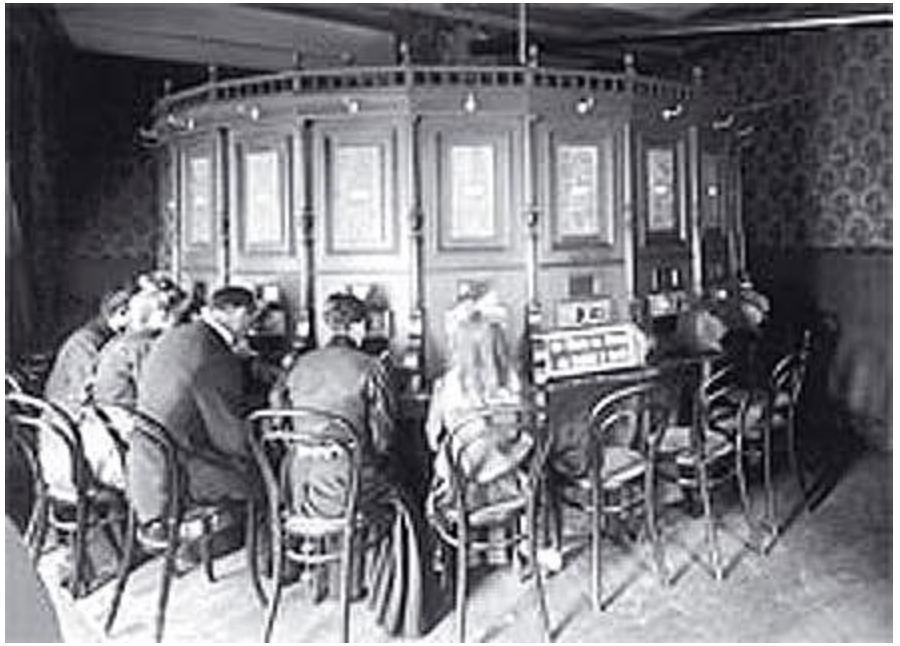
The metaverse is a hypothetical iteration of the Internet as a single, universal and immersive virtual world that is facilitated by the use of virtual reality (VR) and augmented reality (AR) headsets. In common parlance, a metaverse is a network of 3D virtual worlds focused on social connection.



Before VR

First **stereoscope** created by the English physicist Charles Wheatstone, who submitted a paper to the Royal Academy in 1838.

The **stereoscope** had two mirrors at 90° which reflected the gaze laterally towards two specially prepared stereoscopic drawings. Then the principle was applied to photography.



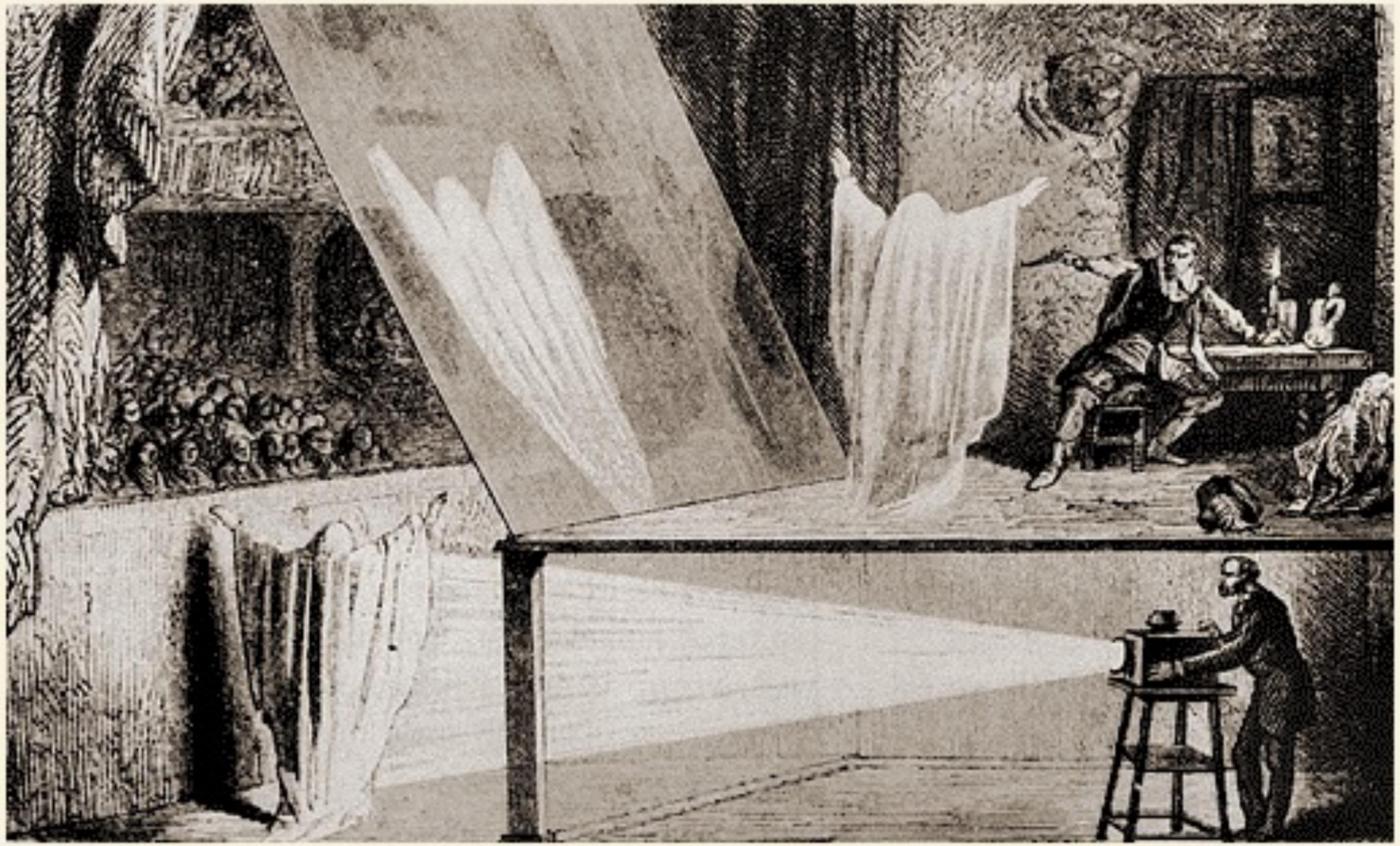
Stereoscope projection at the "Kaiserpanorama" in the Vienna Prater, around 1900

Before AR

Pepper's ghost is an illusion technique used in the theatre, cinema, amusement parks, museums, television, and concerts.

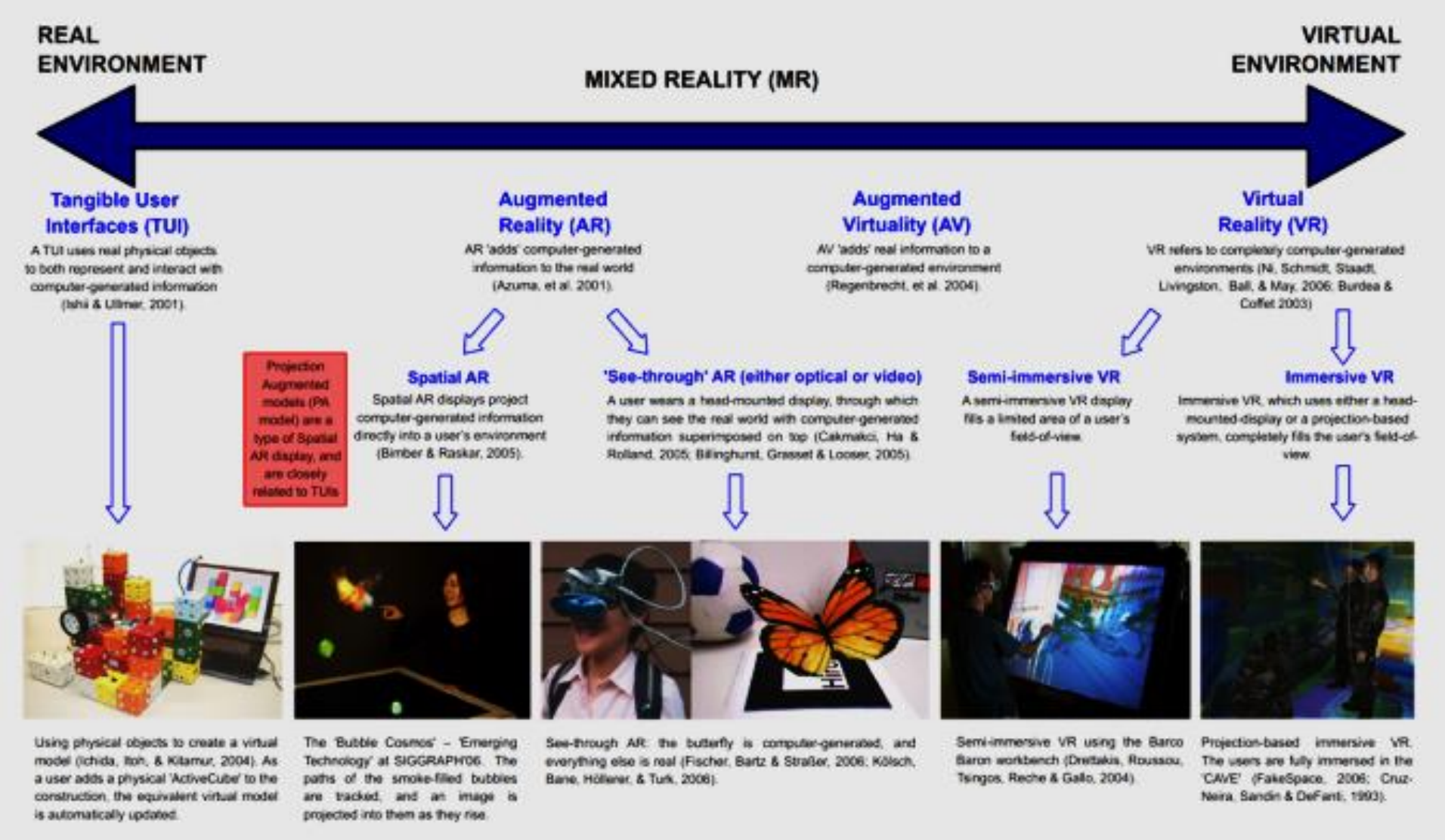
It is named after the English scientist John Henry Pepper (1821–1900) who began popularising the effect with a theatre demonstration in 1862

Pepper's Ghost 1862



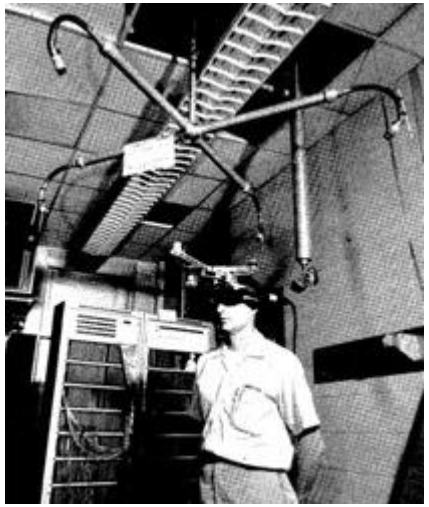
Reality-virtuality continuum (Paul Milgman, 1994)

- Continuous scale that goes from the **all real** (reality) to the **all virtual** (virtuality),
- It encompasses all possible compositions of real and virtual objects



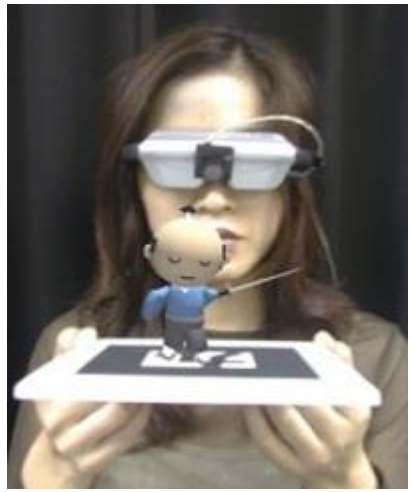
Extended reality history

- **1968** : The Sword of Damocles - **First virtual reality machine** - MIT , (Ivan Sutherland)
- **1992**: Proposal of the **word augmented reality**, (Tom Caudell and David Mizell)
- **1992**: Virtual Fixtures - **first AR system**, at the U.S. Air Force Research Laboratory (Louis Rosenberg)
- **1994**: **Virtual Reality Continuum** Proposal, (Paul Milgram and Fumio Kishino)
- **1996** : Introduction of **2D markers** for virtual objects visualization, (Jun Rekimoto)



Ivan Sutherland

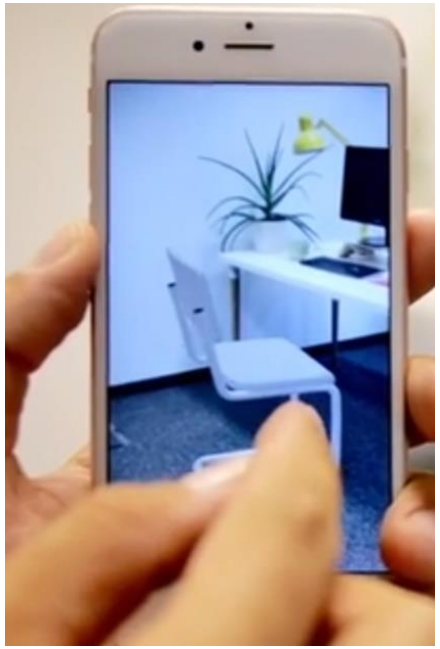
Luis Rosenberf
(First AR application)



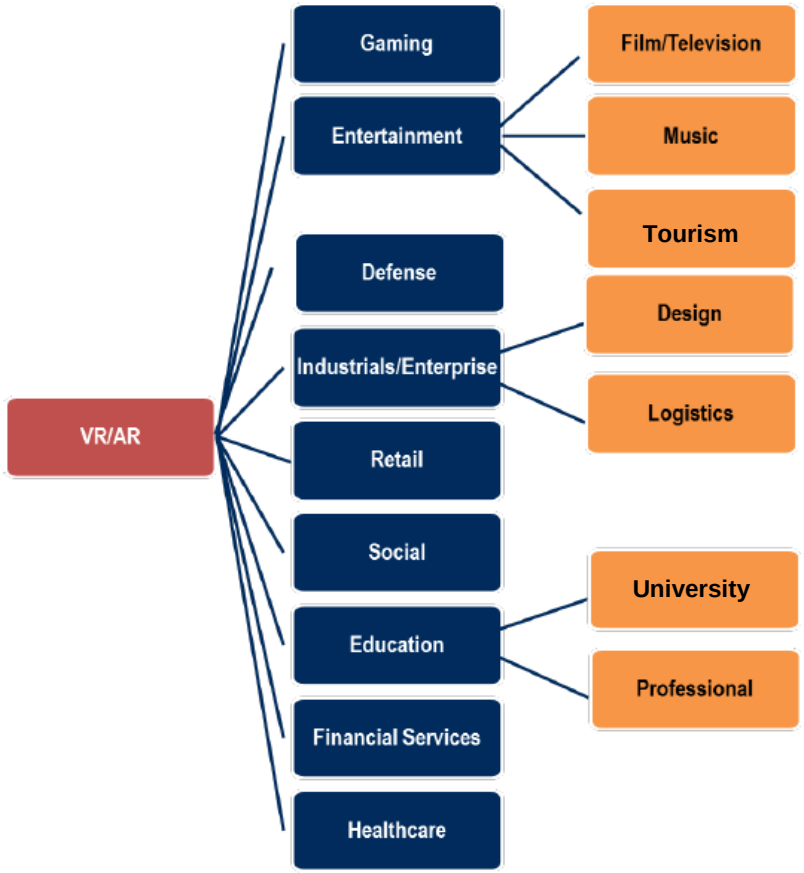
Jun Rekimoto

Extended reality history

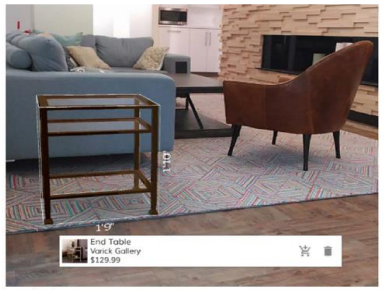
- **2010: virtual dressing rooms** had been developed for e-commerce.
- **2012:** royal Dutch mint strikes the first **coin with augmented reality**.
- **2015:** first **live greeting cards** made using augmented reality through iGreet mobile App.
- **2018: USDZ AR file support** for iPhone so people can experience augmented reality.
- **2018:** Canadian e-commerce company Shopify, integration ARkit2 to **allow merchants to upload 3D** models of their products so that costumers could see them in their real world environments.



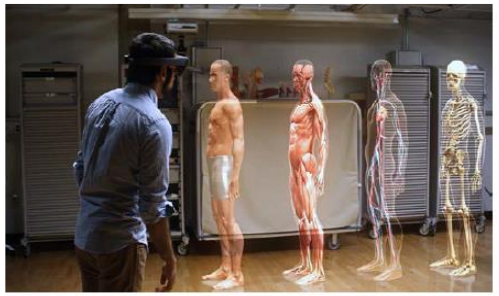
XR use cases



Source: Honeywell



Source: Google



Source: Microsoft

Source: Rockwell Collins

XR use cases

simulation & training

visualization & entertainment

remote control of vehicles, e.g. drones

gaming

robotic surgery

architecture walkthroughs

education

virtual travel

a trip down the rabbit hole

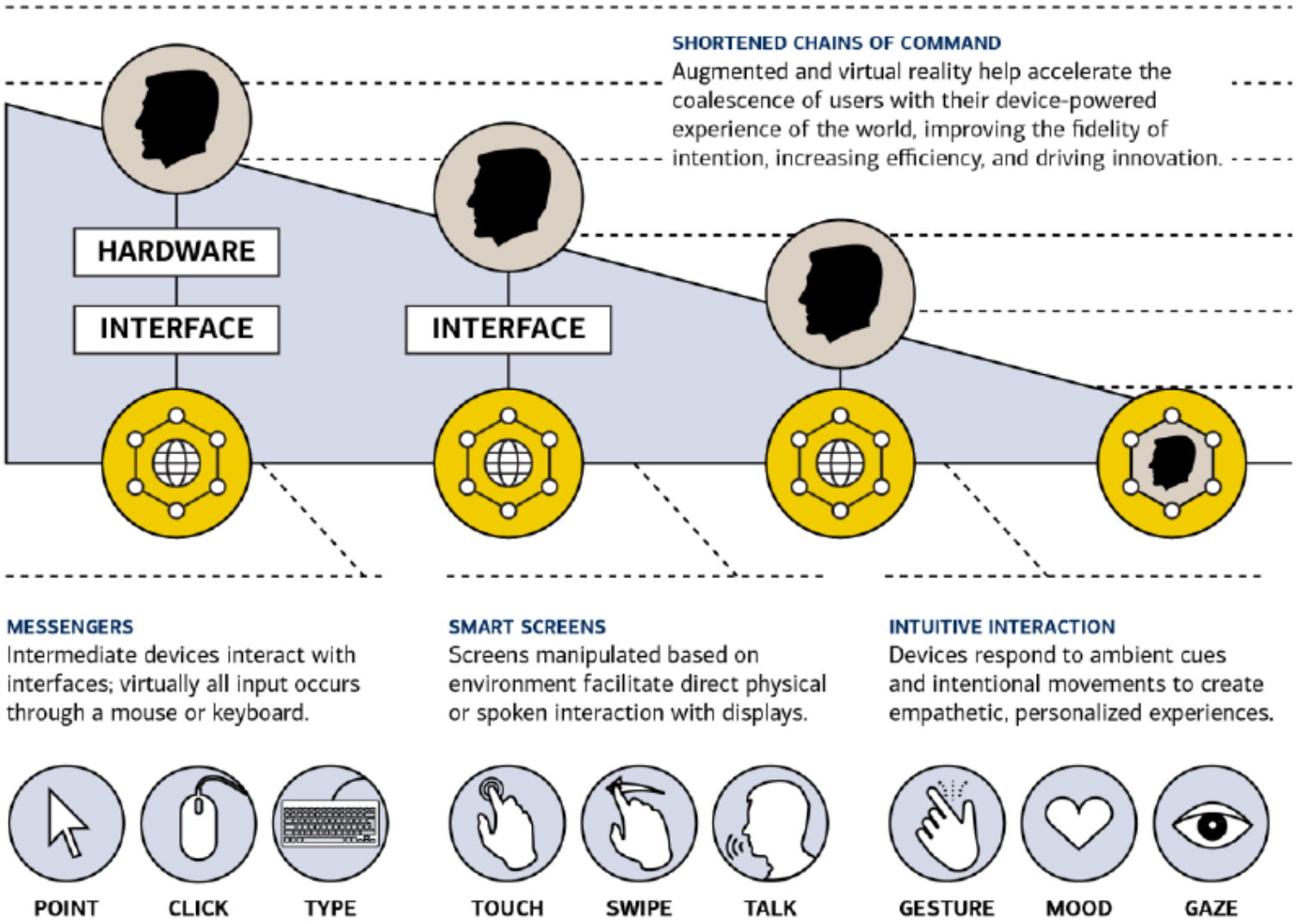
XR use cases

VR at Stanford's Medical School

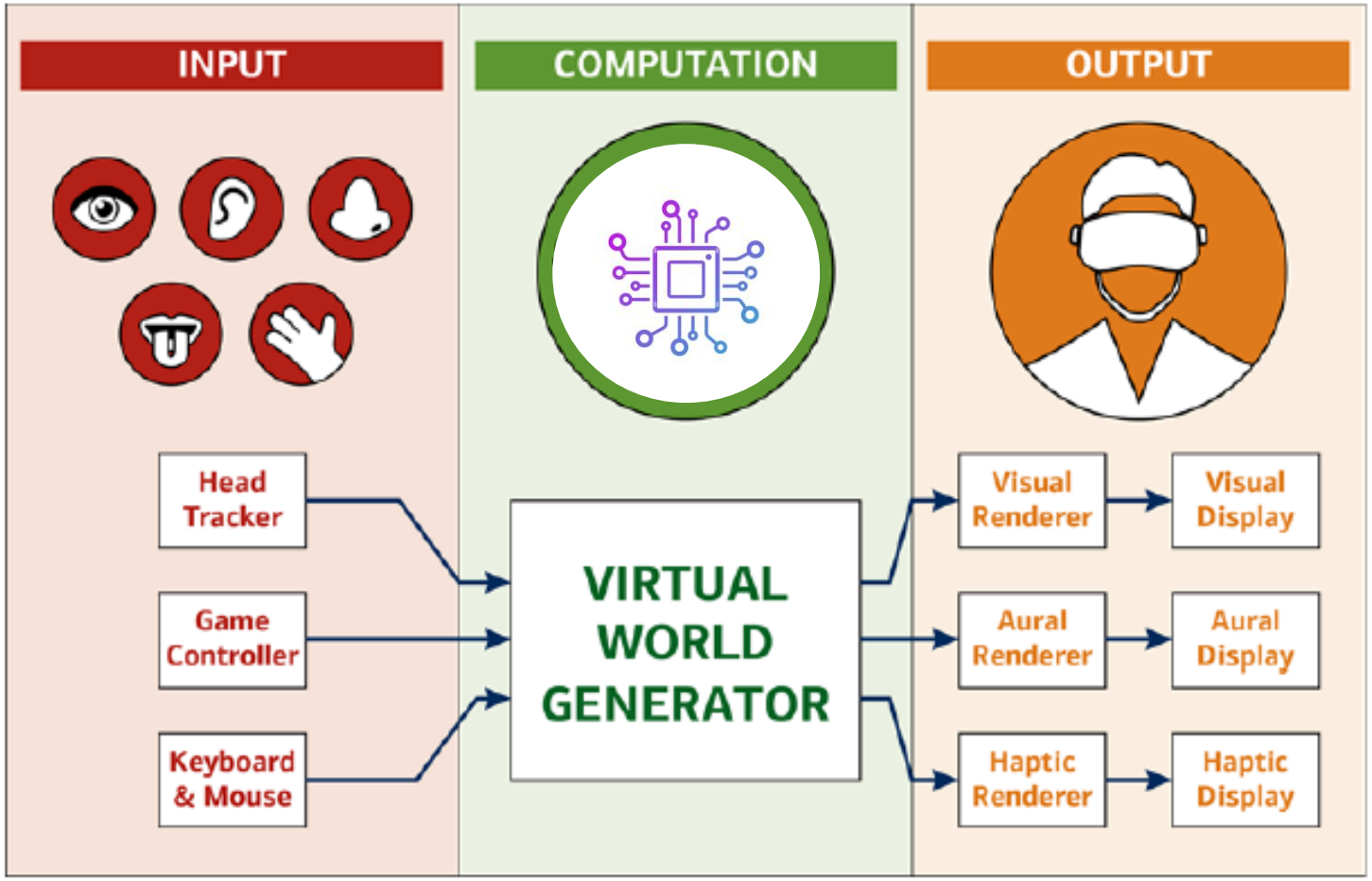
photo from Stanford Medicine News

- Lucile Packard Children's Hospital: used to alleviate pain, anxiety for pediatric patients
- VR Technology Clinic: applications in psychotherapy, mental health, for people with phantom pain, …
- help train residents, assist surgeons planning operations, …

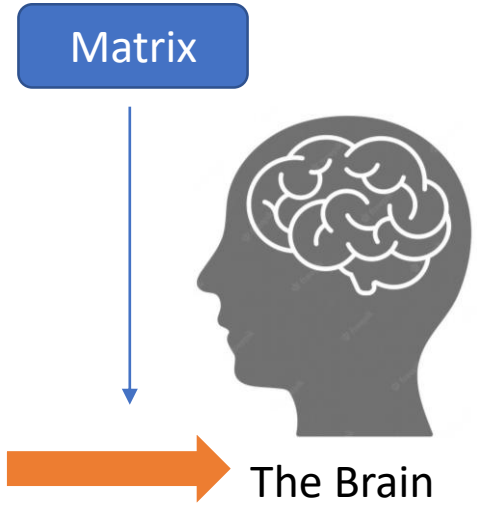
Revolution in Human-Computer Interaction



xR workflow



Source: BofA Merrill Lynch Global research



Revolution in Human-Computer Interaction

- 4th computer revolution after the PC, the laptop, the smartphones

Personal Computer
e.g. Commodore PET 1983

Laptop
e.g. Apple MacBook

Smartphone
e.g. Google Pixel

AR/VR
e.g. Microsoft Hololens

xR : an emerging technologie

National Academy of Engineering

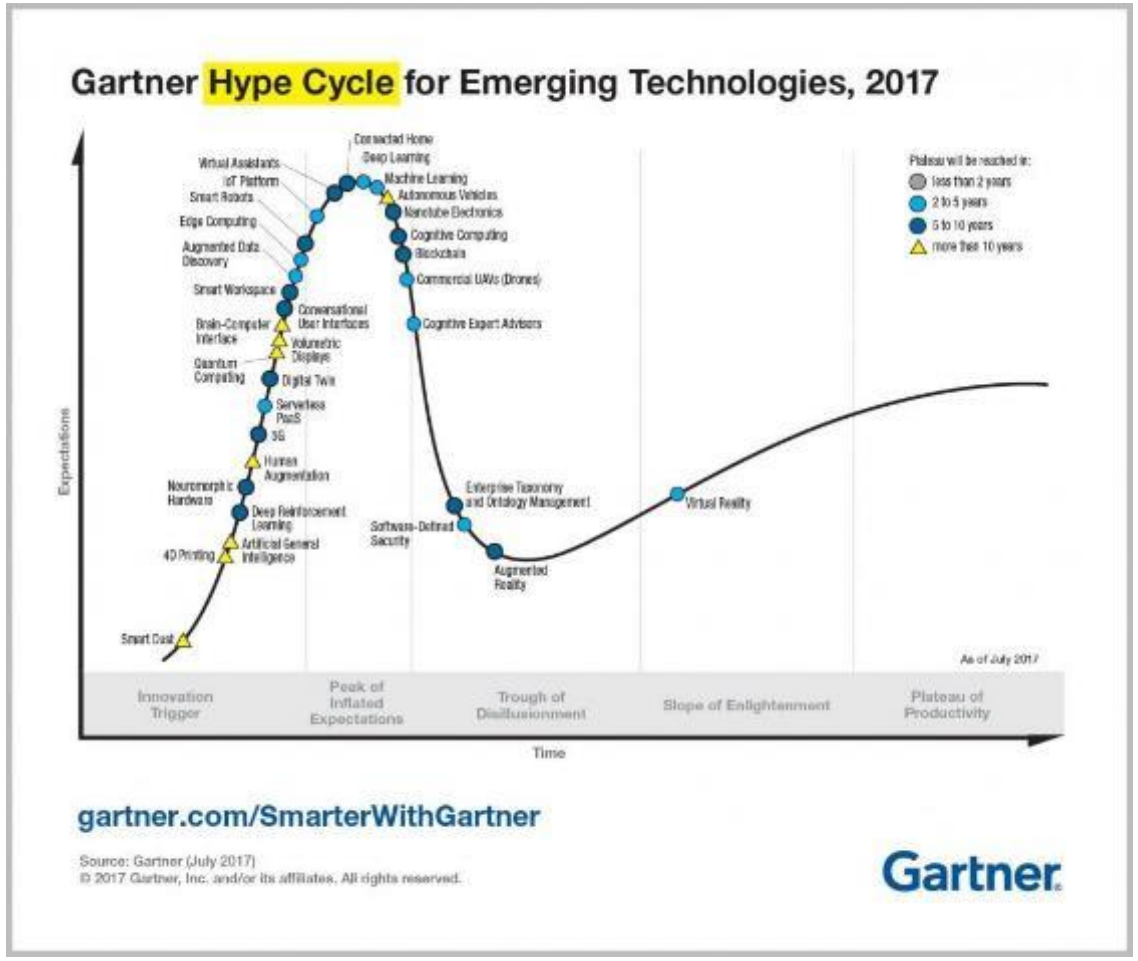
"Enhance Virtual Reality" is 1 of 14 NAE grand challenges for engineering in the 21st century

image from NAE

xR : an emerging technologie

- Curve describing the evolution of interest in a new technology.

- Three major families of emerging technologies in the next 10 years:
  - **Artificial intelligence**
  - **Extended realities**
  - **Digital platforms (IoT, 5G, quantum...)**

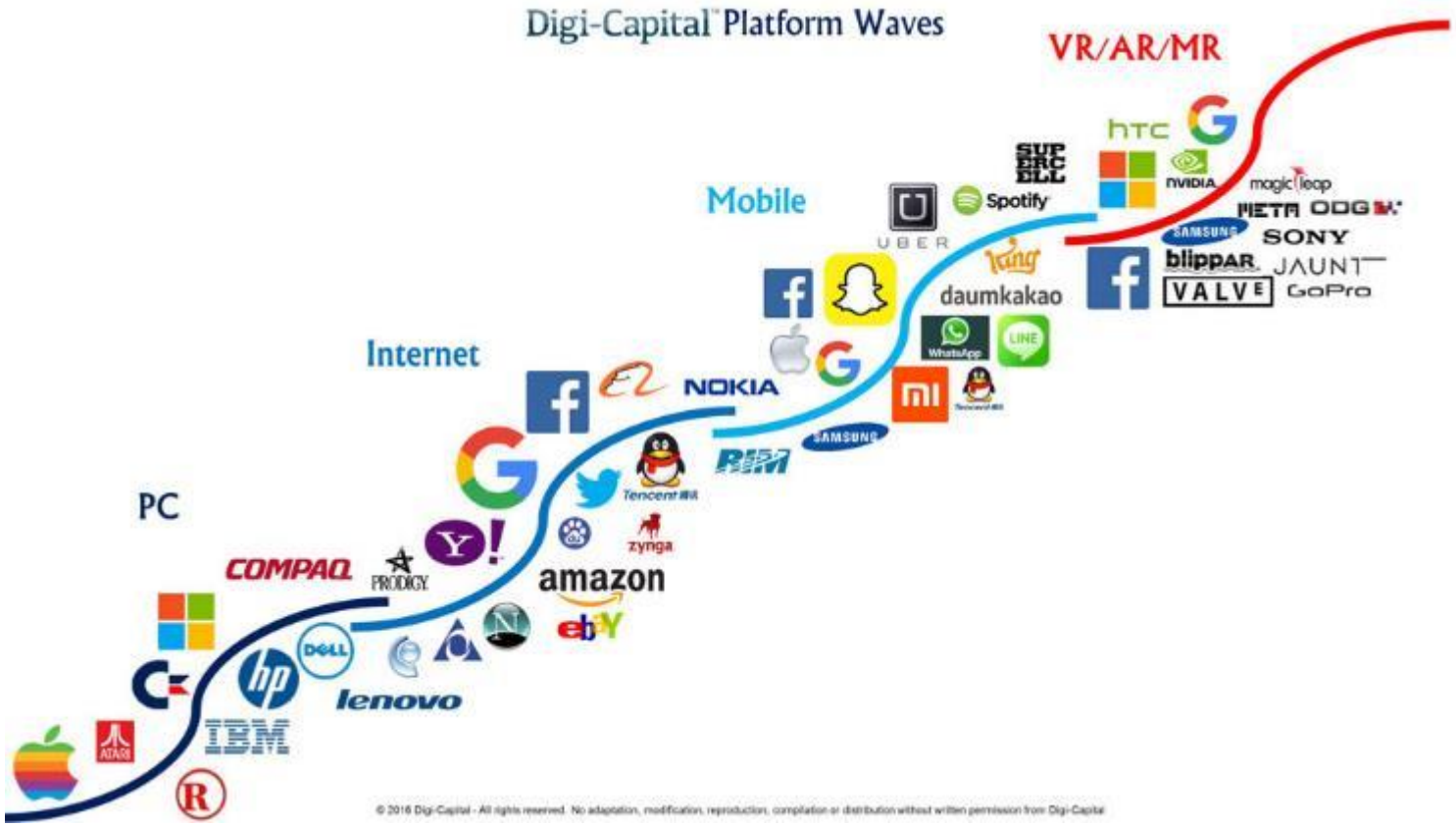


xR ecosystem

Source : Cabinet Digi-Capital

xR ecosystem

- Operators' waves



Exciting Engineering Aspects of VR/AR

- Integrates various technologies such as sensors, Big Data, cloud, AI, and wearable technology.

- cloud computing
- shared experiences

- CPU, GPU
- IPU, DPU?

- sensors & imaging
- computer vision
- scene understanding

- compression, streaming

images by microsoft, facebook

- VR cameras

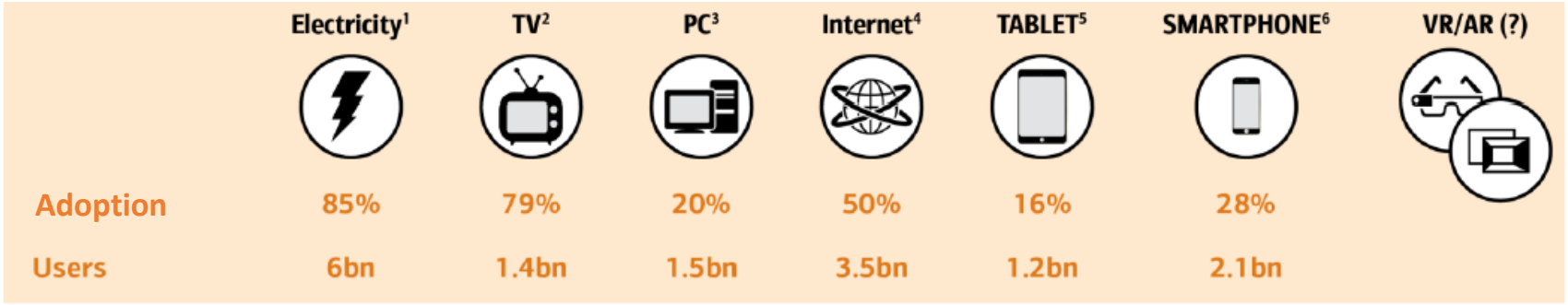
- photonics / waveguides
- human perception
- displays: visual, auditory, vestibular, haptic, …

- HCI
- applications

Adoption of AR/VR

- A computer cycle takes place every 10 to 15 years,
- Each new major cycle completely reshapes the IT landscape.

In 2016



Source: [1] 2012 / World Bank, UN; [2] 2012 / TVTechnology; [3] 2015 / Gartner, UN; [4] 2016 / ITU; [5] 2016 / eMarketer; [6] 2016 / eMarketer

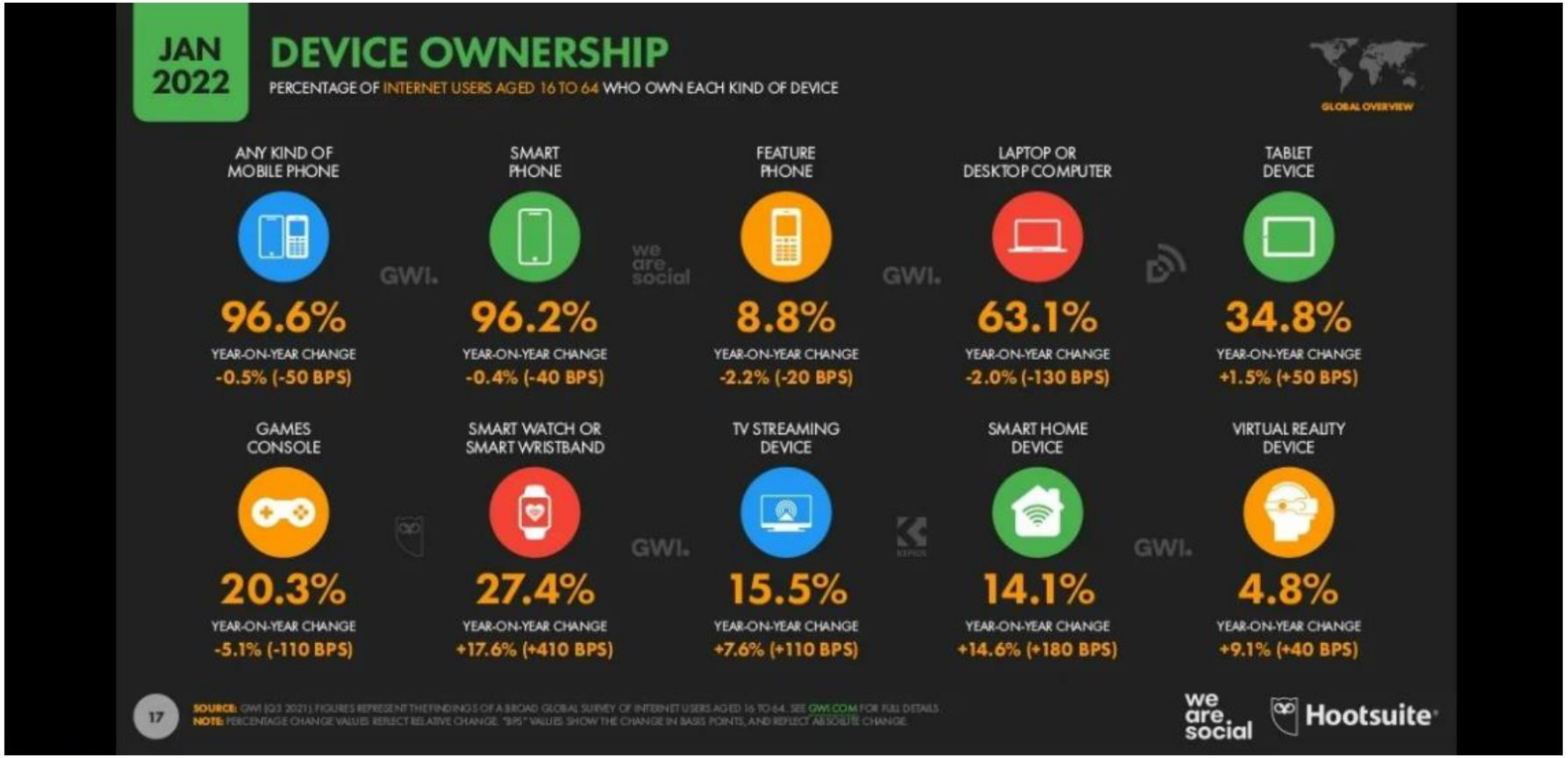
Source: BofA Merrill Lynch Global Research

(Based on industry experts Mitchell Waldrop and Chris Dixon of Andreessen Horowitz)

Adoption of AR/VR

- 96% of the world's population uses a cell phone.
- ~5% of the world's population uses VR/AR devices.

Today (2022)



Extended Reality Types : VR / AR / MR

Virtual Reality

Digital environments
that shut out the real world.

Augmented Reality

Digital content on top
of your real world.

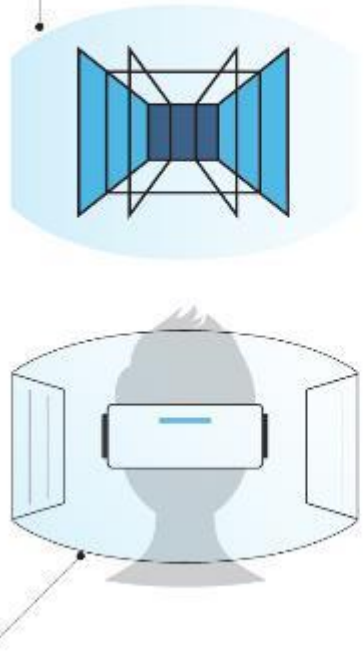
Mixed Reality

Digital content interacts
with your real world.

Extended Reality Types : VR / AR / MR

VIRTUAL REALITY (VR)

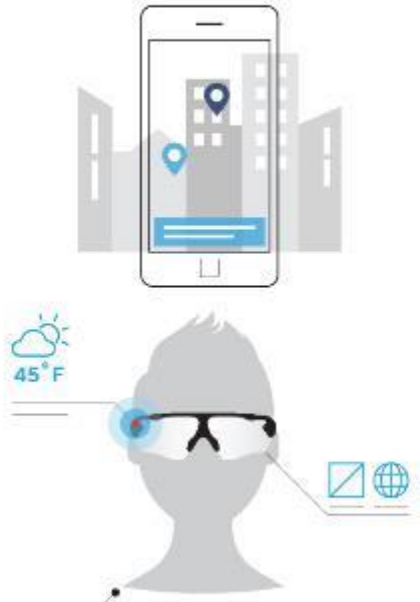
Completely digital environment



Fully enclosed, synthetic experience with no sense of the real world.

AUGMENTED REALITY (AR)

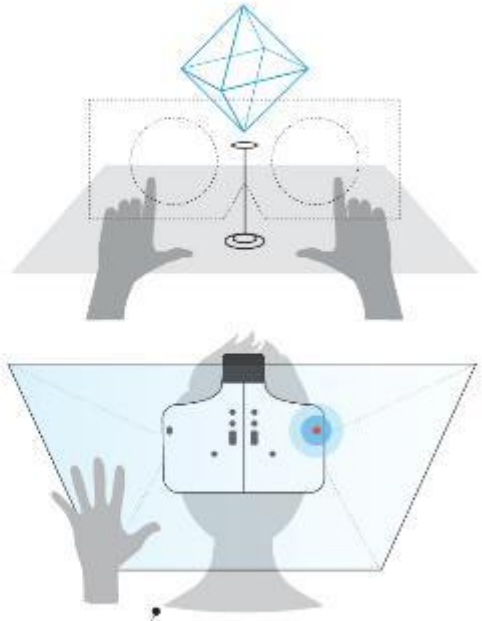
Real world with digital information overlay



Real world remains central to the experience, enhanced by virtual details.

MERGED REALITY (MR)

Real and the virtual are intertwined



Interaction with and manipulation of both the physical and virtual environment.

Also Diminished Reality (DR)

not covered in this course

- Deleting an element on a "real" image in real time
  - Real image

  - Image after deletion

Diminished Reality (DR)

- It is a type of computer-aided reality technology that allows, to remove, conceal, or eliminate real-life objects from your environment in real-time. Those objects are made artificially invisible and replaced with backgrounds or other digital 3D objects.

- It is referred to as the opposite of augmented reality (AR), diminished reality takes from the world instead of adding to it.

- DR and AR can be complementary

- Example : https://www.youtube.com/watch?v=y5nDW5QNWcI

Augmented Reality

Augmented reality

- Augmented reality
  - Interactive experience that combines the real world and computer-generated content (virtual objects)
  - Real environment, virtual objects
  - the virtual is projected onto the real, in real time
    - on screen
    - on the real ...or almost

Types of Augmented Realities

- Augmented reality
  - Marker-based
    - Recognition-based
  - Marker-less
    - Location-based
    - Projection-based
    - Overlay-based

Recognition-based Augmented Reality

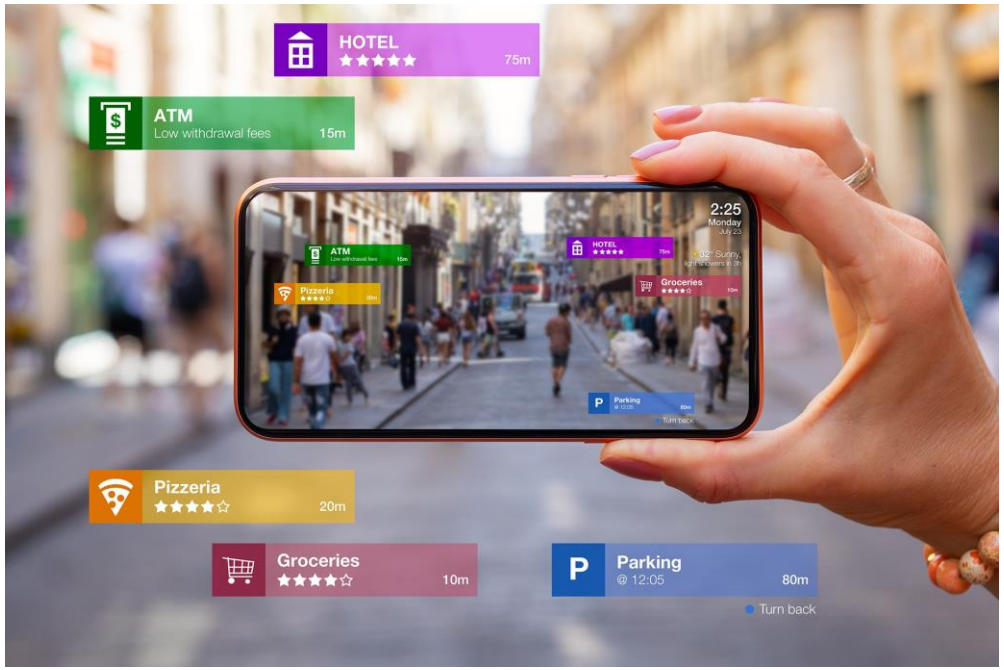
- AR type that uses markers that must be recognized to display elements such as a 3D version of an object or image or additional information about an object.
- Recognition-based augmented reality is one of the most widely used at the moment, since it only requires smartphones or tablets to make it work.

Overlay-based Augmented Reality

- Replaces, entirely or partially, the real vision of an object to show you an "augmented" version.
- A variation of recognition-based augmented reality, but instead of using a specific marker, it uses real objects that are detected in real time.

Location-based Augmented Reality

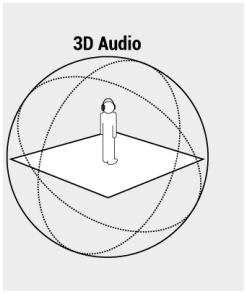
- At the opposite of recognition-based augmented reality. Location-based augmented reality shows you things based on where you are physically at that moment, without having to use a marker, just your surroundings.
- To operate, it uses the components of an average smartphone: accelerometer, digital compass and of course, GPS. These are the elements responsible for knowing your position.



Projection-based Augmented Reality

- It projects an image onto physical elements and spaces in the real world.
- One of the most appealing, as it is possible to make these projections interactive, like a keyboard projected onto a desk.
- Can also be used to see how an object fits into its future location and choose its possible position and orientation.
- Holograms is another example of projection-based AR.

Types of augmentation



- **Visual**
  - See virtual objects
- **Sound**
  - Listen to virtual 3D Sound
- **Haptics**
  - Touch new feeling
- **Movement**
  - Undergo movements
- **Smell, taste**
  - Artificially smell and taste

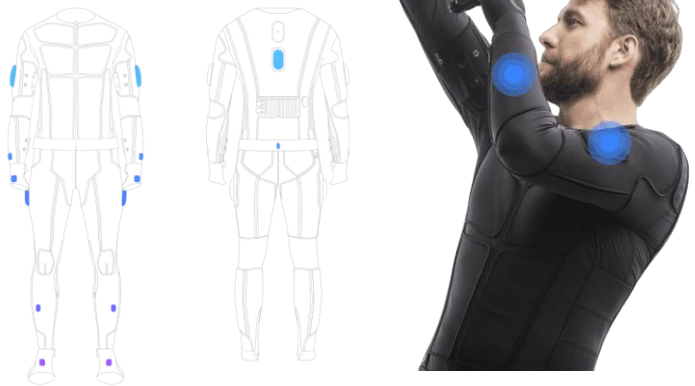
Haptic AR

Haptic Feedback

TESLASUIT's full body haptic feedback system uses electro muscle stimulation (EMS) and transcutaneous electrical nerve stimulation (TENS) to simulate a range of real-life feelings and sensations.

Motion Capture

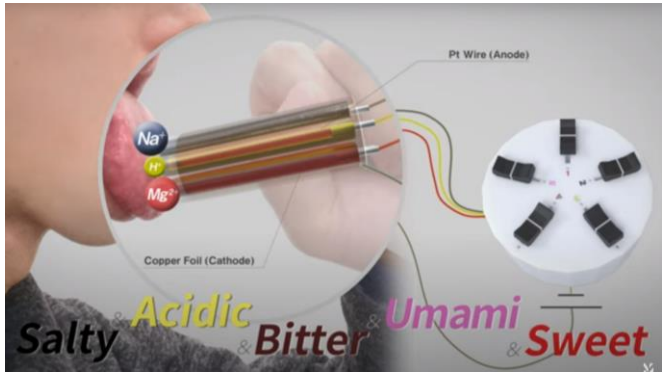
TESLASUIT's motion capture system uses 14 Inertial Measurement Unit (IMU) sensors to identify specific points around the TESLASUIT to track, record and monitor the movements and positioning of users. Each IMU sensor is made up of an accelerometer, gyroscope, and magnetometer.



https://teslasuit.io/

Taste AR

Production of a novel taste display which uses ion electrophoresis in five gels containing electrolytes that supply controlled amounts of each of the five basic tastes to apply a given taste to the user's tongue



Homei Miyashita (Meiji University), https://dl.acm.org/doi/abs/10.1145/3334480.3382984

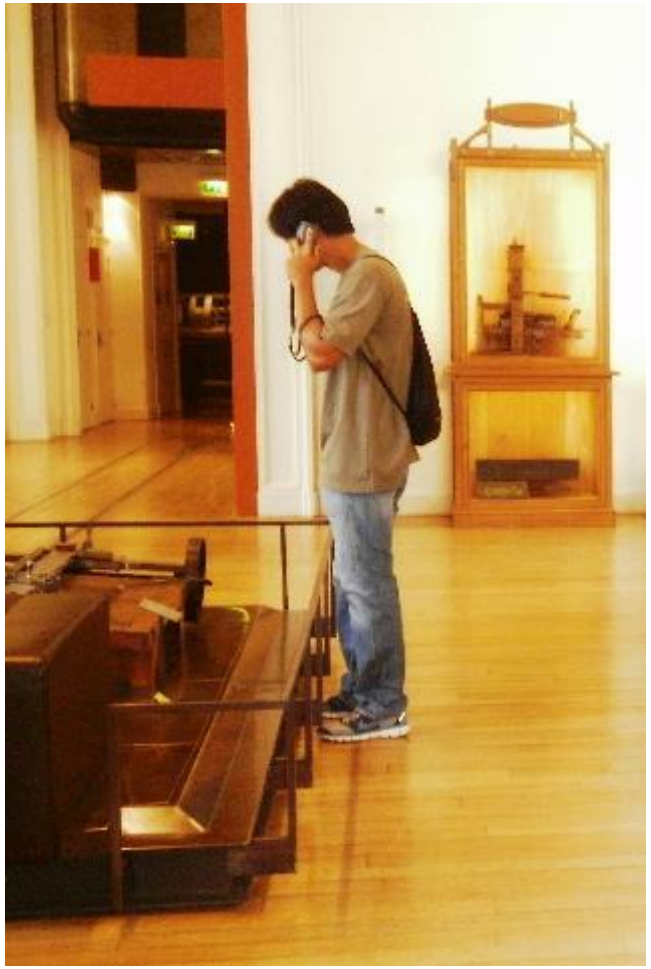
Sound AR

Spatialized audio guide (SARIM)

Automatic detection of the position and visitor orientation

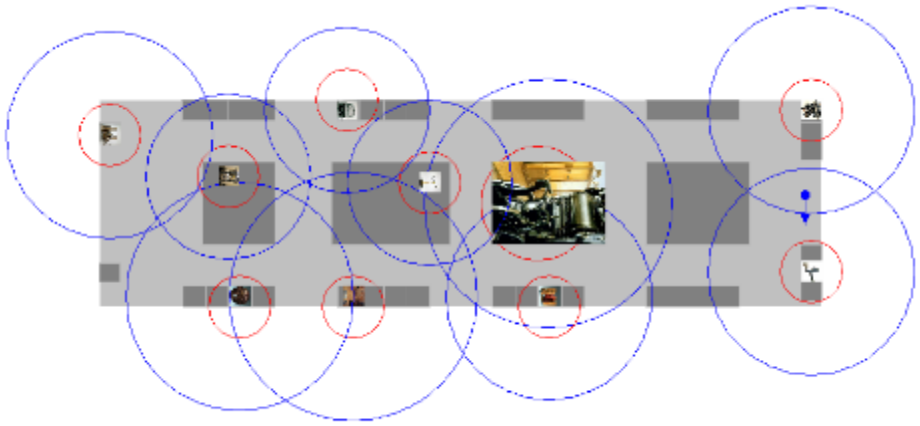
Classic audio guide (audiopass)

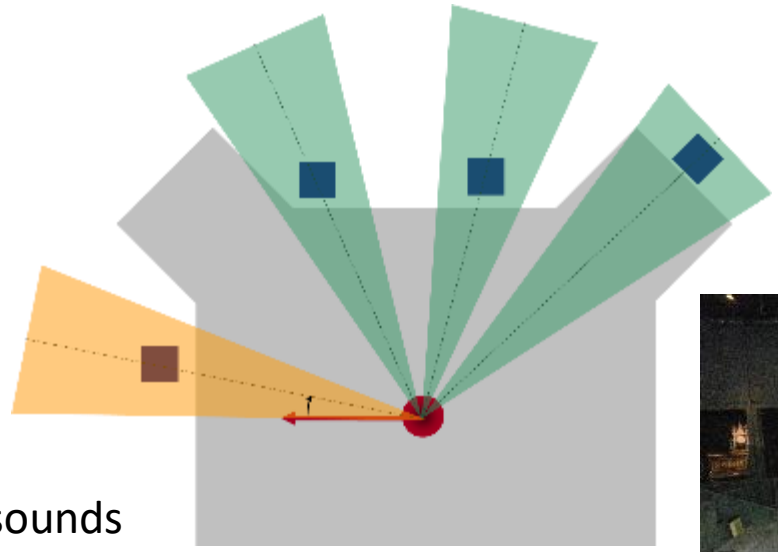
Manual selection of the object by the visitor and the desired content



Kaghat & Azough, Musée des arts et métiers, Paris, https://www.sciencedirect.com/science/article/abs/pii/S0045790620304614

Sound AR





- Immerse the visitor in an environment of ambient machine sounds
- Automatically gide the visitor through the museum

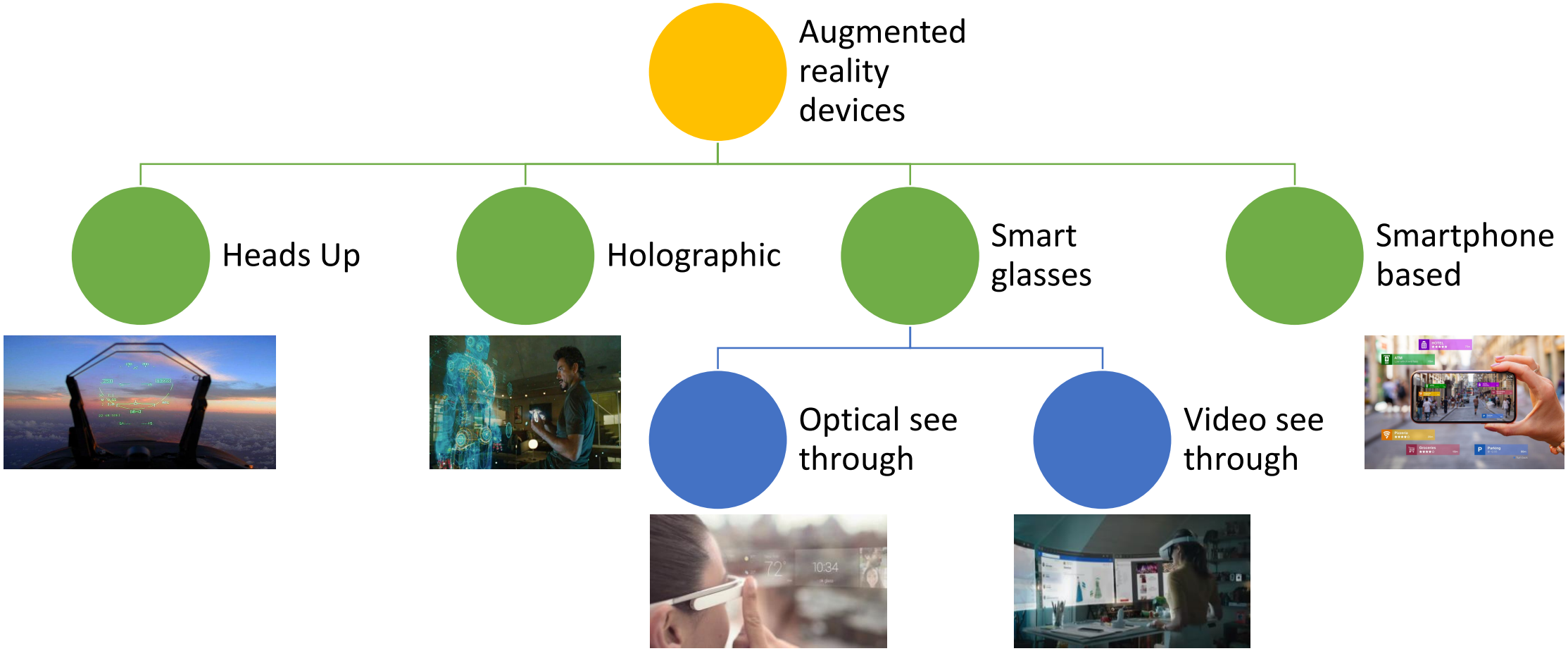
Experiments repeated in a real environment








Types of AR devices



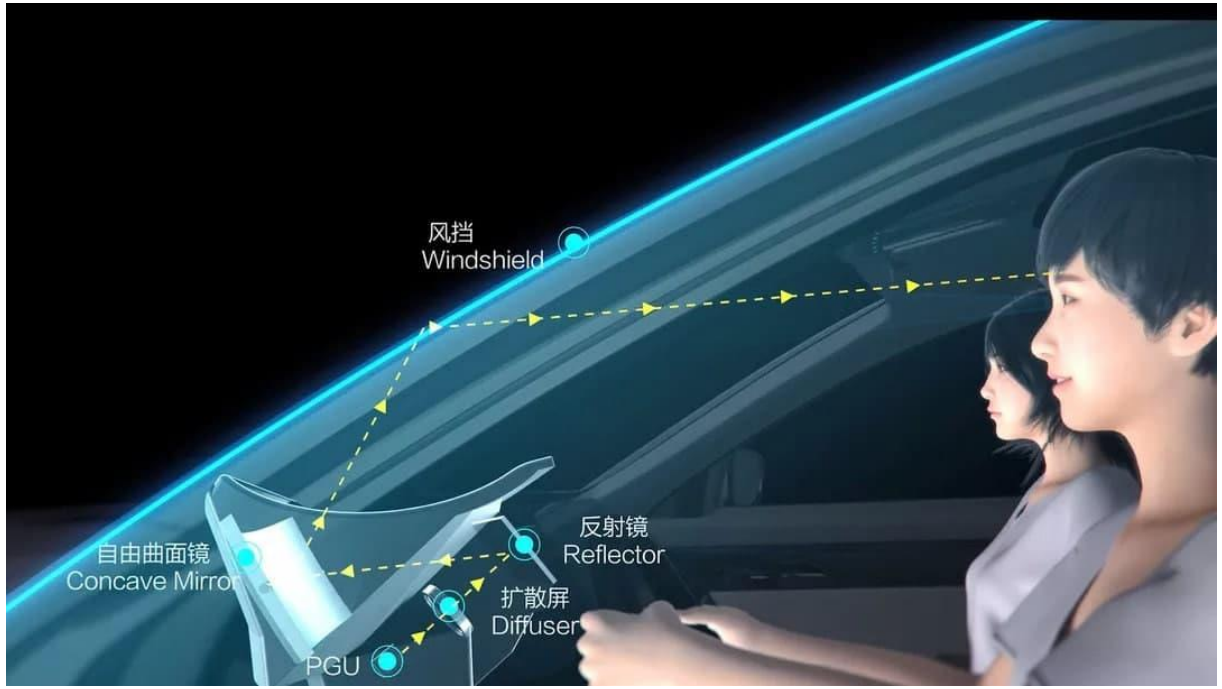
Head up displays (HUD)

- A pilot can see information through a transparent screen in the front. Just look forward, and all the information is presented on a glass. Also called **head-up guidance system**
  - https://www.youtube.com/watch?v=_0BWoIBmq0s

- HUD comes up with 3 main components:
  - **a projector unit,**
  - **a viewing glass (combiner)**
  - **a computer (symbol generator)**.

Head up displays (HUD)

- HUD in automotive industry :
  - The viewing glass is the windshield itself
  - https://www.youtube.com/watch?v=Wkf_WEek8bc
    https://www.huaweicentral.com/huawei-ar-hud-showcase-at-munich-international-auto-show/



Head up displays (HUD)

- **Helmet mounted displays**
  - The projection is presented through a screen of the helmet and is mainly used for military airforce pilots
  - https://www.youtube.com/watch?v=TqGe4Pr5qvg
  - helmet is custom-made and estimated to cost at least $400,000 each

https://www.journal-aviation.com/actualites/thales-remporte-une-nouvelle-commande-de-viseurs-de-casque-scorpion-pour-les-f-16-de-la-garde-nationale-aerienne-americaine~55252.html

Head up displays (HUD)

- **Helmet mounted displays**
  - Used also in Industry :
    - https://www.youtube.com/watch?v=4V7OOIchM7k

Holographic display

- A holographic display uses light diffraction to display 3D objects in the form of a still image or animated sequences in real life. It was originally invented in 1948 by a physicist, Dennis Gabor. He was awarded the **Nobel Prize in Physics** in 1971 for his invention and development of the holographic method
- User can freely see characters or objects from all angles and sides – looking as if they're all alive.
- https://www.cosmopolitan.fr/,hologramme-michael-jackson-billboard-music-awards,1899026.asp

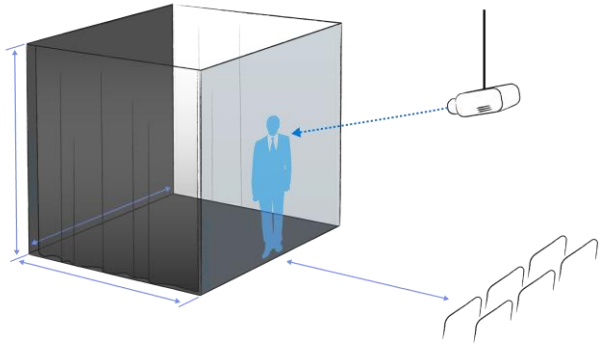
Mélenchon political meeting

Michael Jackson is back !

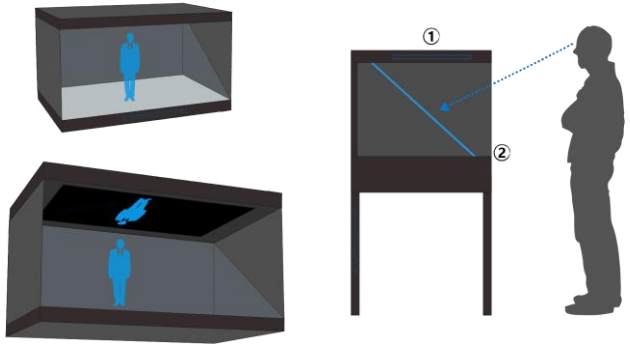
Iron Man

Holographic display

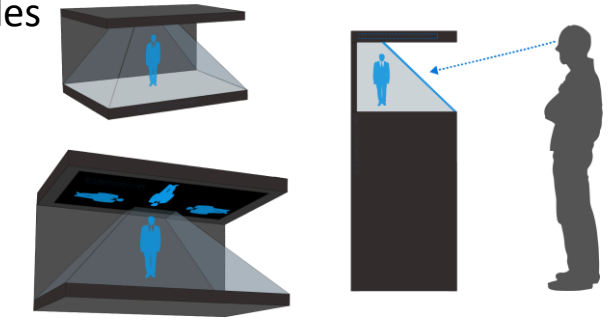
- The scenic hologram
  - Projection on a tissue or a glass



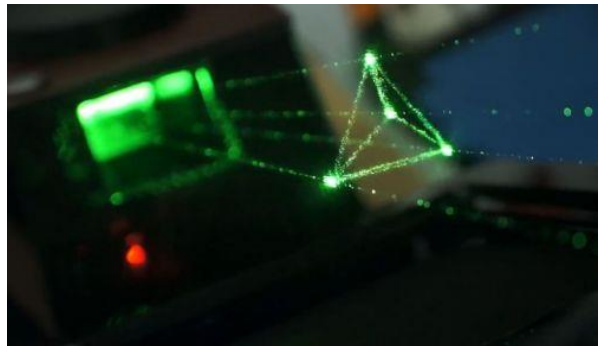
- The showcase hologram
  - inclined glass by 45°, top projection



- Pyramid hologram
  - multiply the inclined windows to observe the projected object from several angles



- laser-based volumetric hologram (experimental)
  - Needs no support for light reflection
  - https://mashable.com/video/holovect-3d-projections-star-wars#6YEfJY0CcSqM



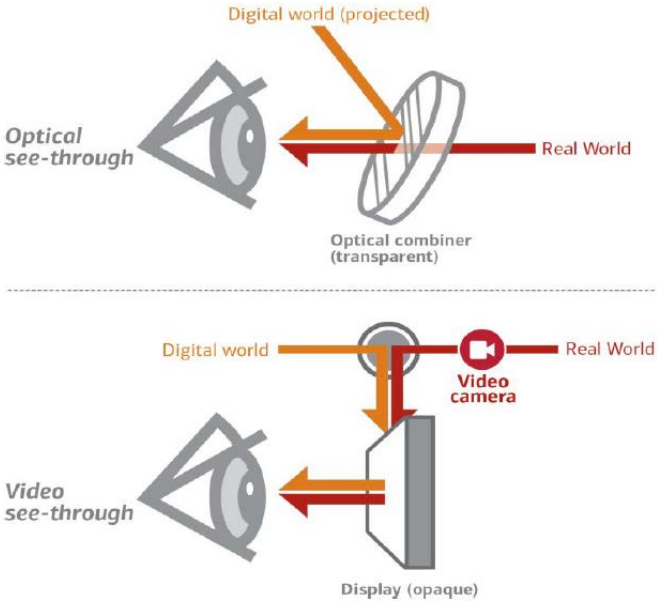
AR Smart Glasses

- Smart glasses are one of the more popular types of augmented reality devices. Theses are glasses that augment the vision.

- Smart glasses are of two types:

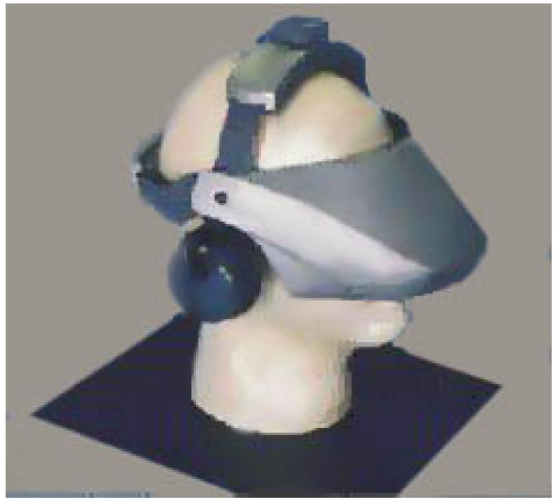
  - **Optical see-through** :
    - Virtual objects are projected on a transparent support

  - **Video see-through**
    - Virtual objects are added to the view filmed by the camera in real time, then displayed on the screen

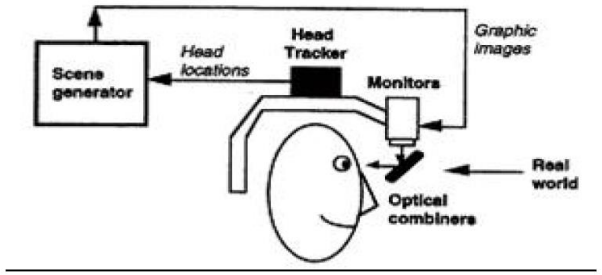


AR Smart Glasses

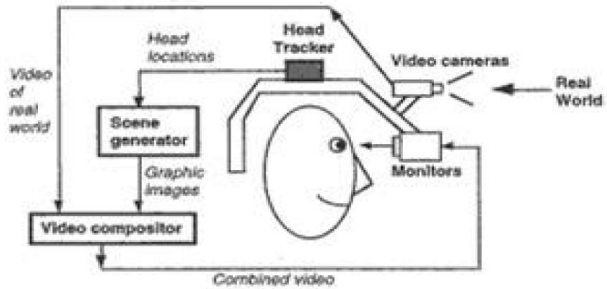
Optical See-Through HMD.



Video See-Through HMD.



Optical See-Through Scheme.



Video See-Through Scheme.

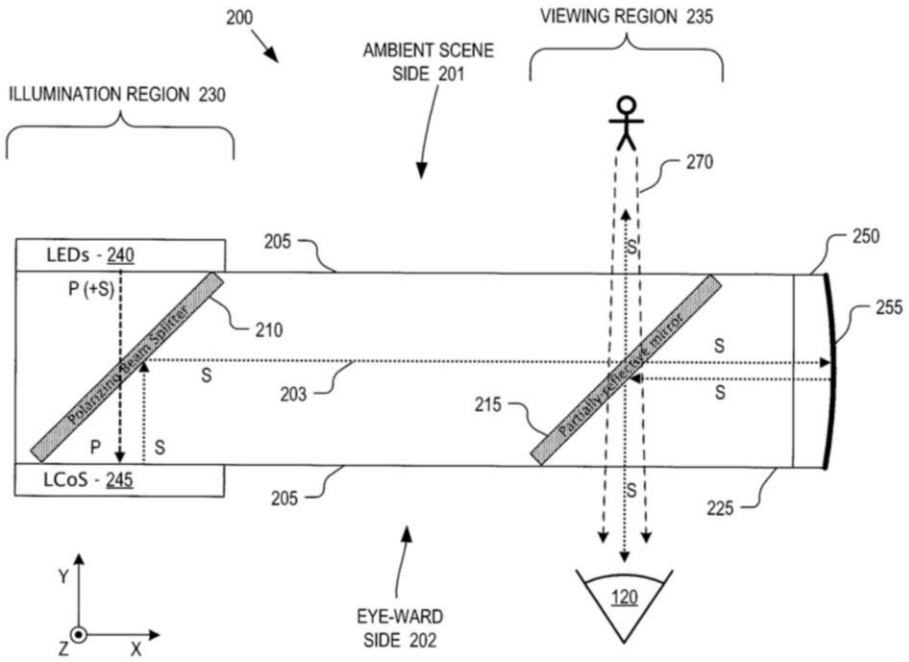
Optical see through smart Glasses

- Selection Criteria:
  - Battery life, Processor power, Screen resolution, Microphone, Speaker
  - Connectivity options (Bluetooth, WiFi, etc.)
  - Internal sensors (cameras, GPS, gyroscopes, magnetometers and accelerometers)
- Examples:
  - https://www.youtube.com/watch?time_continue=11&v=7OM3G7BBfQ4

Source : www.aniwaa.fr

Optical see through smart Glasses

- Google Glass
  - https://www.youtube.com/watch?v=4EvNxWhskf8
- Google Glass Enterprise Edition 2:
  - https://www.youtube.com/watch?v=5IK-zU51MU4



Optical see through smart Glasses

- Magic leap 2
  - Lightweight and advanced AR device
    - Used in industry
      - https://www.youtube.com/watch?v=uR_XOiakAME
    - Used in healthcare
      - https://twitter.com/sentiarco/status/1520451521241960448
    - Some characteristics :
      - Field of View (FOV) : 70° diagonal
      - Installed Memory (RAM): 16GB LPDDR5
      - Dimming Technology : Built-in 120Hz
      - Storage : 256GB
      - Weight : 260g
      - Battery autonomy : 3.5hrs
      - Price : Starting from $3299

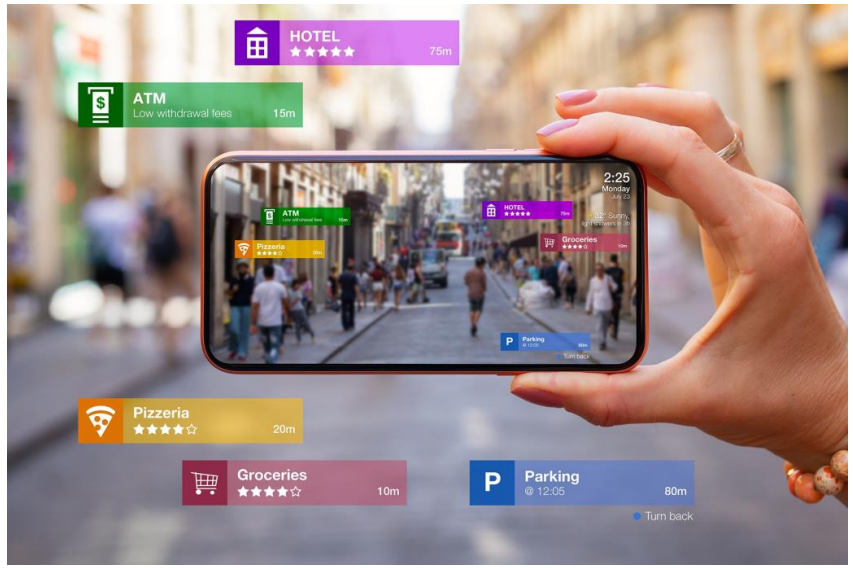
Video see through smart Glasses

- Theses are VR headsets that are equipped with an inbuilt camera which is often used for creating AR experiences on the device.
- They generally suffer from latency in capturing and rendering the real world, but the graphical content is richer.
- Examples:
  - HTC Vive VR headset
    - https://www.youtube.com/watch?v=xkw133wvPYM

  - Meta Quest 2
    - https://www.youtube.com/watch?v=5_bVkbG1ZCo

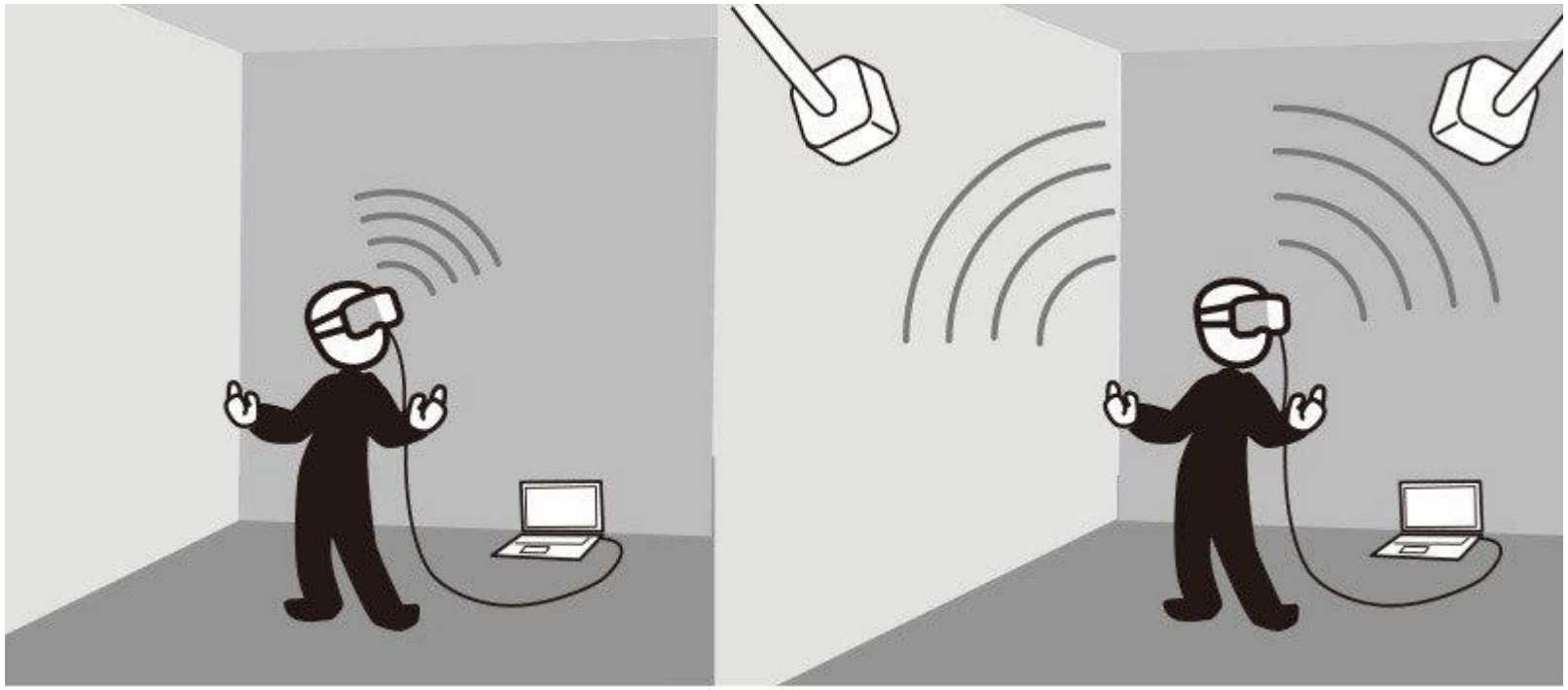
Handheld mobile AR

- A type of video see through AR that runs on mobiles or tablets.
- Promoted by the development of many AR libraries like ARKit, ARCore, MRKit
- Many popular applications :
  - Snapchat lenses
  - Games : Pokemon go
  - Live translation (https://www.youtube.com/watch?v=eCFigxb7lWU)



Configurations for user tracking

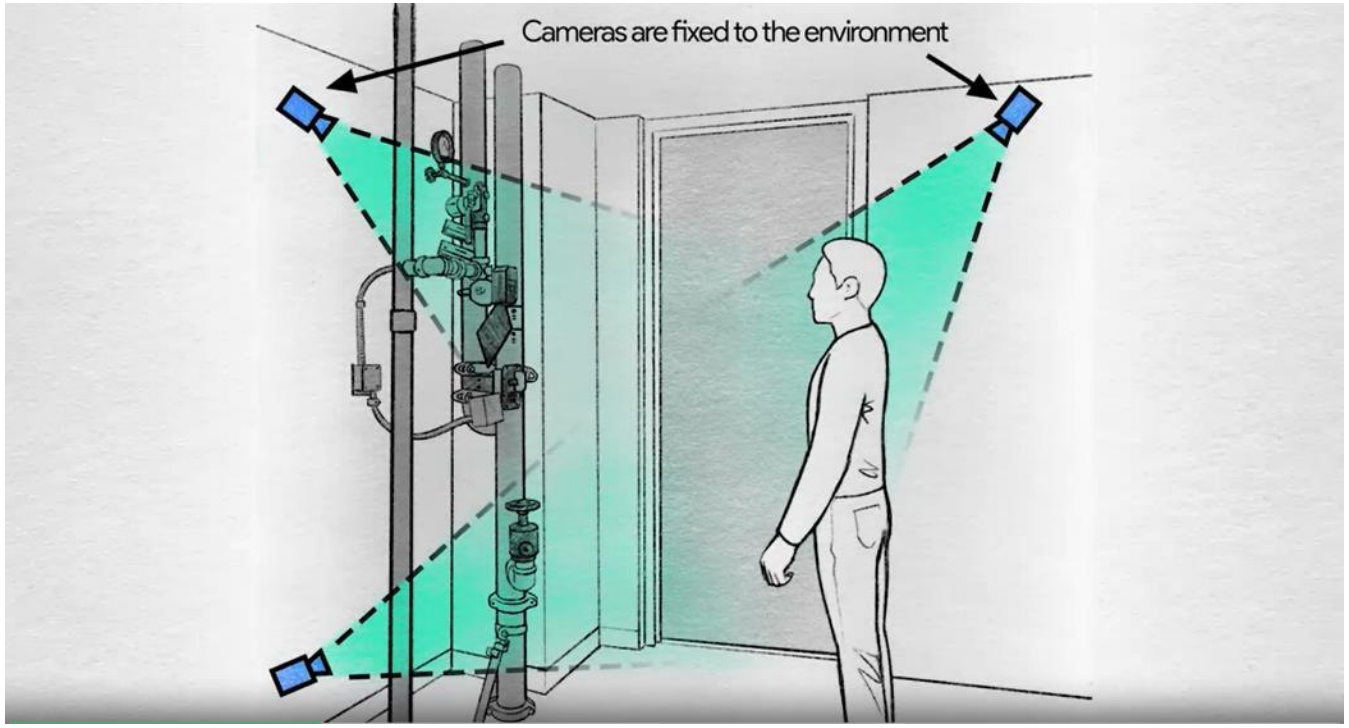
- Inside out tracking
- Outside in tracking



Outside-in tracking

- Cameras fixed in the augmented space
- Example:
  - Oculus rift
  - HTC Vive

- (+) Gain in functionality,
- (-) loss in portability

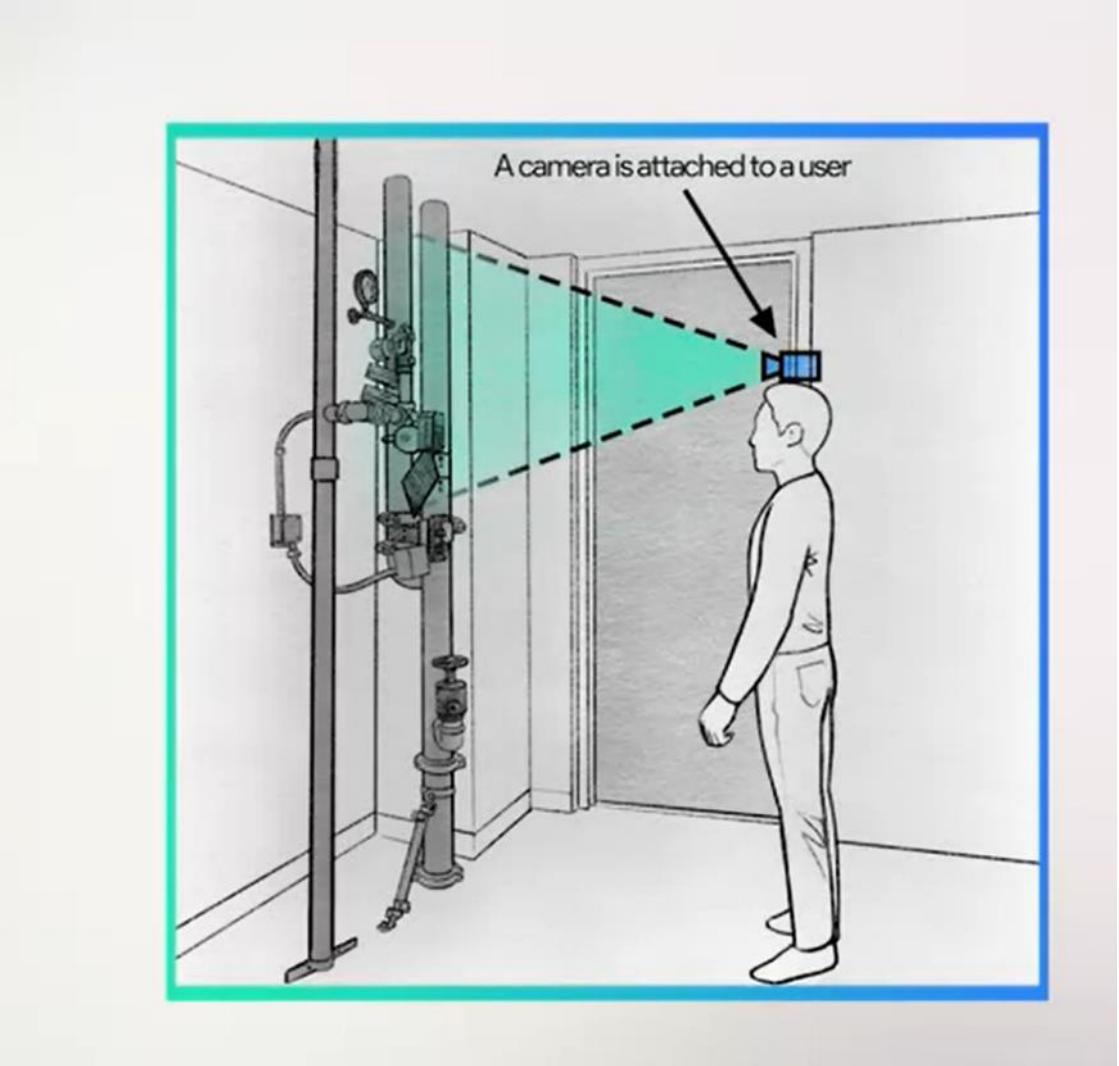


Inside-out tracking

- Many cameras and sensors are attached to the user's helmet

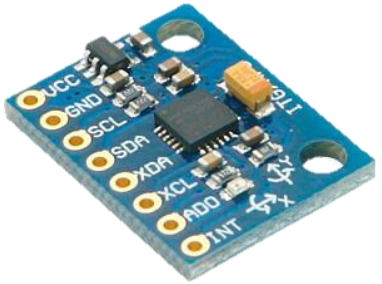
- Example:
  - Hololens:
    - 5 cameras to analyze the environment
    - 1 camera to measure the depth
    - 1 HD camera video,
    - 1 light sensor
    - 4 microphones
  - Oculus Quest

- (+) : Gain in portability
- (-) :
  - Footprint
  - Energy consumption
  - Heater

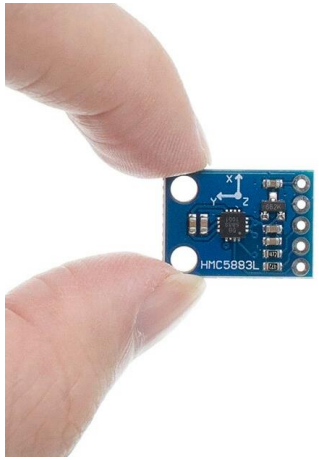


Motion tracking for AR

- Accelerometer :
  - measures acceleration : the change in velocity divided by time.
  - Acceleration forces can be static, like gravity, or dynamic, like motion or vibration.

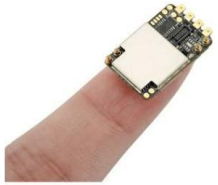


- Gyroscope:
  - Measures orientation and angular velocity.
  - It measures the rotation of the phone, and the AR experience updates in consequence.



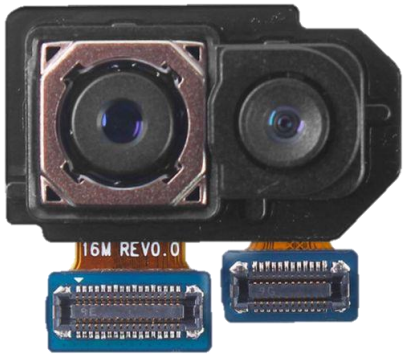
- Magnetometer:
  - Gives smartphones simple orientation linked to the Earth's magnetic field (N, S, E, W)
  - This feature is essential for location-based AR applications.

- GPS :
  - Global satellite navigation system that provides geolocation and time information to a GPS receiver, such as in your smartphone.
  - This feature is essential for location-based AR applications.



Visualizing the real world with AR

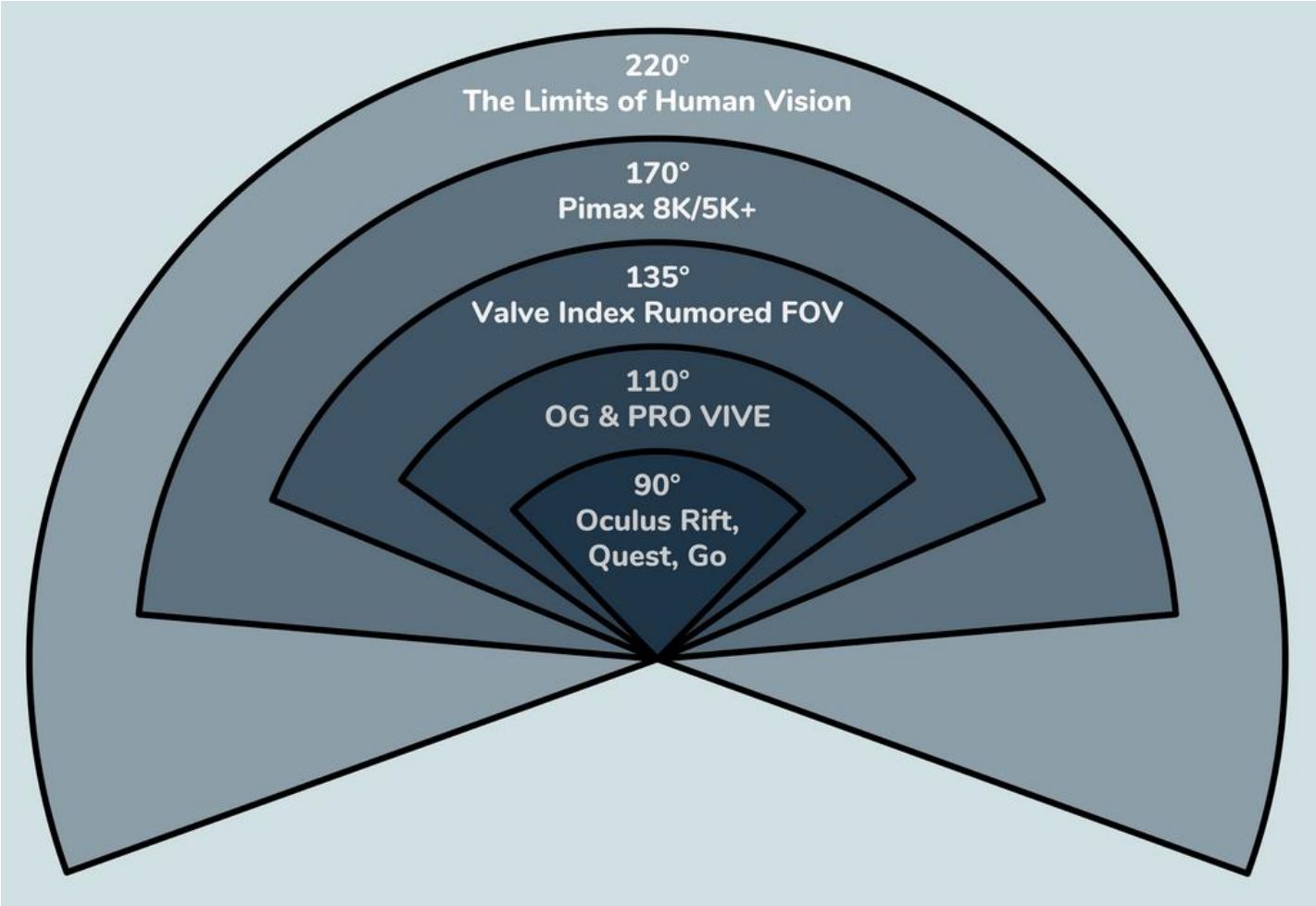
- Phone Camera:
  - With mobile AR, your phone's camera provides a live feed of the surrounding real world on which AR content is overlaid.
  - Complementary technologies such as machine learning, image processing and computer vision helps to produce high-quality images and spatial maps for mobile AR.



- Display:
  - The screen of the smartphone is important to get sharp images and display 3D rendered assets.
  - A smart phone with screen specs of 5.5-inch AMOLED QHD (2560 x 1440) display at 534 ppi, which means the phone can display 534 pixels per inch, resulting in rich and vivid images.

Field of view (field of view)

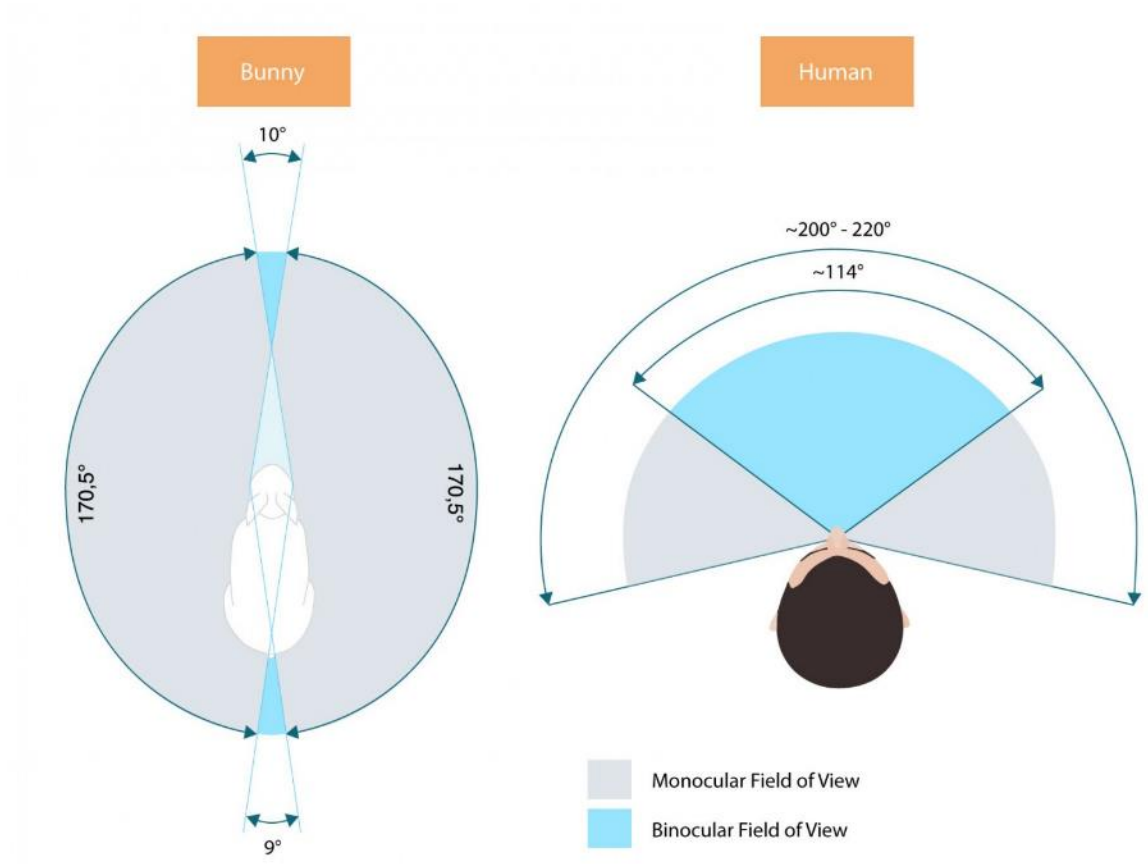
- The "field of view" refers to the portion of vision covered by the display system of a VR headset.
- A wide field of view immerses the user in a virtual environment, while a narrow field of view can feel like using binoculars.



Field of view (field of view)

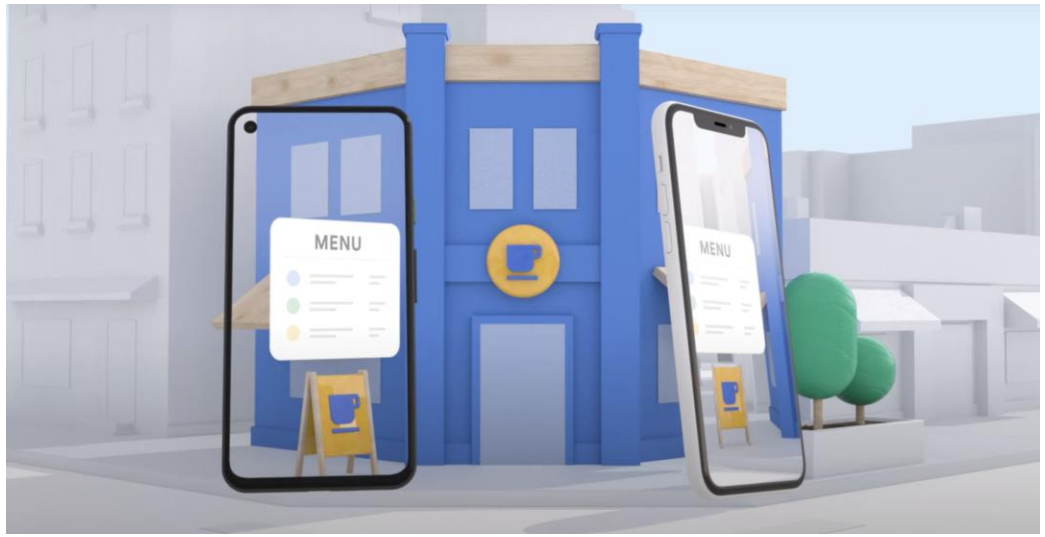
- There are two types of fields of vision that work together to form human vision.
  - The monocular visual field describes the field of vision of only one eye. For a healthy eye, the horizontal monocular field of view is between 170° and 175° and consists of the angle from the pupil to the nose,
  - The binocular visual field is the combination of the two monocular visual fields of most humans. When combined, they provide humans with an area of vision of 200°-220°.

- While a wider field of view is important for immersion and presence, it is in this binocular stereoscopic field of view that most of the action takes place in everyday life, as well as in virtual or augmented reality headsets.



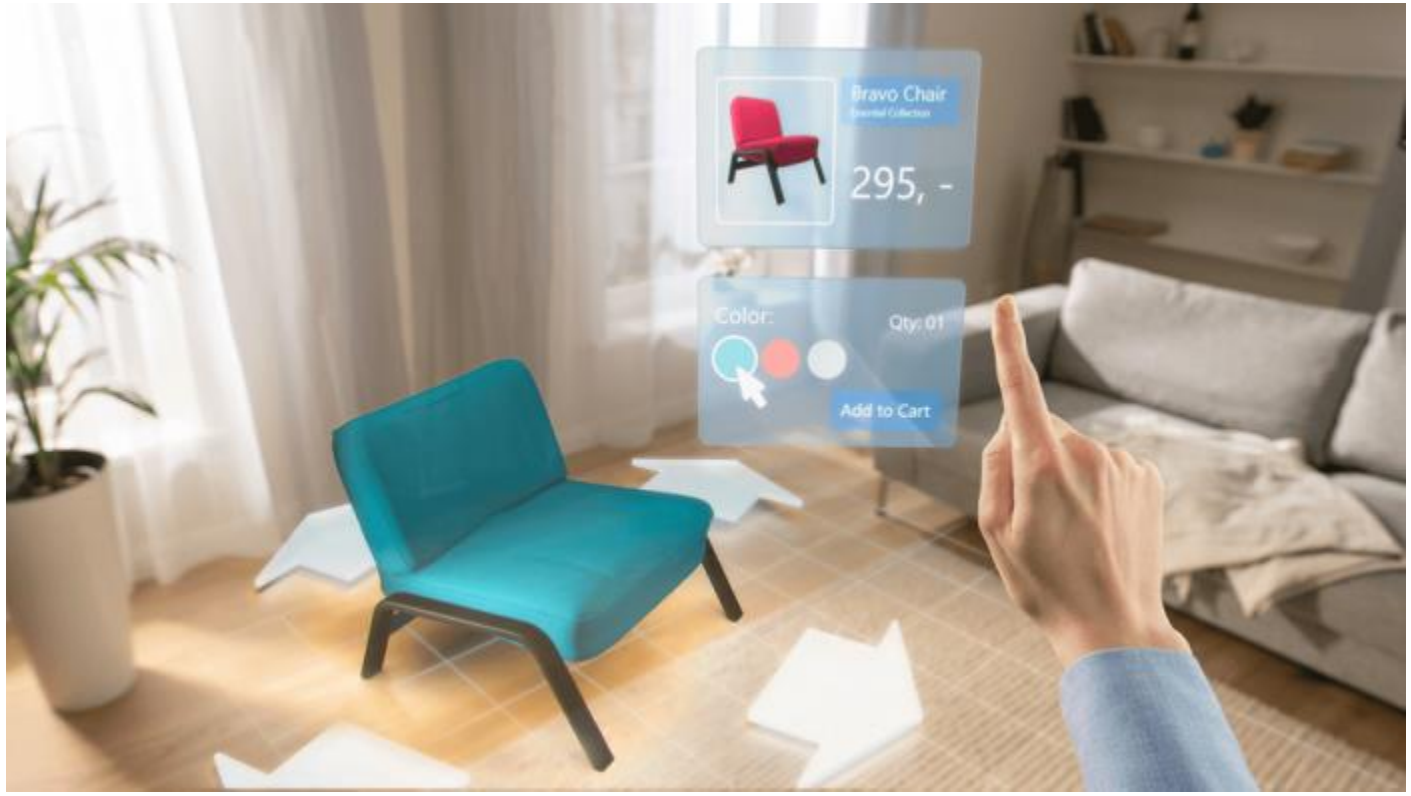
Shared AR: Cloud Anchors

- With Cloud Anchors in place, users can save and share AR experiences arround the world, whether it's for education, gaming, shopping or creative expression.
- Cloud anchors enables :
  - Persist AR experiences in the real world : place AR object in physical environment and another to see the same object at the same place at a later time. (virtual signs that help users find their way, virtual notes on their kitchen..).
  - Real-time collaborative experiences : enable real-time collaboration between users. (play a virtual game of ping-pong on the coffee table, paint a virtual mural together with their community.
- https://www.youtube.comch?v=b4mgaIuCozk



Plane ground recognition

- Use a set of features to recognize the soil
  - Invariant points
  - The soil must be quite variable in texture
- Use anchors to attach virtual content to a trackable point in the real world.



SLAM : Simultaneous localization and mapping

- For Augmented Reality to work, the device needs to know its 3D position in the world.
- This is calculated through the spatial relationship between itself and multiple keypoints. This process is called “Simultaneous Localization and Mapping” – *SLAM* for short.
- The algorithm has two aims:
  - **Build a map** of the environment
  - **Locate the device** within that environment
- SLAM for AR
  - https://www.andreasjakl.com/basics-of-ar-slam-simultaneous-localization-and-mapping/
- SLAM with a Kinect
  - https://www.youtube.com/watch?v=AMLwjo80WzI

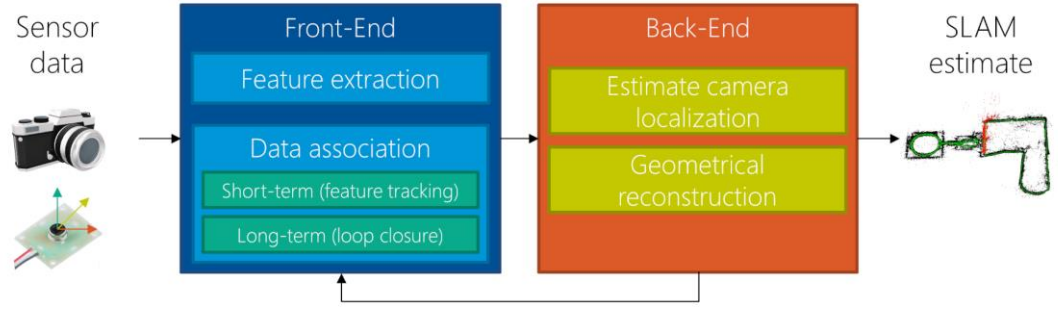
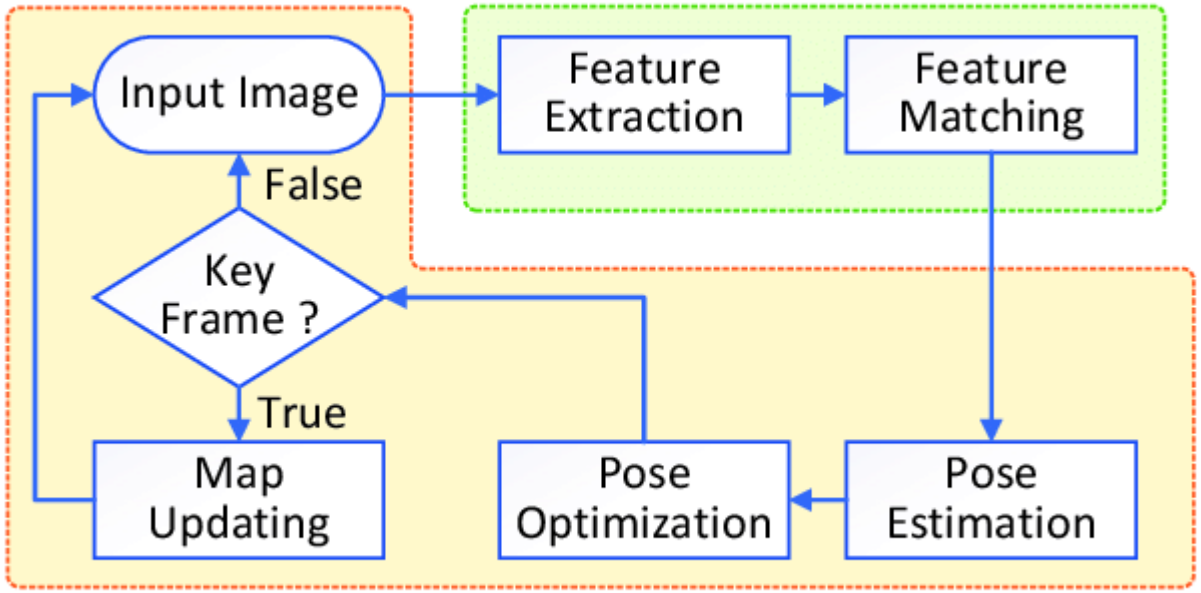


Diagram based on: Cadena, Cesar, et al. "Past, present, and future of simultaneous localization and mapping: Toward the robust-perception age." *IEEE Transactions on Robotics* 32.6 (2016): 1309-1332.
SLAM estimate: R. Mur-Artal, J. M. M. Montiel and J. D. Tardós, "ORB-SLAM: A Versatile and Accurate Monocular SLAM System," in *IEEE Transactions on Robotics*, vol. 31, no. 5, pp. 1147-1163, Oct. 2015.
3D Model of motion sensor by gerduleb: https://www.remix3d.com/details/G009SVNP5RSM
3D Model of camera by Microsoft: https://www.remix3d.com/details/G009SXQ93TH9



AR development libraries comparaison (SDK, ToolKit)

	ARKit	ARCore	Wikitude	EasyAR	ARmedia	Vuforia	MAXST	DeepAR	ARToolKit	XZIMG
2D recognition	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3D recognition	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes
Lighting estimation	Yes	Yes	No	No	No	No	No	No	No	No
SLAM	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	No
Cloud recognition	Yes	Yes	Yes	Yes	No	No	Yes	No	No	No
Geolocation	Yes	Yes	Yes	No	Yes	No	No	No	No	No
Free version	Yes	Yes	Yes (trial only)	Yes	No	Yes (trial only)	Yes (trial only)	Upon request	Yes	Yes (trial only)

https://jasoren.com/top-ar-sdk-in-2018/

AR development libraries

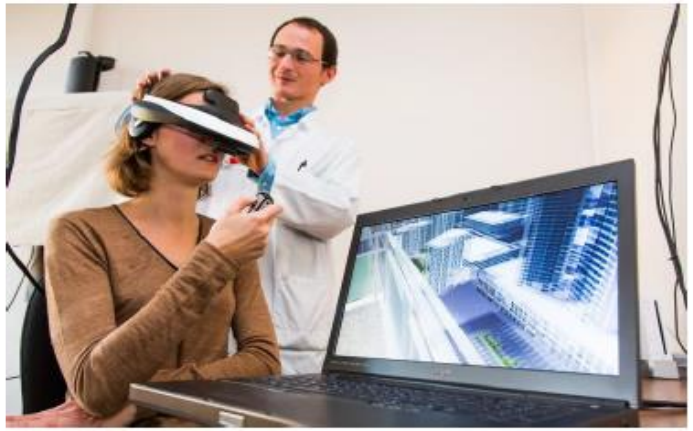
- Recommended development environment :
  - vuforia / ARCore / ARKIT
  - Unity

- Quick sample : https://www.youtube.com/watch?v=khavGQ7Dy3c

Virtual Reality

Virtual reality

- Completely immerse the user in a virtual world in a very real way.
- Simulate the physical presence of a user in an artificially generated environment.
- Artificially reproduce a sensory experience, which can include sight, touch, hearing and smell.



Types of VR headsets

- Connected by cables to a powerful PC

PC based

Smartphone based

- Carries a smartphone as a display medium

- Works without external PC

Standalone

Console based

- Connected to a game console

PC based and console based VR headsets

HTC VIVE

- **Metascore**: 4.4/5
- **Platform(s)**: SteamVR, VIVEPORT
- **Country**: Taiwan
- **VR headset price**: $599 (see on **Amazon**)

Oculus Rift

- **Metascore**: 4.1/5
- **Platform(s)**: Oculus
- **Country**: US
- **VR headset price**: $399 (see on **Amazon**)

Razer HDK2

- **Metascore**: 3.3/5
- **Platform(s)**: OSVR, SteamVR
- **Country**: US
- **VR headset price**: $399 (see on **Amazon**)

Sony PlayStation VR (PSVR)

- **Metascore**: 4.3/5
- **Platform(s)**: PlayStation
- **Country**: Japan
- **VR headset price**: $299 (see on **Amazon**)

Smartphone based VR headsets

- Criteria of choice
  - Immersive Experience
  - Display / Field of view (FOV)
  - Compatibility with the mobile
  - Access to VR applications
  - Cost of purchase

Samsung Gear VR

- **Metascore:** 4.0/5
- **FOV:** 101°
- **OS:** Android
- **Country:** South Korea
- **VR headset price:** $130 (see on **Amazon**)

Google Daydream View 2 (2017)

- **Metascore:** 3.8/5
- **FOV:** 100°
- **OS:** Android
- **Country:** US
- **VR headset price:** $99

VR BOX

- **Metascore:** 3.5/5
- **FOV:** 78°
- **OS:** Android, iOS
- **Country:** China
- **VR headset price:** $9 (see on **Amazon**)

Pansonite VR Headset

- **Metascore:** 3.6/5
- **FOV:** 120°
- **OS:** Android, iOS
- **Country:** US
- **VR headset price:** $50 (see on **Amazon**)

Canbor VR1002

- **Metascore:** 3.5/5
- **FOV:** 120°
- **OS:** Android, iOS
- **Country:** US
- **VR headset price:** $29 (see on **Amazon**)

VeeR VR Google Cardboard

- **Metascore:** 4.0/5
- **FOV:** 95°
- **OS:** Android, iOS smartphones
- **Country:** China
- **VR headset price:** $8 (see on **Amazon**)

Standalone VR headsets

DPVR M2 PRO

- **Metascore**: –
- **Platform(s)**: Google Play Store
- **Country**: China
- **VR headset price**: $590 (see on **GearBest**)

Oculus Quest (Project Santa Cruz)

- **Metascore**: –
- **Platform(s)**: Oculus
- **Country**: United States
- **VR headset price**: $399

Oculus Go

- **Metascore**: 4.2/5
- **Platform(s)**: Oculus
- **Country**: United States
- **VR headset price**: $199 (see on **Amazon**)

Xiaomi Mi VR

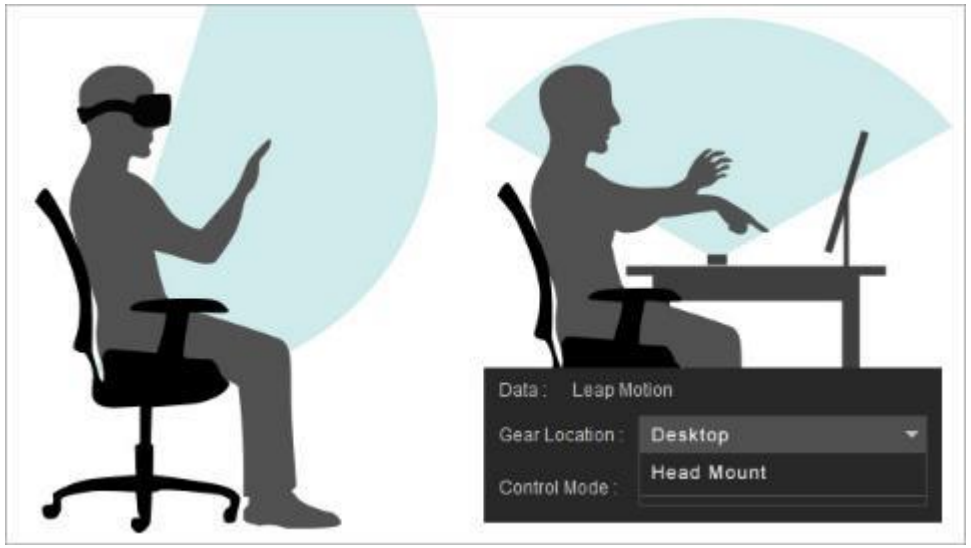
- **Metascore**: –
- **Platform(s)**: Oculus
- **Country**: China
- **VR headset price**: $235 (see on **GearBest**)

The Xiaomi Mi VR is one of the best standalone VR headsets.

VR – 360° cameras

	Entry level			Mid-tier		Professional Grade			
	LG 360 Cam	Ricoh Theta S	Samsung Gear 360	Kodak SP360	GoPro Omni	GoPro Odyssey	Nokia OZO	Facebook Surround 360	Jaunt ONE
Price	US$199.99	US$349.95	US$350	US$899	US$5,000	US$15,000	US$60,000	TBD	N/A
Company	LG	Ricoh	Samsung	Kodak	GoPro	GoPro	Nokia	Facebook	Jaunt (private)
Resolution	2K	1080P	3840 x 1920	4K	4K	4K	2K	4K, 6K, 8K	8K x 4K, or 16K x 8K
Misc	2 200 degree fish-eye	30fps for up to 25 minutes at a time	2 180 degree fish-eye	2 SP360 235 degree action cameras	6 camera modules in a cube formation	16 camera modules in a circular array	8 195 degree lenses	Open source. 17 cameras, 1 fish-eye pointing up and 2 pointing down	Only available to select partners. 2 versions, 24G with synchronized global shutters, or 24R with synchronized high res sensors

Finger tracking – Leap Motion



Tilt Brush - Google

Mixed Reality

Mixed reality

- Also known with the names
  - Merged reality
  - Hybrid reality
- Natural fusion of Real worlds and Virtual objects.
- Visualizations of 3D holographic virtual content with a headset.
- Intuitive interactivity with holographic content :
  - MR = AR + intuitive interaction (hands, occlusions)

MR headsets

- Optical See-through

Microsoft HoloLens

- **FOV:** 35°
- **Country:** United States
- **MR headset price:** $3,000

Meta 2

- **Pays** : États-Unis
- **Prix** : 1715 € *(pour le moment, uniquement le kit de développeur Meta 2 est disponible)*

Magic Leap One

- **FOV:** 40°
- **Country:** United States
- **MR headset price:** $2,295

Dimension NXG AjnaLens

- **FOV:** 95°
- **Country:** India
- **MR headset price:** $1,500

AR, MR et VR headsets

- Video See-through

HP Windows Mixed Reality (VR1000-100)

- **Metascore**: 3.6/5
- **Platform(s)**: Windows Mixed Reality, SteamVR
- **Country**: US
- **VR headset price**: $449 (see on **Amazon**)

Lenovo Explorer

Metascore: 3.4/5
Platform(s): Windows Mixed Reality, SteamVR
Country: China
VR headset price: $449 (see on **Amazon**)

Acer Windows Mixed Reality (AH101)

- **Metascore**: 3.6/5
- **Platform(s)**: Windows Mixed Reality, SteamVR
- **Country**: Taiwan
- **VR headset price**: $399 (see on **Amazon**)

Mixed reality – Microsoft Hololens

Source: Volvo