Introduction to Augmented Reality

Fivos DOGANIS

Course contents

- **Theory**
  - Definitions
  - History, 3 Types of AR
  - Technologies, Calibration, Registration, Tracking
  - Rendering, Interactions
- **Practice**
  - Overview of existing apps and tools
  - AR Web **Programming**
    - **AR.js**, **WebXR**

whoami

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cover photo: www.instagram.com/steveroe_

isep
École d'ingénieurs du numérique

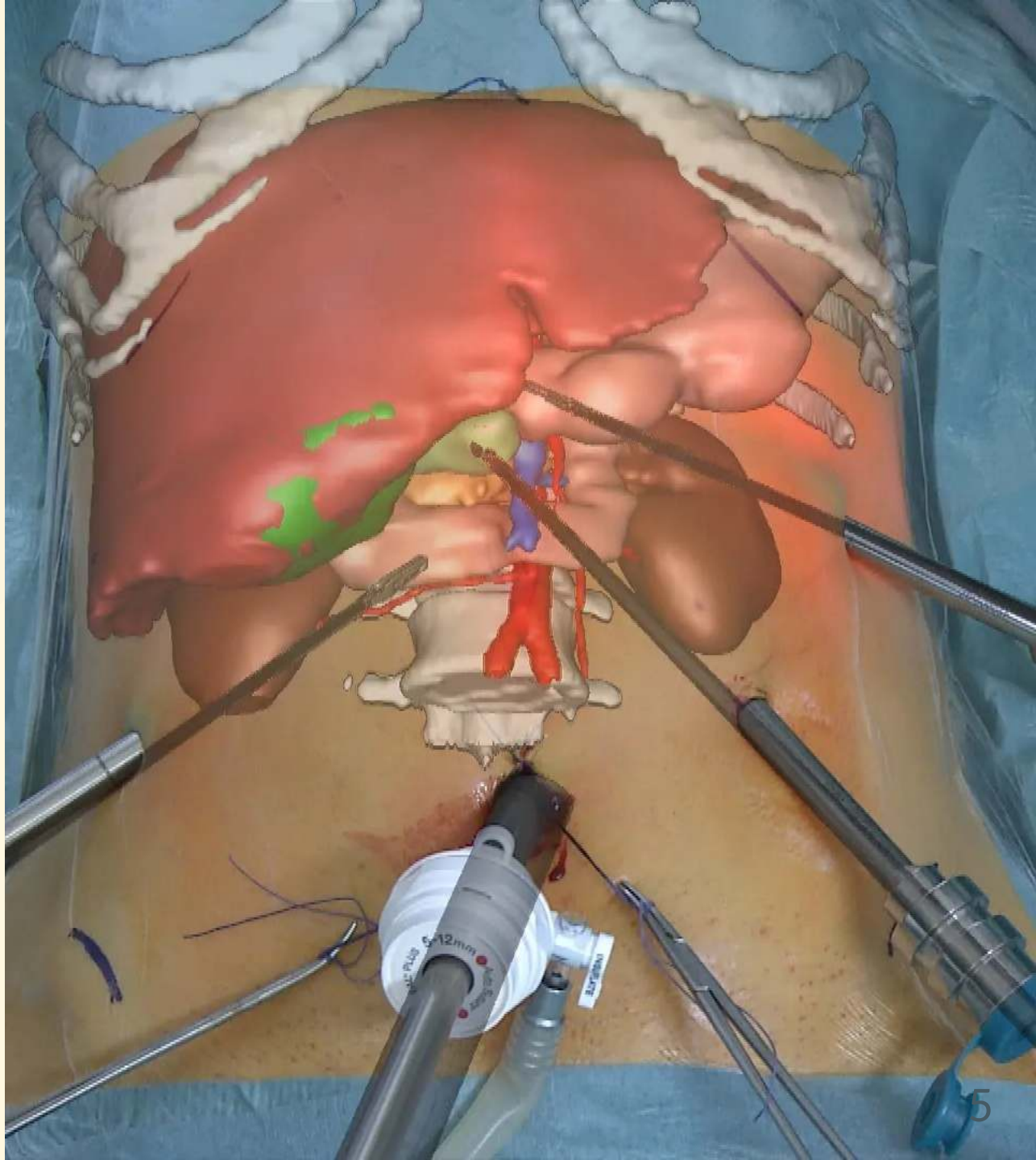
UNIVERSITY OF HULL

University of Hull

- Master of Science by Research (2001)
  Augmented Reality in Archaeology: Registration Issues

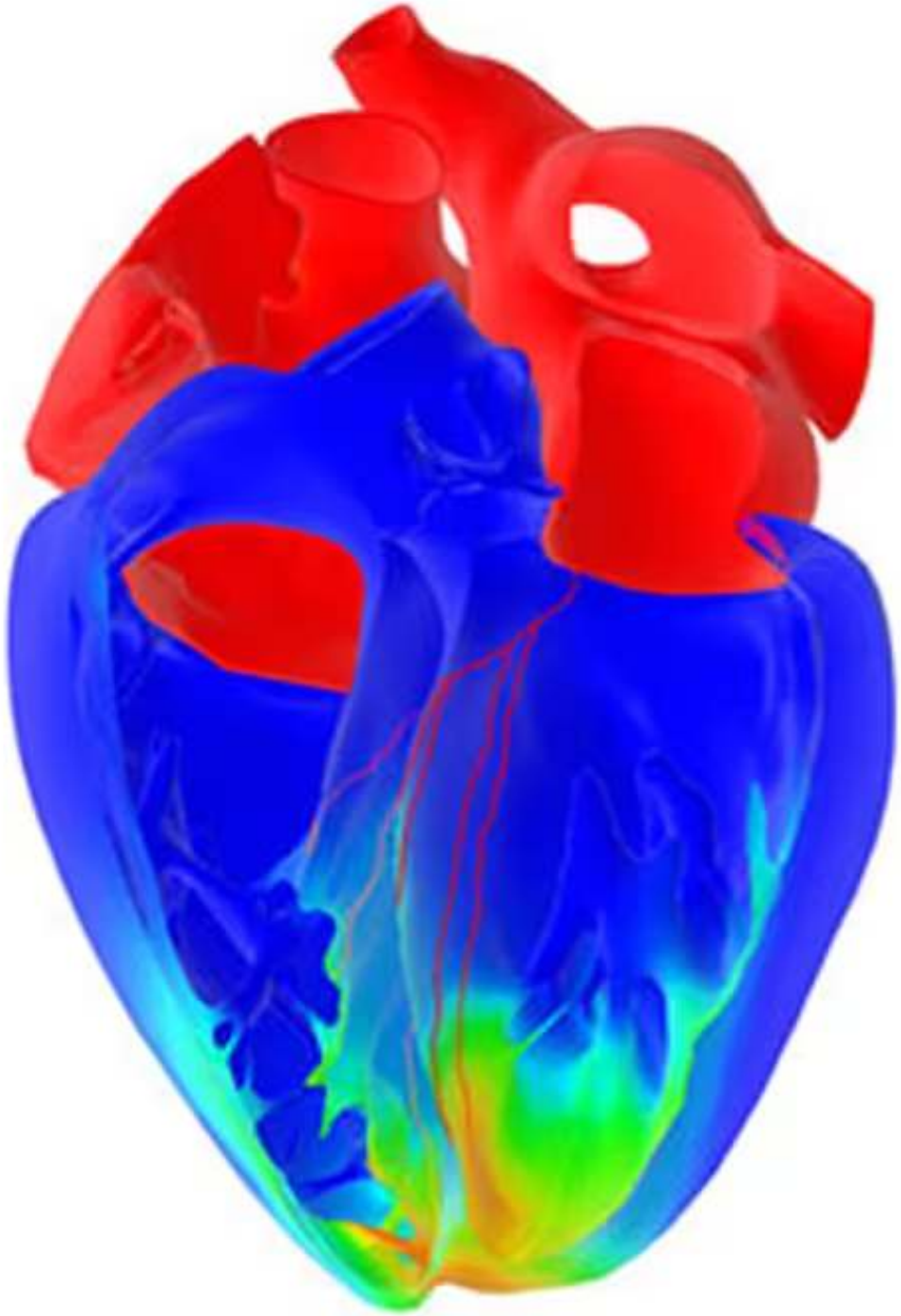
IRCAD (2002 - 2003)

- Institut de Recherche contre les Cancers de l'Appareil Digestif
- Startup
  - Virtual-Surg team
- Augmented Reality Research Engineer



Dassault Systèmes (2003+)

- 3D Visualization Engineer
  - Scenegraph, Materials
  - Geometry, Tessellation
- Virtual and Augmented Reality (XR) Engineer
- XR Research Engineer
- XR Research Manager



Dassault Systèmes

From Shape to Life

1981
3D Design

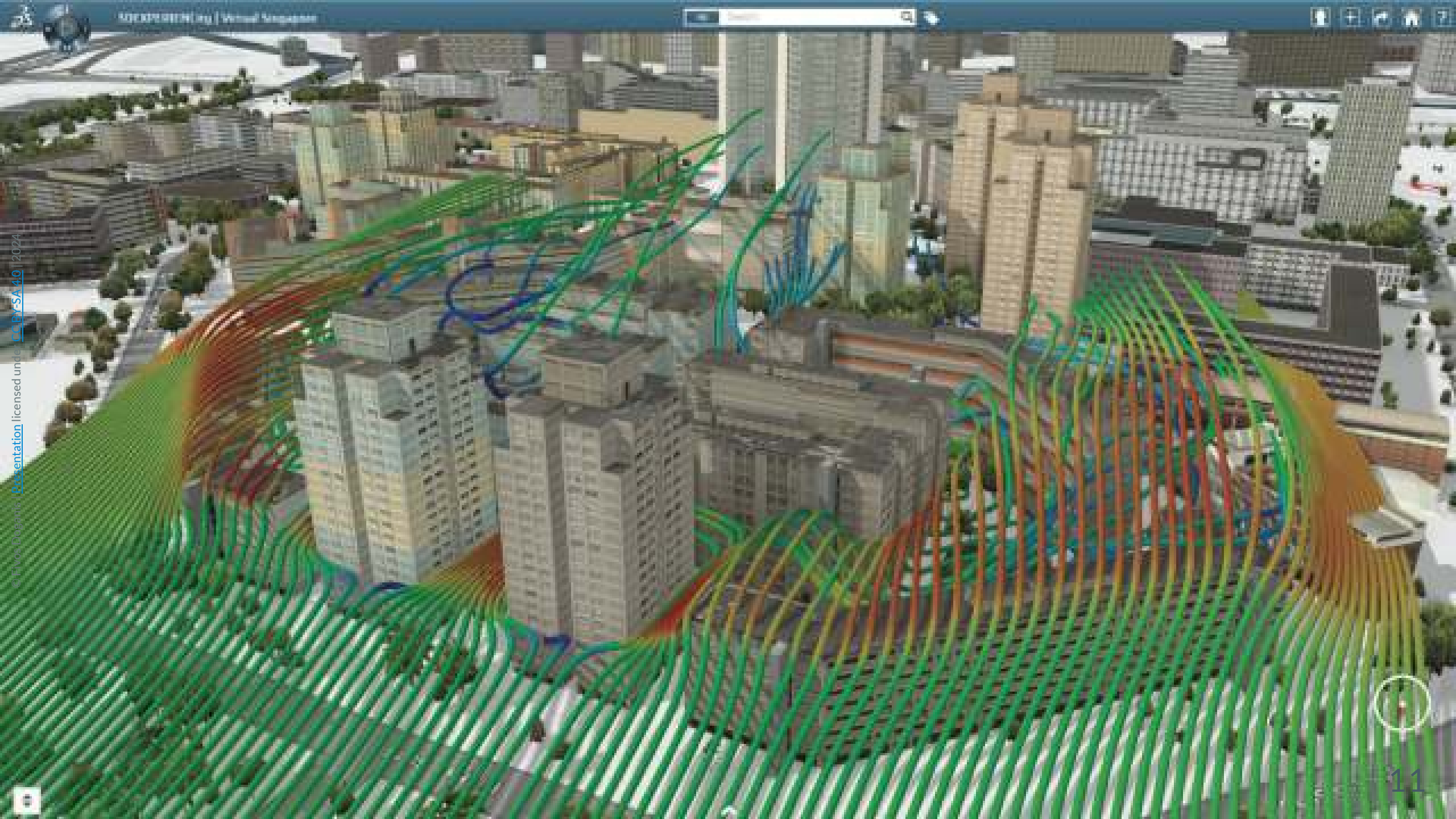
1989
3D DMU
Digital Mock-up

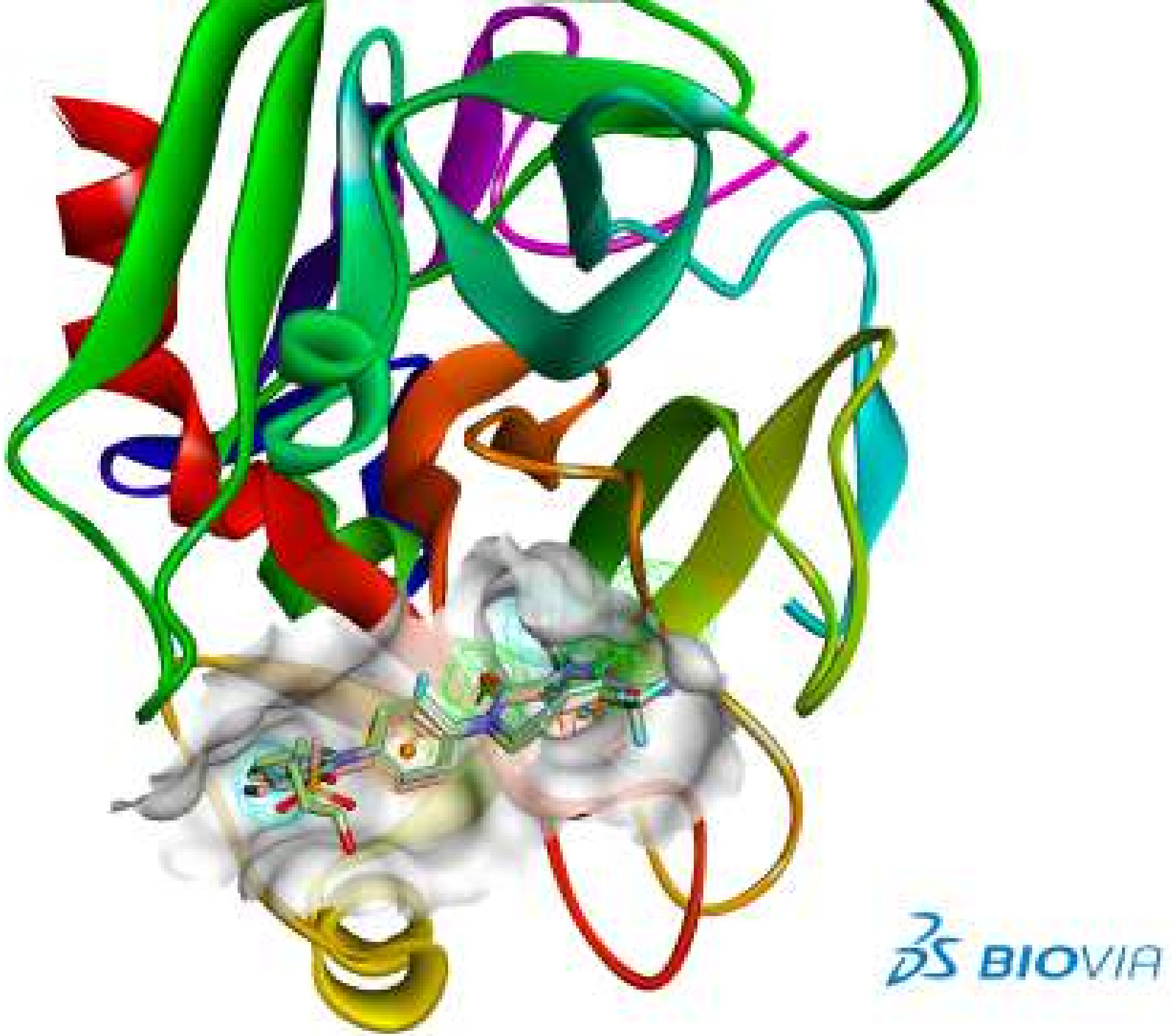
1999
3D PLM
Product Lifecycle Management

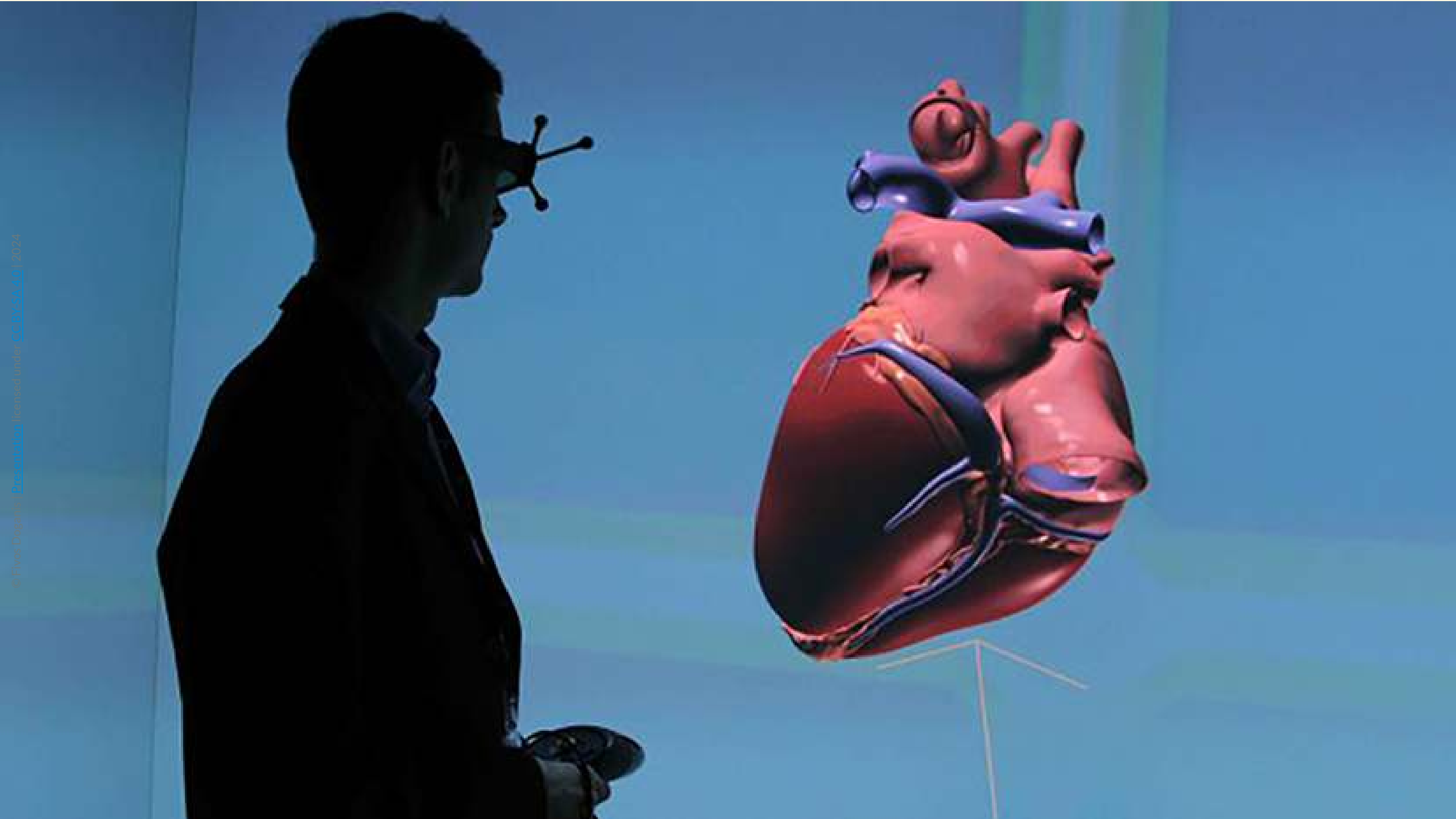
3DEXPERIENCE®

2012
3DEXPERIENCE® platform

2020
Virtual Twin Experience of **Humans**







Course audience

- Anyone looking for a simple introduction to Augmented Reality
- Computer Science students and engineers looking for a way to create cross-platform XR prototypes or even full-fledged apps

➡️ Feel free to skim through technical sections and use this course as future reference

Course prerequisites

- **Math** 🔢
  - 3D vectors and matrices
- **Programming** 💻
  - **JavaScript** notions, or any similar language (HTML kept minimal)
- 3D Web API 🧊
  - **THREE.js notions strongly recommended** (see Web 3D course)
  - alternatives: Babylon.js, WebGL, WebGPU
- Desktop + Smartphone (or, even better, a XR HMD!) 📱 🥽
  - VSCode

📅 Planning

- **Day 1** (6 hours)
  - 📖 **Theory**
  - 🍜 Lunch
  - 💻 **Exercises**
  - 🛸 Explore examples + choose a personal **project**
- **Day 2** (6 hours)
  - 🖋️ Evaluation: **Quizz** 20 questions / ~20 min
  - ⭐ **Personal project / game jam** ➡️ bonus points!

Project evaluation criteria

Bonus points for:

- originality 👀
- interactions 👋
- physics 💥 / animations 🕺 / sounds 🎶 / eye-candy 🎇
- GIS 🌍
- code quality ✨, tricks 😏, performance ⏱️
- fun 🎉
- **clever use of AR 📱 🥽**

AR Applications

Consumer applications

- Entertainment
  - Games: Pokemon GO AR+,Minecraft Earth (RIP 💀)
  - Social Networks: SnapChat (City Painter), Facebook
- Interior Design
  - IKEA Place
  - HomeByMe AR
- IGN: Time Machine

Pokemon GO AR+

Minecraft Earth

CHRISTIAN MARCLAY X SNAPCHAT

PLAYING POMPIDOU

SnapChat

IKEA Place

HomeByMe

IGN Time Machine

Professional applications

- Industry
- Healthcare
- Marketing

Renault Trucks

Zeal AR

Alain Afflelou

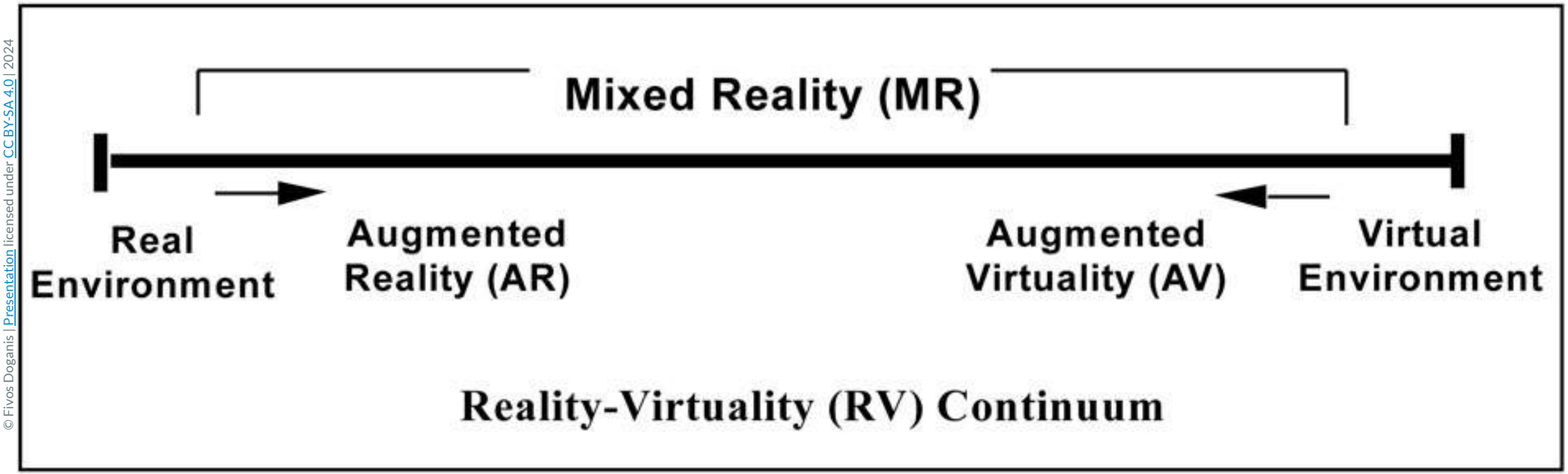
Definitions

Reality
Virtual Reality
Augmented Reality
Mixed Reality
Extended Reality
Metaverse
Spatial Computing
...

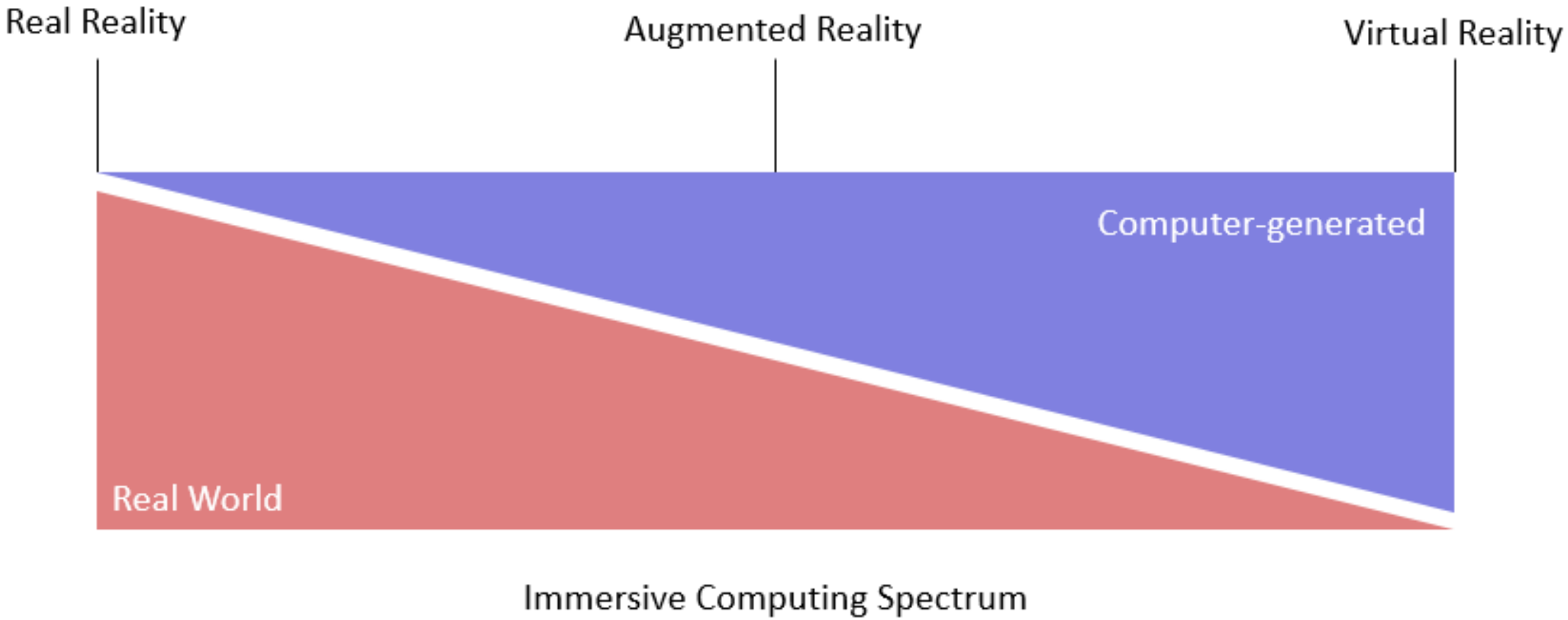
Definitions

- Milgram's **Reality-Virtuality Continuum**

Milgram, Paul; H. Takemura; A. Utsumi; F. Kishino (1994). *"Augmented Reality: A class of displays on the reality-virtuality continuum".*



Google's version



Properties of an AR system ★

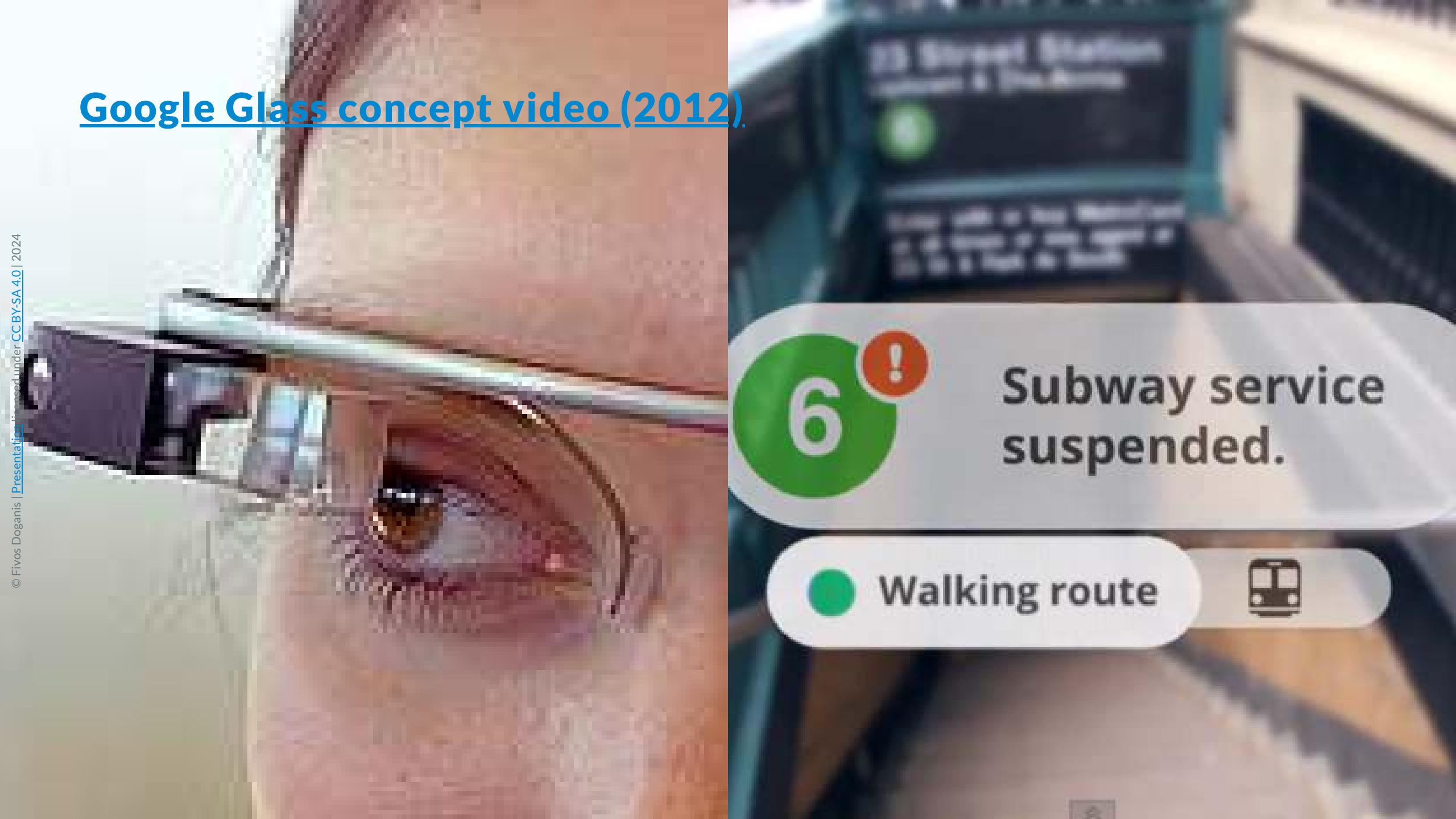
(according to Azuma, 2001)

- **combines real and virtual objects** in a **real environment**
- runs **interactively**, and in **real time**
- **registers** (aligns) real and virtual objects with each other.

Not AR:

- special effects in movies
  - technology close to AR
  - **not real time** ❌
  - not in a real environment ❌
- Google Glass
  - combines real and virtual objects in a real environment ✅
  - **no registration** ❌
  - it's a **HUD** (**H**ead-**U**p **D**isplay)
    - can still be useful! (maintenance, sports etc.)

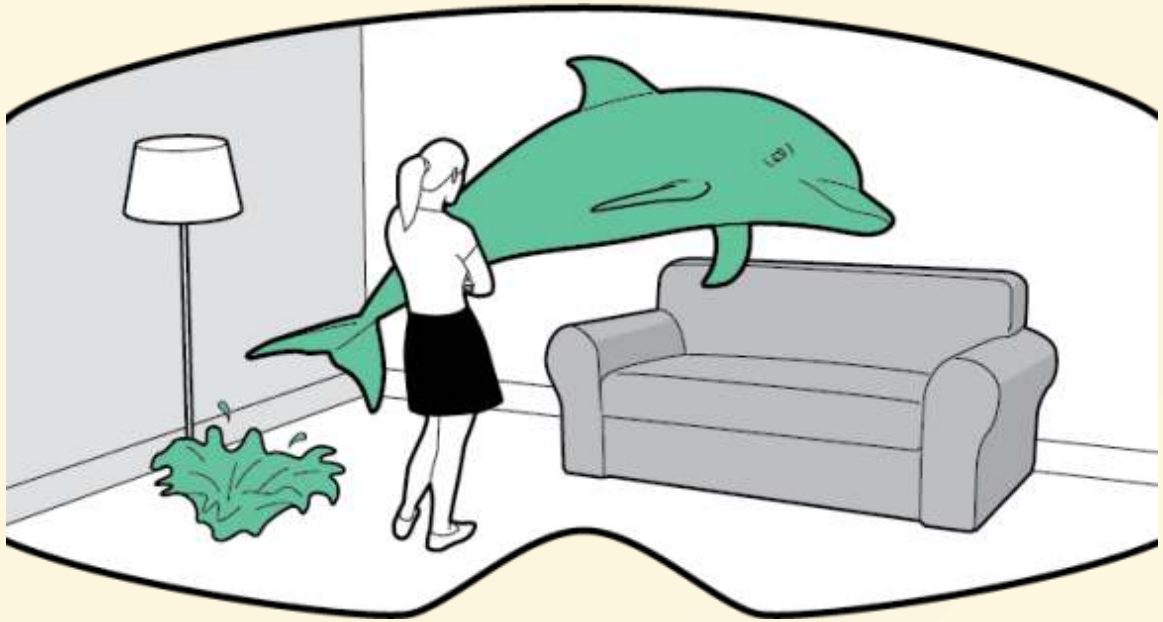
Google Glass concept video (2012)

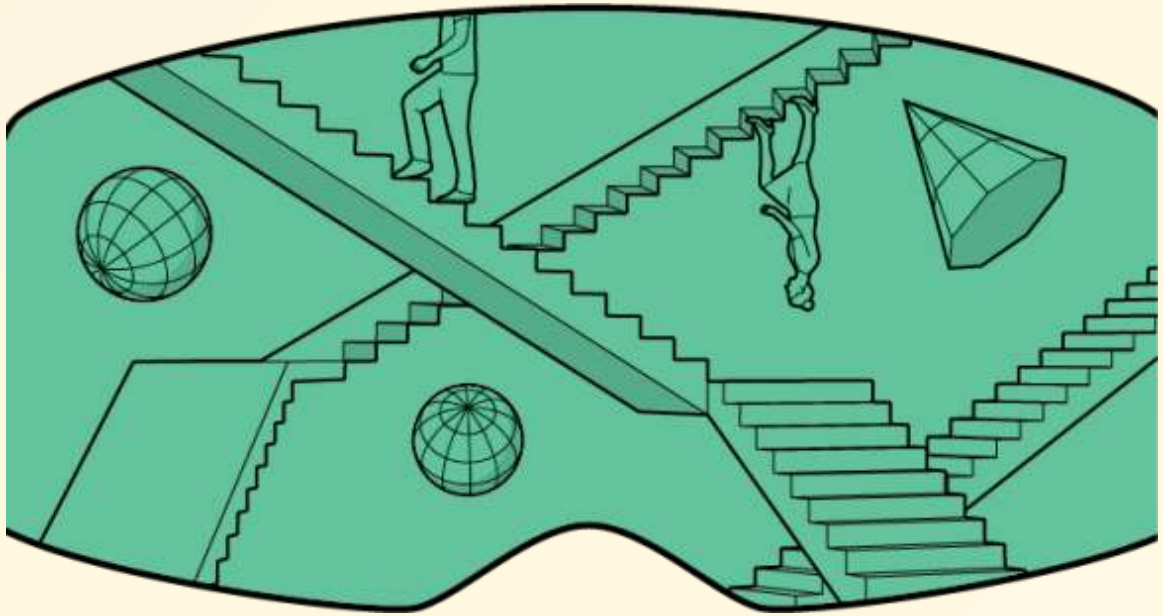


Definitions ★

- **VR** : Virtual Reality Jaron Lanier, 1987
- **AR** : Augmented Reality Thomas P. Caudell, 1990
- **MR** : Mixed Reality
  - marketing term used by Microsoft
  - ⚠️ **no clear definition**! ➡️ Term must be defined before use!
    - cf. What is Mixed Reality?
- **XR** : X = { e**X**tended / Cross (**+**) / Any (*) / A+V } Reality
  - **recent** generic term which **encompasses AR and VR**

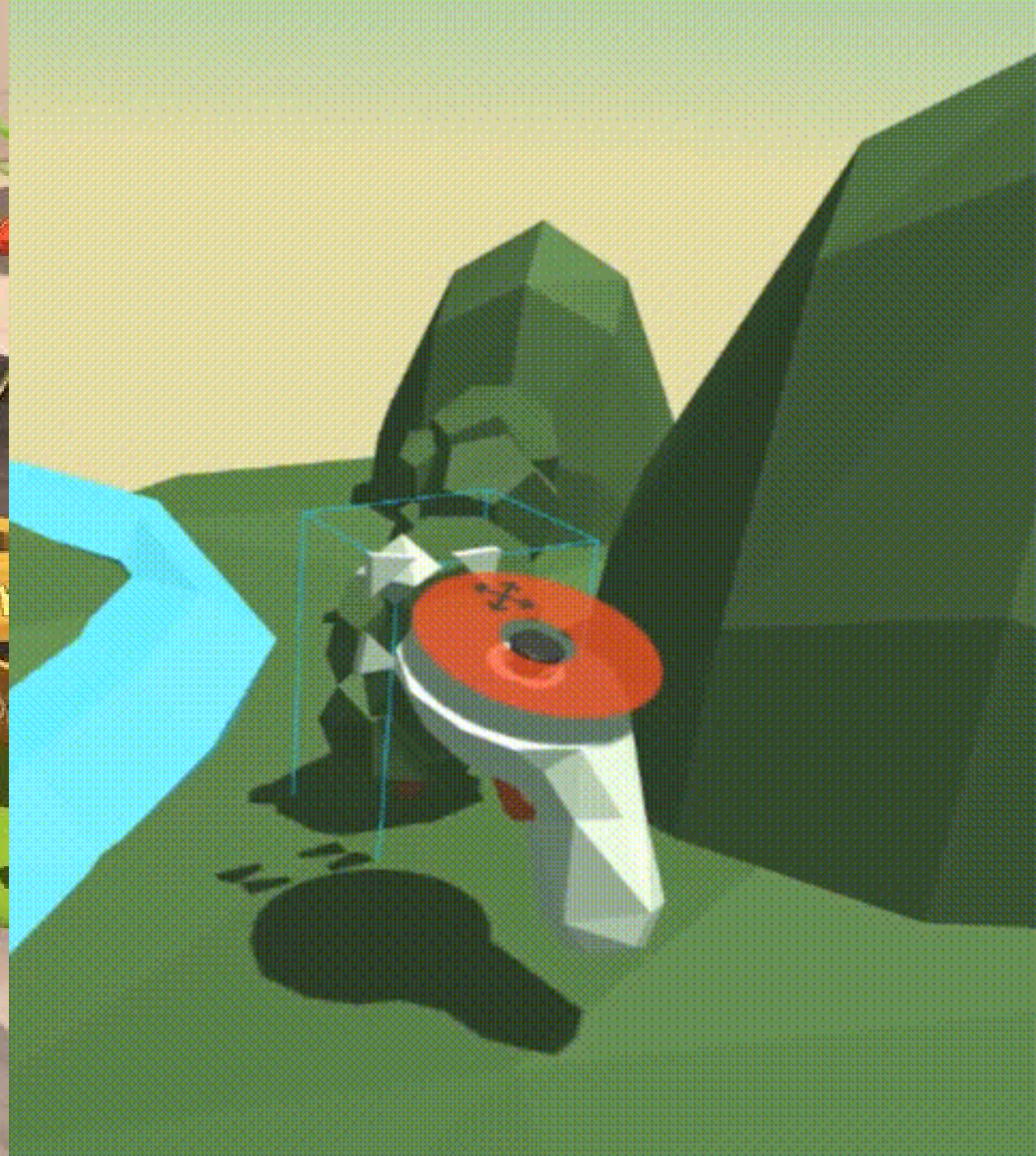
AR | VR





images:https://www.wired.com/2016/04/magic-leap-vr/

AR | VR



AR or VR?

- Similar technologies
  - 3D rendering
  - Tracking
  - Immersive interactions
- **Different effects** on the user

Effects of VR

- **Isolates** the user from the real world
- **Teleports the user** to another world, which is entirely virtual

Tiltbrush

The limits of VR

- Reminder: **continuum**!
  - No clear boundaries
- When the whole world is modeled and registered in 3D, is it still VR?
- Photogrammetry / Lightfields
  - VR but immersion in a world entirely rebuilt in 3D

Greg Madison @ Unity

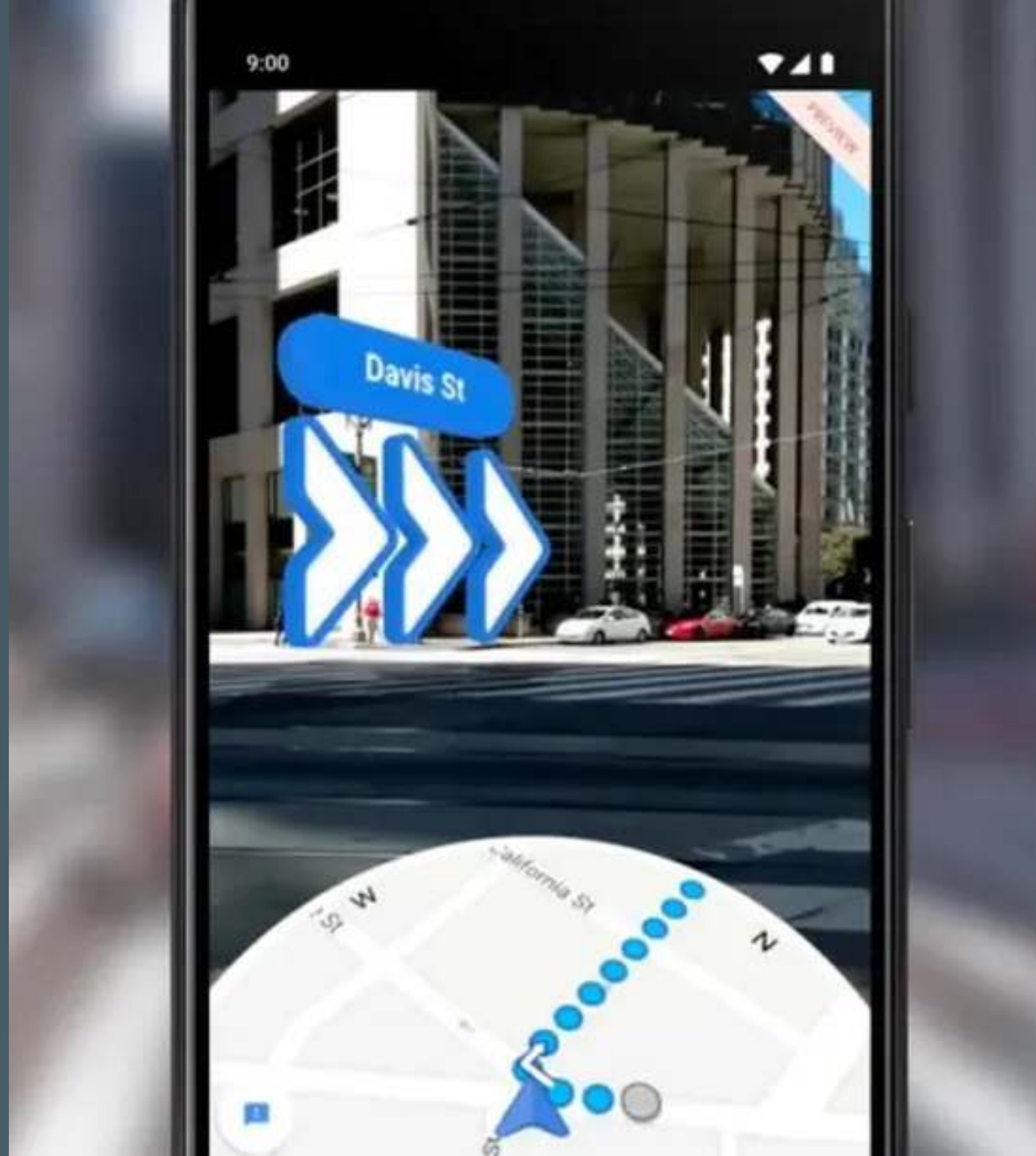
VersaillesVR

Effects of AR

- The user **stays in the real world**
- AR **enhances** the real world with contextual information
- Augmented user: acquires **new senses**!
- Information becomes visible
  - spatialized **information overlaid on top of the real world**

Google Maps AR

The browser of the future? 🧐



Brake fluid

Audi AR manual (Metaio, 2012)

2.0 TFSI

The limits of AR

- Reminder: **continuum**!
  - No clear boundaries
- When more virtual elements than real ones: **Augmented Virtuality**
  - Window to the real world
  - Real users visible

Augmented Virtuality

Varjo Teleport

video

Dangers of AR ★

- **Information overload**: Hyper-reality
  - Diminished Reality desirable?
- **Excessive assistance, altered behaviors, surveillance**
  - Black Mirror: Nosedive
- **Digital divide**
  - Some people will feel **handicaped**, missing a sense, **daltonians**
- **Privacy**: Cloud Wars
  - MAMAA* vs Open AR Cloud

MAMAA = Meta Alphabet Microsoft Apple Amazon

Hyper-reality (concept)

Black Mirror (fiction)

Scene Responsiveness (Meta 2023)

paper video

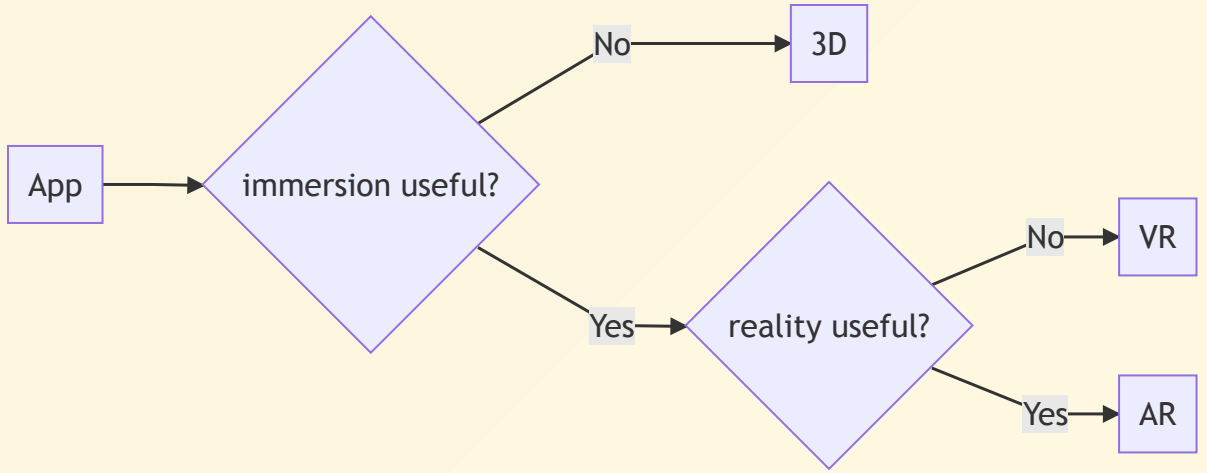
Takeaways ⭐

- VR **immerses** the user in a **virtual wolrd**
- AR **brings virtual objects** into **the real world**

Choosing the right paradigm

- Immersion useful ?
  - Yes ➡️ VR
  - No ➡️ 3D
- Immersion and real environment useful ?
  - Yes ➡️ AR
  - No ➡️ VR
- Keep in mind continuum to pick the right paradigm to create the best possible experience

Choosing the right paradigm



History

Understand technological evolutions to anticipate the future

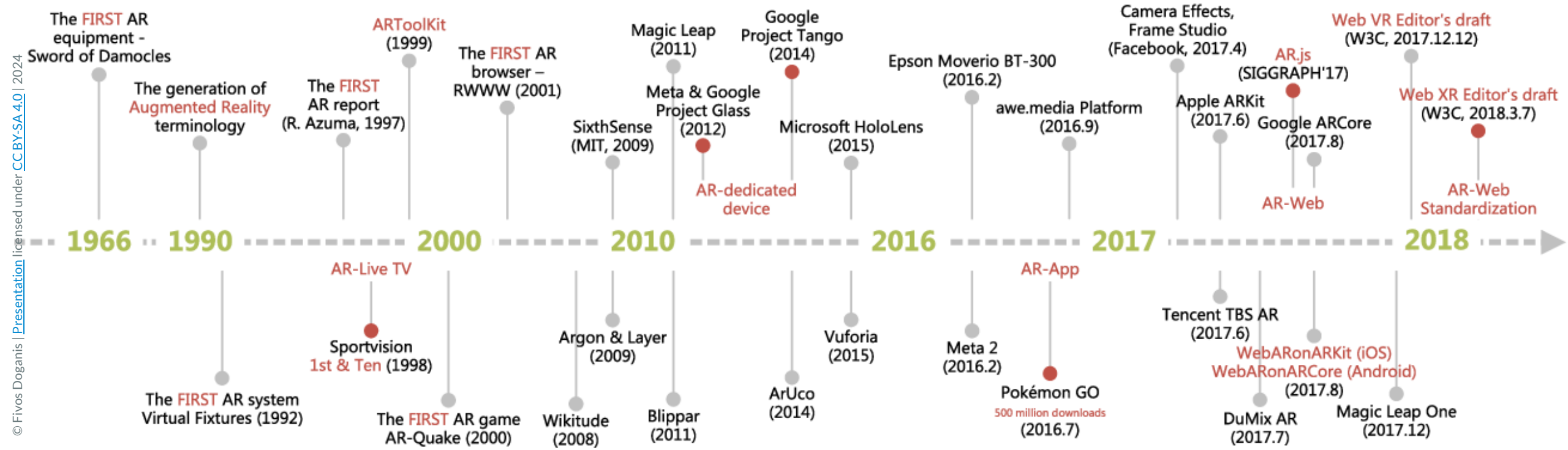


Fig. 1. ***Historical evolution of AR.***

History

Key milestones

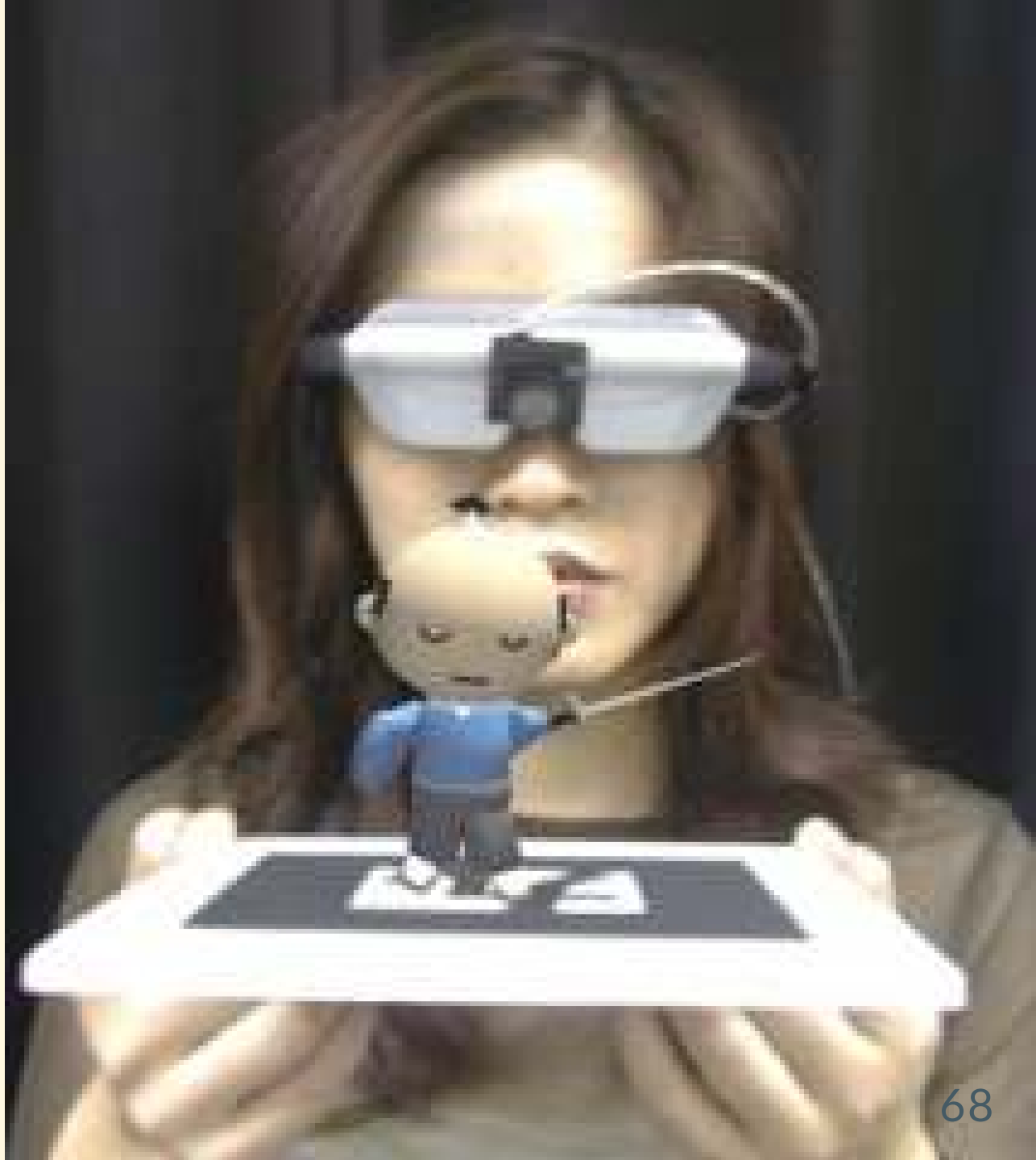
Prehistory (1966) ⭐

- Ivan Sutherland invents the first AR headset
- Can display a cube
- Follows the movements of the head (**6 DOF**)
- Nickname : The Sword of Damocles
- paper: *The Ultimate Display*

Markers (1999)

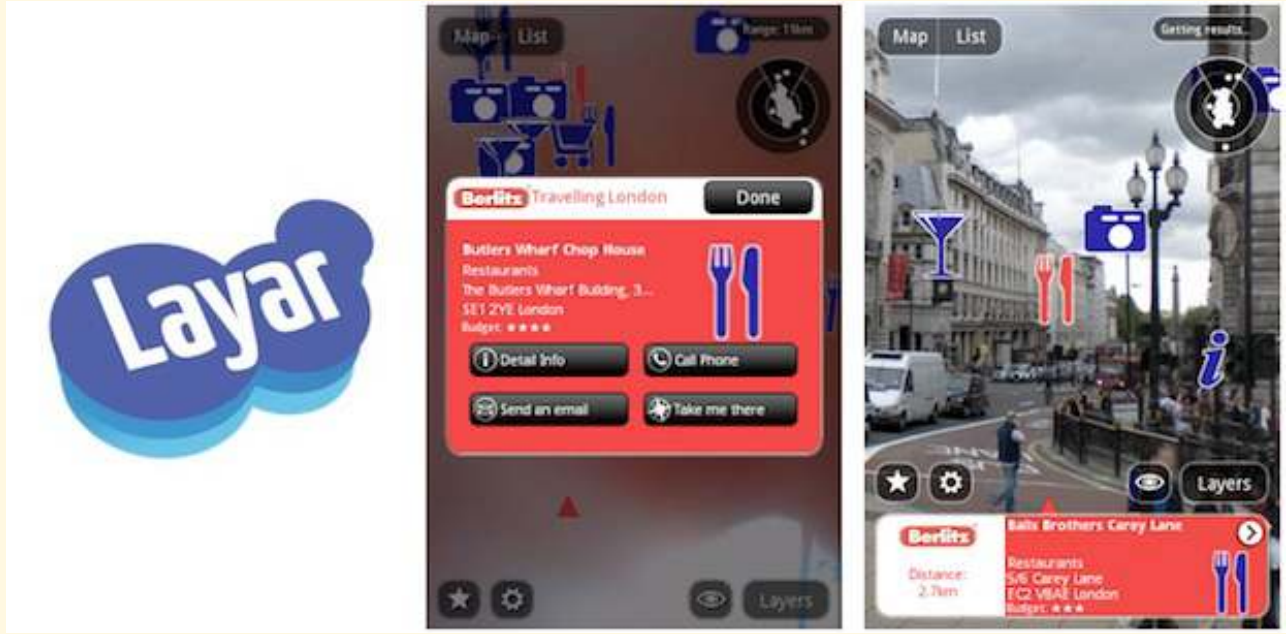
- Monochrome markers
- **ARToolkit** created by Hirokazu Kato

- Alternatives: ARTag, ArUco
- PC + Webcam



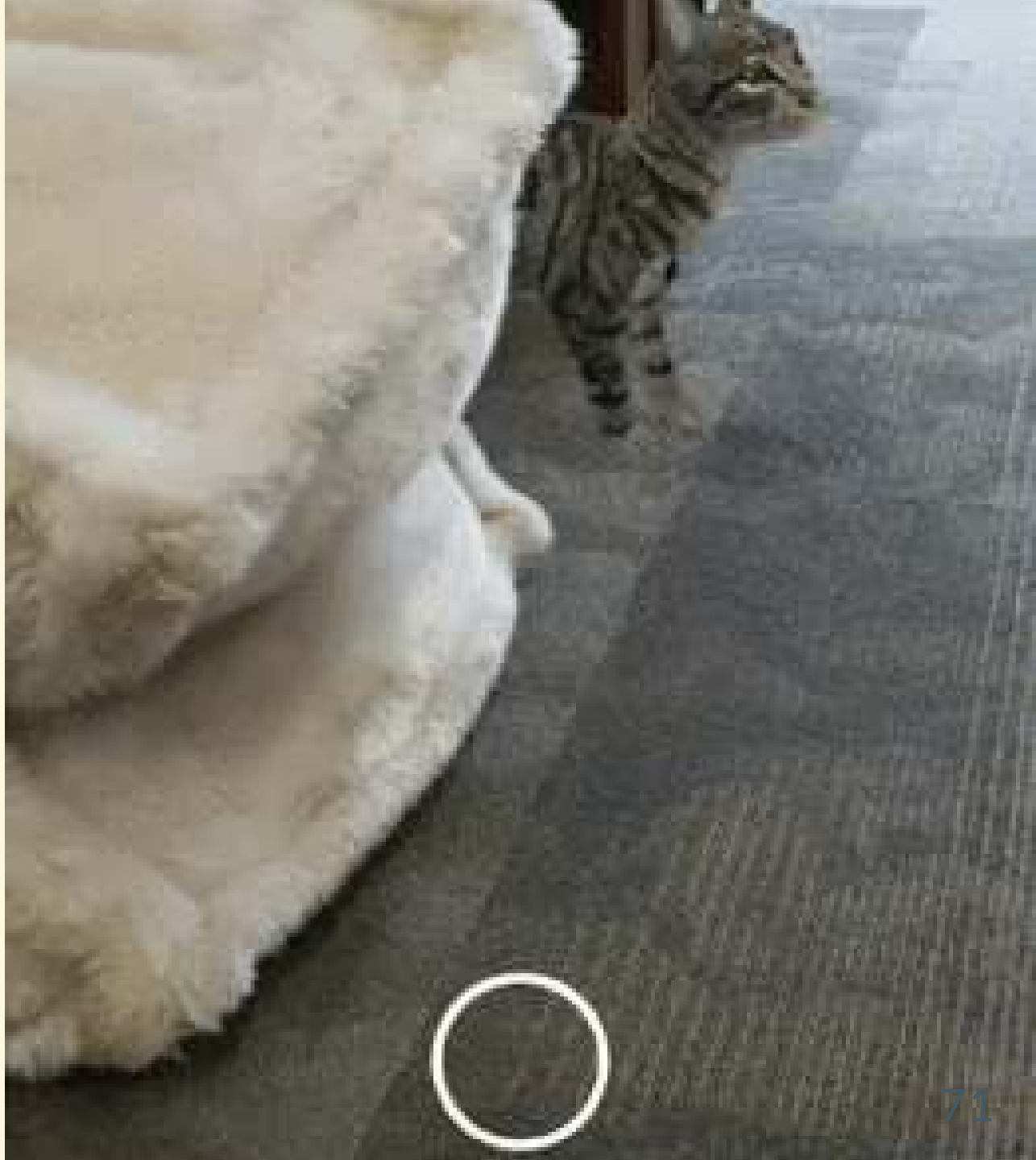
NFT, GPS (2005)

- **NFT**: **N**atural **F**eature **T**racking
  - Color photo tracking
- Wikitude, Layar (**GPS**)
  - no image processing needed with GPS!
- Vuforia
- Marketing use-cases
- PC, mobile phones, tablets



SLAM, 3D (2015)

- **3D environment tracking**
- **SLAM**: ★ **S**imultaneous **L**ocalization **A**nd **M**apping
- **3D object tracking**
- Deep Learning
- Occlusion 3D
- ARKit, ARCore
- Smartphones, HoloLens, Azure Kinect



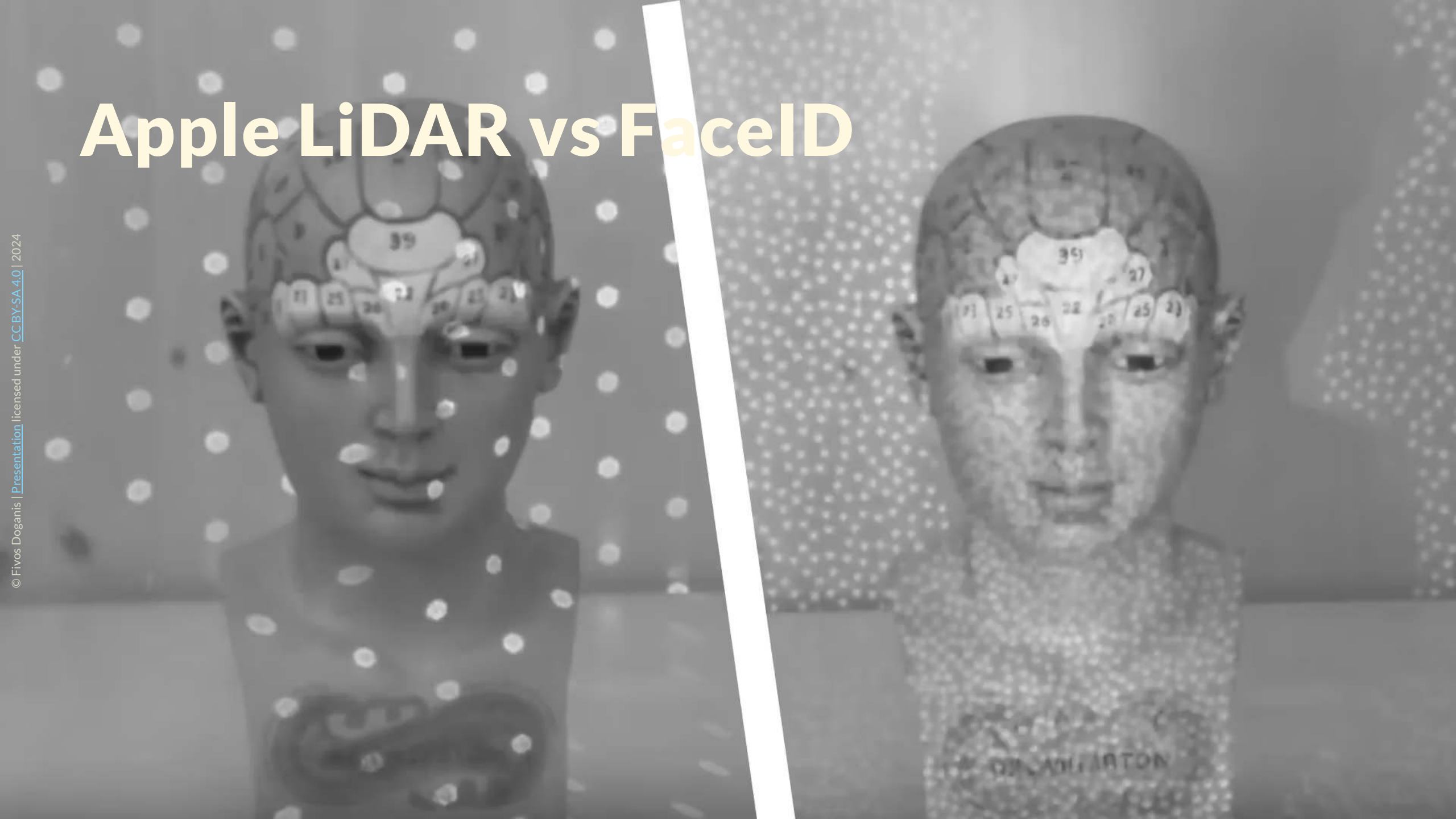
Azure Kinect + HoloLens 2

HoloLens 2

Apple LiDAR

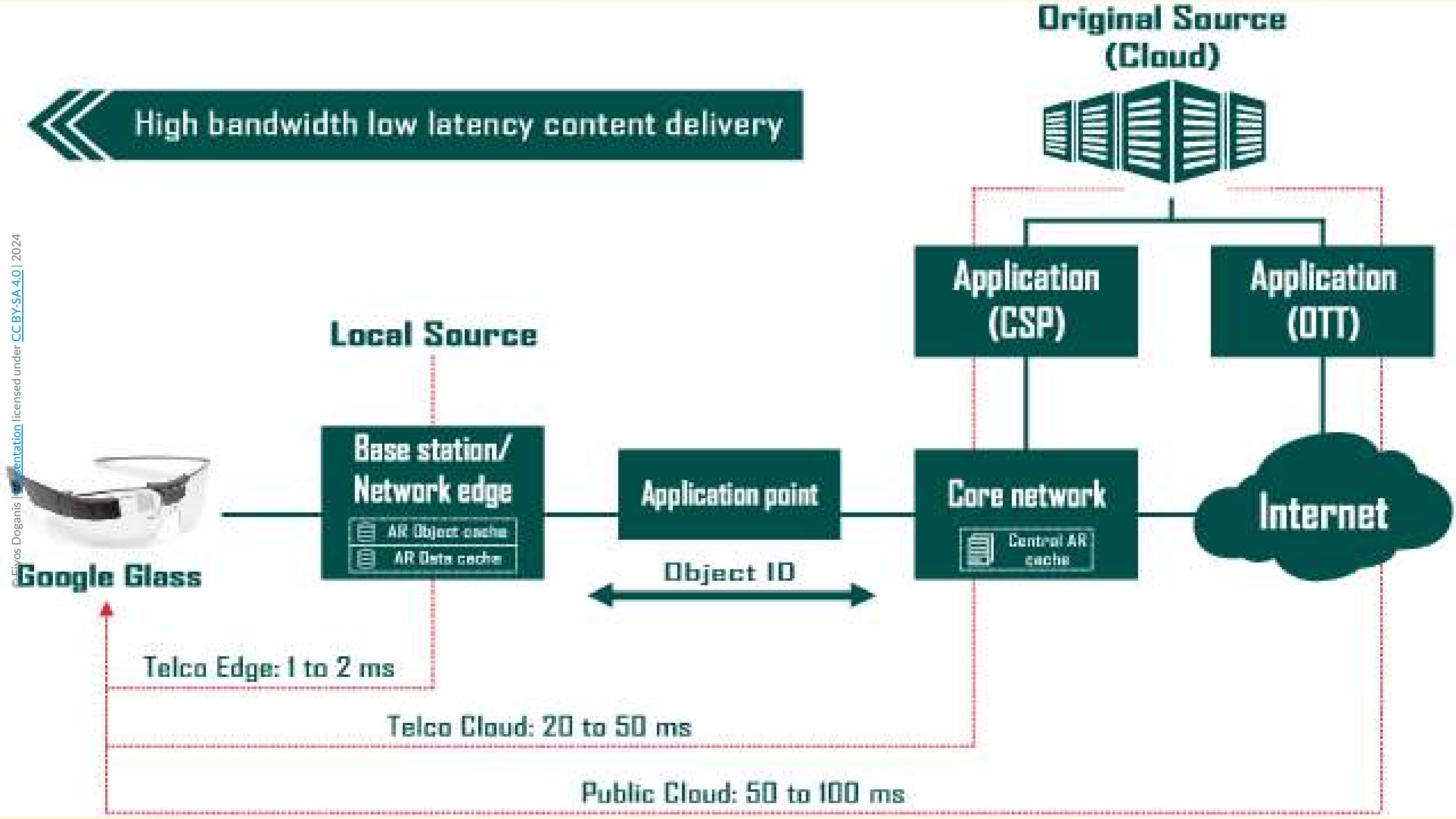
iPad Pro 2020, iPhone 12 Pro

Apple LiDAR vs FaceID



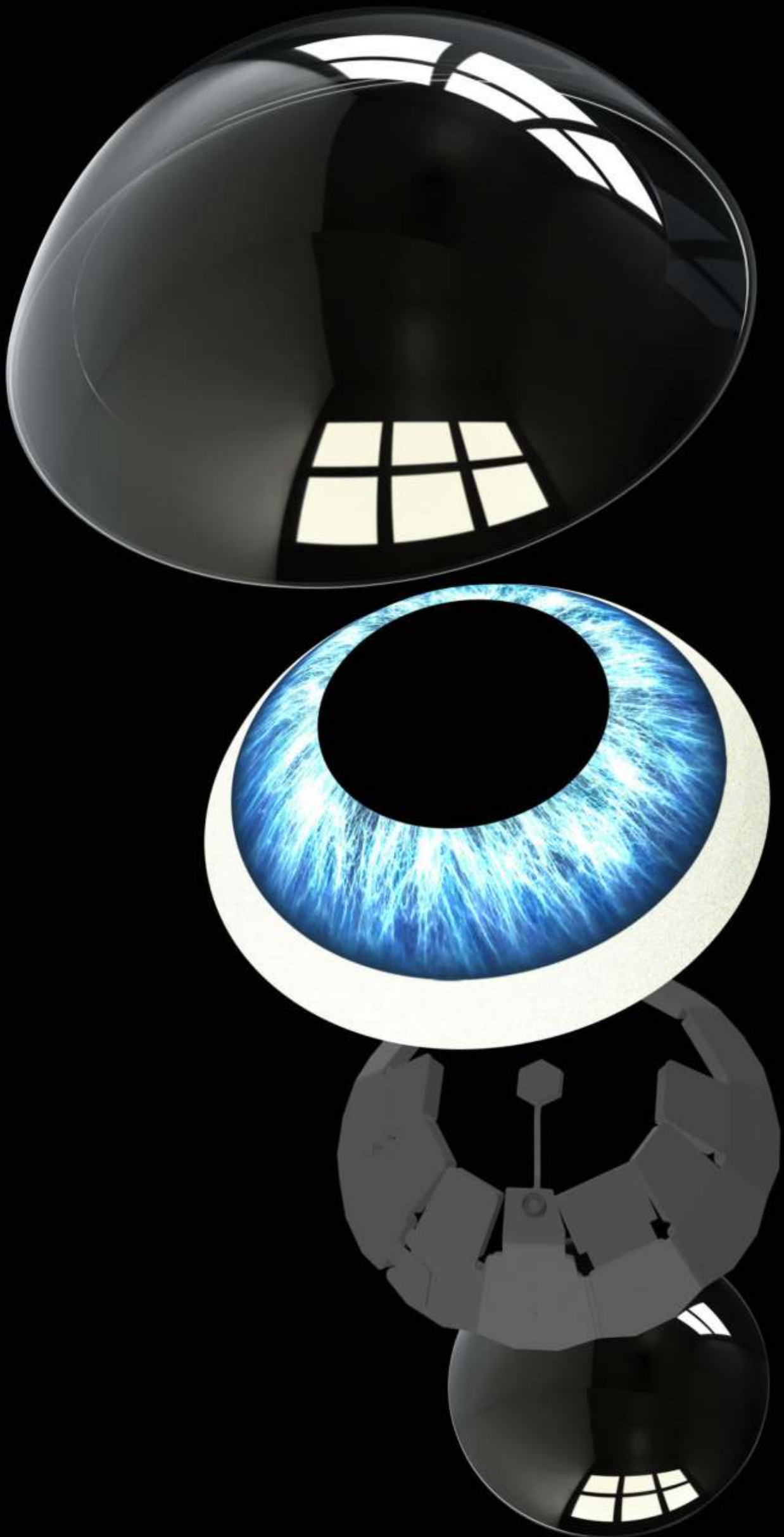
Near future

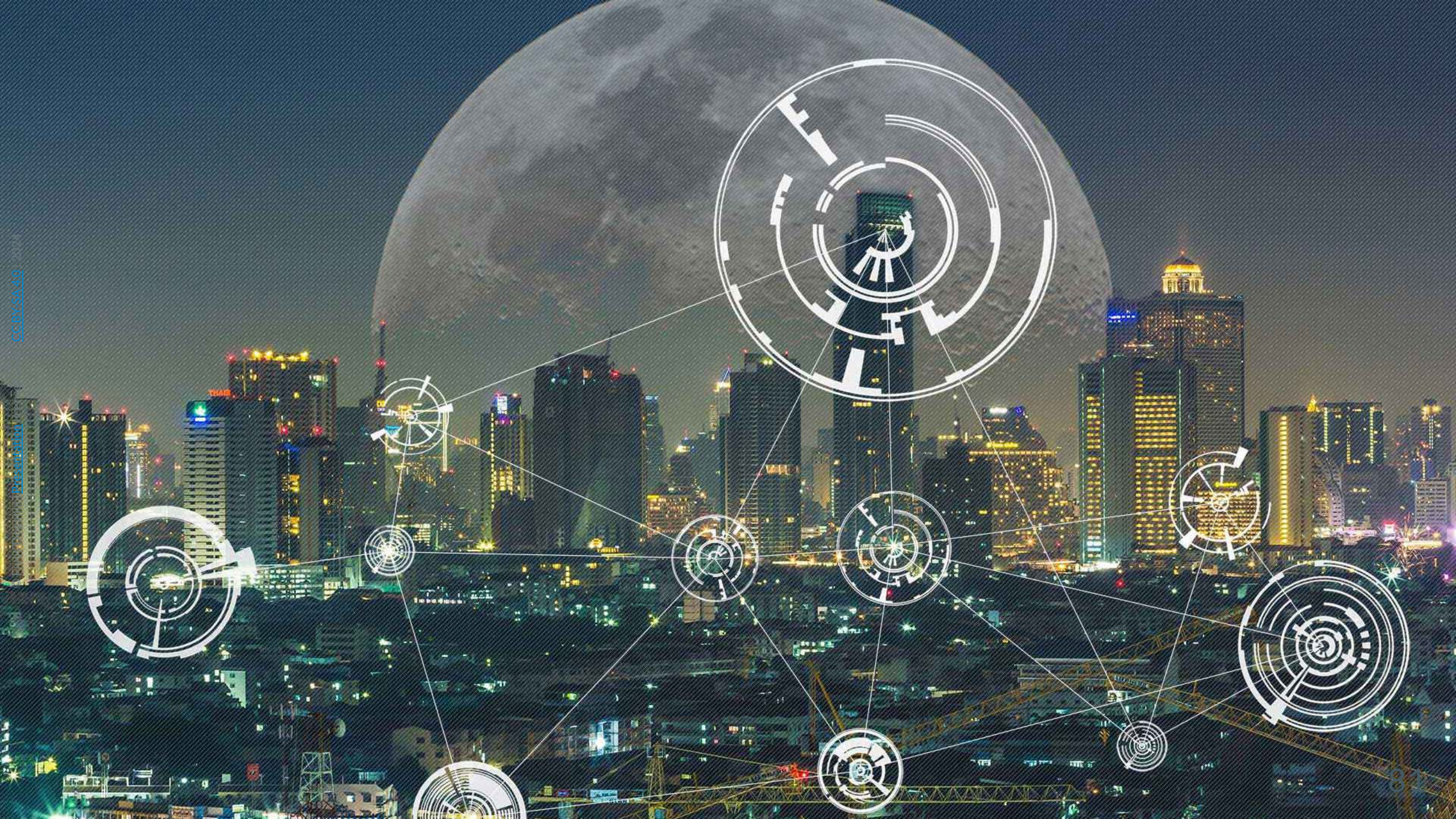
- Form-factor: glasses 😎
- **AI**
  - contextual assistance
  - understands both environment and user
- **5G**
  - application and information streaming (**Edge Computing**)
- Spatialized Web: **AR Cloud**



Far future

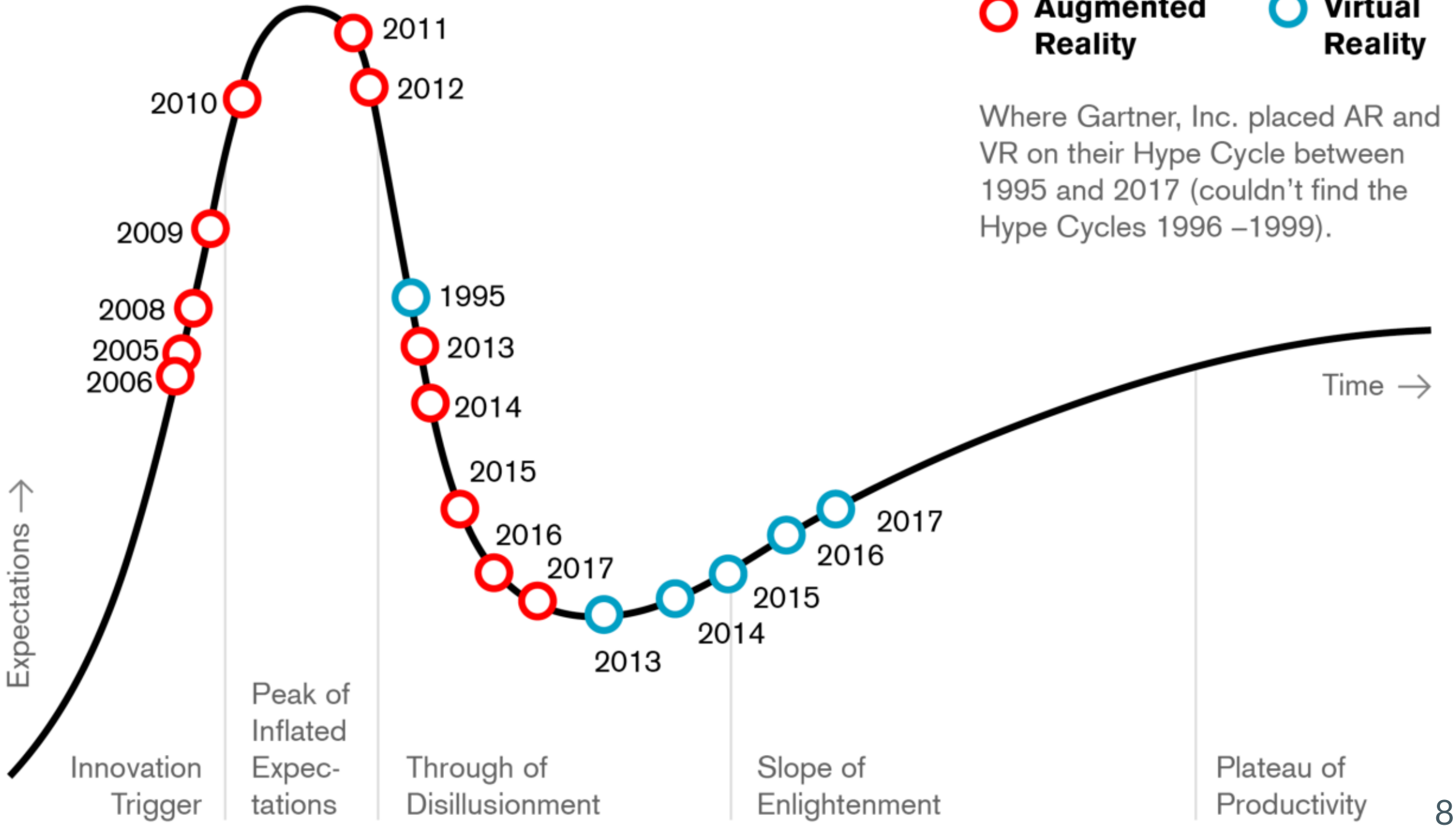
- AR will **replace or complement smartphones**
  - users will raise their heads again
    - but will they see better?
- Contact Lens (Mojo Vision)
  - RIP (2023) 💀
- **Ambient Computing**
- Ubiquitous Computing
- **Smart Cities**





Gartner Hype Cycle

- Technology trends evolution
- Gartner
  - 2005 - 2017 period



Where do we stand now?

- We are getting close to productivity for AR and VR
- Or AR is nows considered as "productive" since 2020?
- Future trends:
  - AR Cloud
  - "Metaverse" and "Digital Humans"

2023

Magicverse Layers

The Layers of Spatial Computing

A nearly infinite number of application layers make up the city-scale Magicverse.

User choices and contextual AI power this system of systems, navigated through a spatial computing interface.

Spatial Application Layers

Entertainment

Communications

Health & Wellness

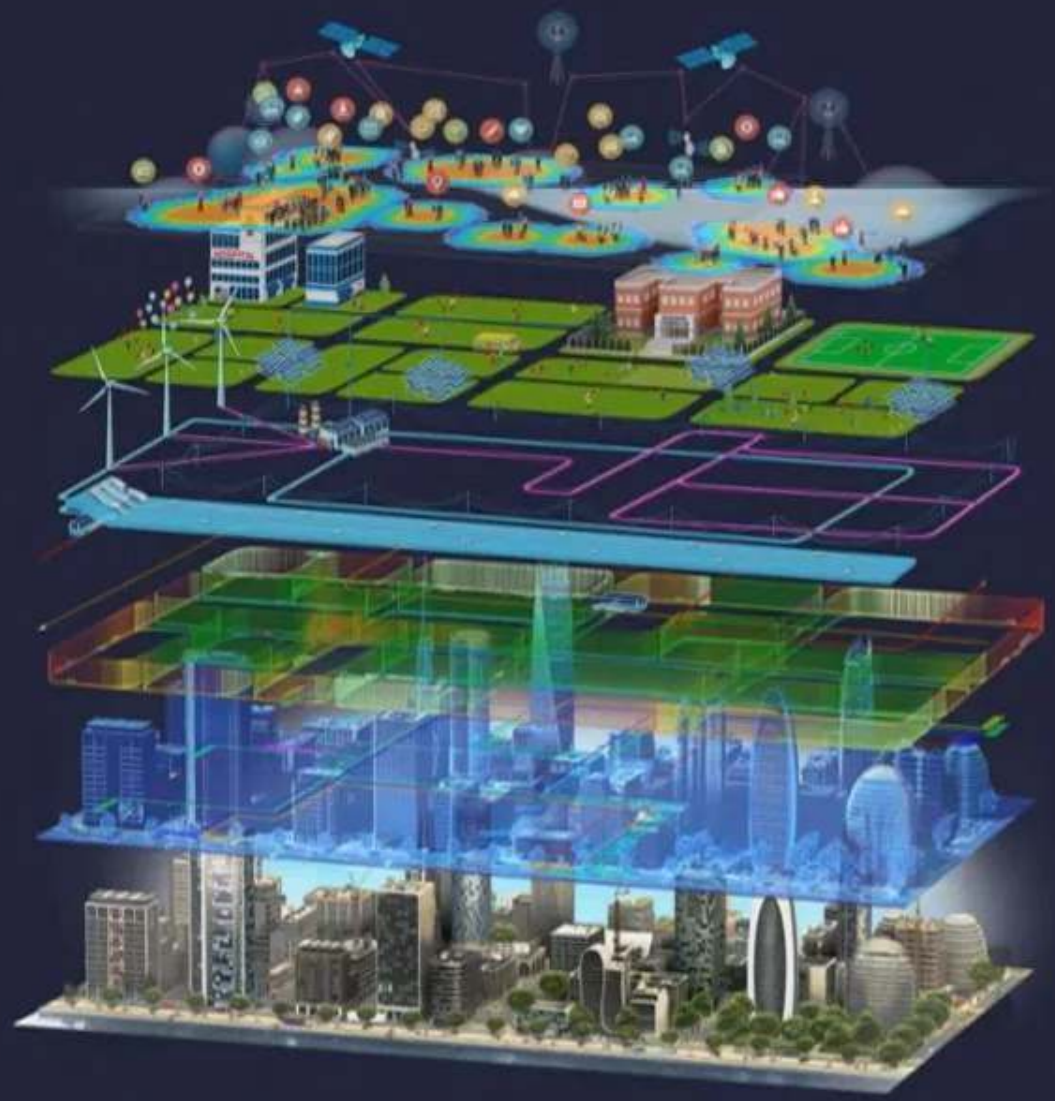
Energy & Water

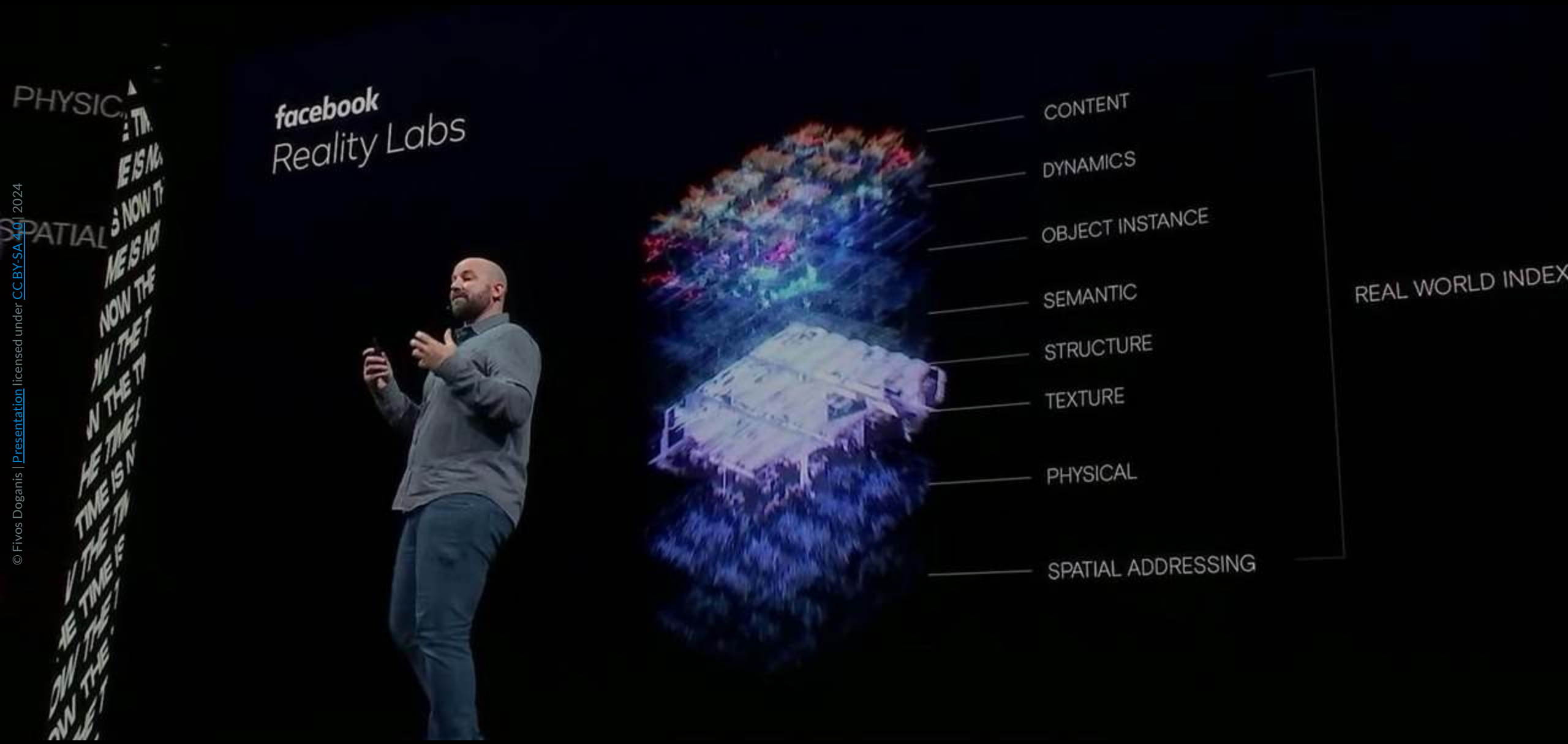
Mobility

Base Layers

Digital World

Physical World





OPEN AR CLOUD

BUILDING A BETTER REALITY, TOGETHER

MAMAA Strategies

Meta, **A**lphabet, **M**icrosoft, **A**pple, **A**mazon
and others!

> **AR *[is for]* adding shared meaning in the interaction between people**.
> *Johnny Lee*, Google I/O 2017

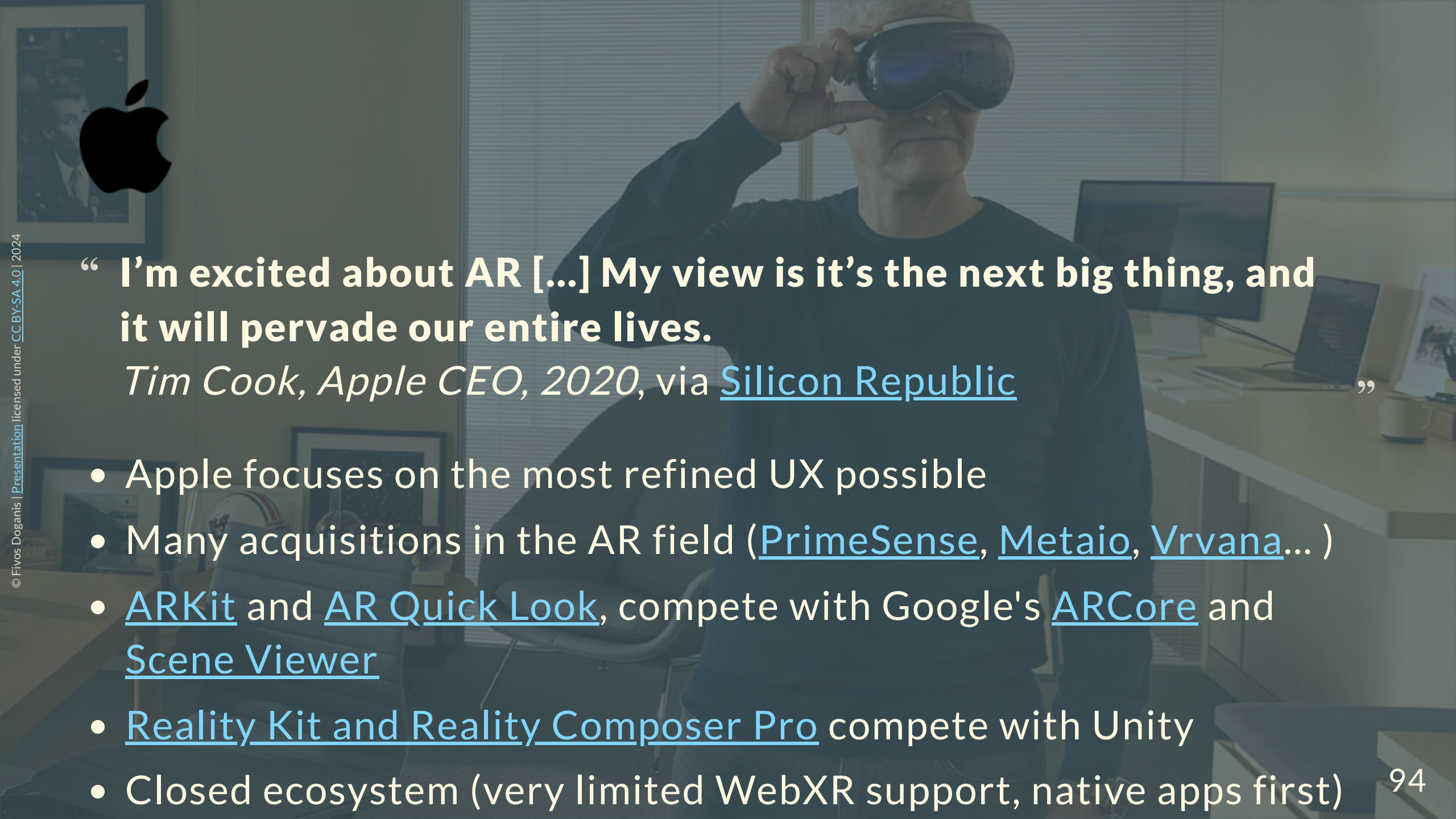
- Dropped mobile VR (Cardboard 💀, Daydream 💀)
- Dropped Tango 💀, to reach more devices: rely on **RGB camera + AI**
- API ARCore, competes with Apple's ARKit
- Google wants to provide **cross-platform AR services**
- Google + Qualcomm + Samsung XR Headset coming in 2025

> **The Web connects the world's information, and AR connects information with the physical world. So together they can be applied to solve real life problems.**
>
> *Andrey Doronichev*, Google I/O 2017

Google Glass Enterprise Edition 2

Google Glass killed, for the second time, in 2023 💀

Gorillaz mobile AR app



> **I'm excited about AR [...] My view is it's the next big thing, and it will pervade our entire lives.**
> *Tim Cook, Apple CEO, 2020*, via Silicon Republic

- Apple focuses on the most refined UX possible
- Many acquisitions in the AR field (PrimeSense, Metaio, Vrvana...)
- ARKit and AR Quick Look, compete with Google's ARCore and Scene Viewer
- Reality Kit and Reality Composer Pro compete with Unity
- Closed ecosystem (very limited WebXR support, native apps first)

Hardware

- Adds **LiDAR** for a robust **SLAM** (e.g. white walls scenario)
- Extends its 'wearables' category
  - AirPods
  - Apple Watch
  - **Apple Vision Pro**
    - unveiled in June 2023
    - released in February 2024

People Occlusion + Scene Understanding (iOS)

Eye tracking (visionOS)

"Spatial Computing", "EyeSight", Real Virtual Continuum

Avatars

Collaboration

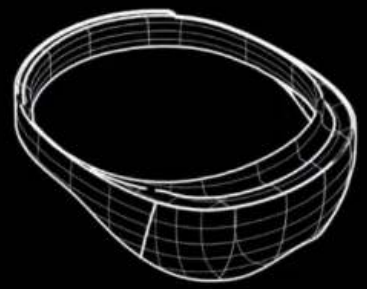
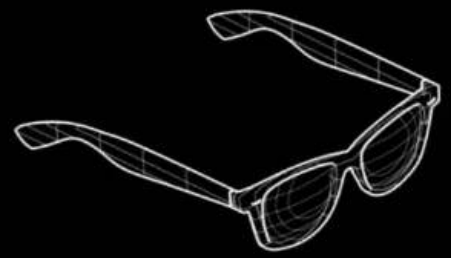
Meta

- Created **Horizon Worlds social network** for virtual encounters, and **Horizon Workrooms for remote collaboration**
- Believes that **AR will replace smartphones** and all other screens in 10 years and does not want to miss this revolution: Project Aria
- Interested in **personal data**, centers of interest of their users (eye-tracking, scanned environment), although they claim the opposite
- VR with Oculus, but they now focus on AR, cf. Infinite Office
- ~~AR filters Facebook and Instagram via Spark AR~~ RIP 💀
- Great WebXR supporter

Oculus Infinite Office

Meta Quest 3: focus on AR

Michael Abrash in 2019

VR	AR
	
FULL CONTROL OF PIXELS	SOCIALLY ACCEPTABLE
FEWER CONSTRAINTS	WEIGH 70 GRAMS
BEST MIXED REALITY	DISSIPATE 500 MILLIWATTS

Project Aria

Next?

> I might get myself in trouble for saying this; I think it might be the **most advanced piece of technology on the planet in its domain**. In the domain of consumer electronics, it might be **the most advanced thing that we've ever produced as a species**.
>
> *Andrew 'Boz' Bosworth, Meta CTO*, January 2024

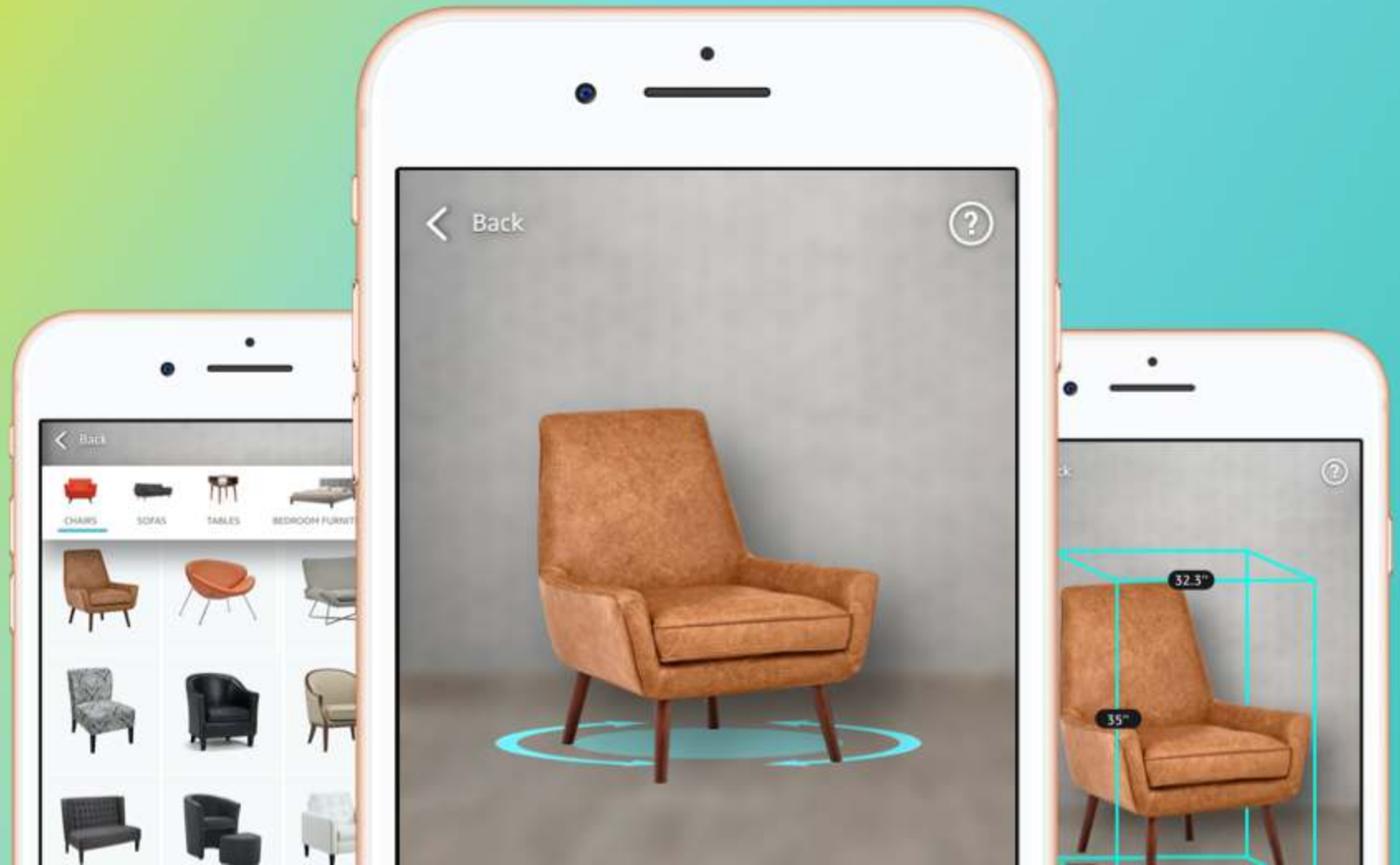
Project Orion (2024)

$10 000 prototype

- Amazon focuses on e-commerce and its Web Services
- AR View to see a product at home before buying it
- Offers Sumerian as a paid tool via AWS (Amazon Web Services) to create XR experiences
- Pushes machine learning, smart assistants (Alexa)
- Bets on AR on demand via 5G with its Wavelength Project
  - **5G + Edge computing**
  - AWS

View in Your Room

Design and Decorate Your Home with Augmented Reality



- Consumer: Minecraft
- Focuses on AR and industry, to maximize added-value
  - assistance and training
- HoloLens 1 et 2, Kinect
- VR: OEM Partners
- Windows Mixed Reality: RIP 2023 💀
  - now provides popular software to competitors!

Other players

- Hardware
  - Magic Leap, Lenovo, NReal, Qualcomm, Snap
- SDK
  - Wikitude, Kudan
  - PTC Vuforia: IoT
- Web
  - ~~Firefox Reality~~ Wolvic
  - Chrome

Takeaways

- Big tech companies invest massively in AR, which they see as **a promising technology** evolving fast
  - hardware
  - algorithms
  - services, **data**
- Many players try to bring their users into their **closed ecosystem** (hardware, app store, cloud)
- Others focus ont the openness of the **Web** to **create and share open AR experiences**
  - ➡️ **ultimate goal of this course!** 🎉

Further reading

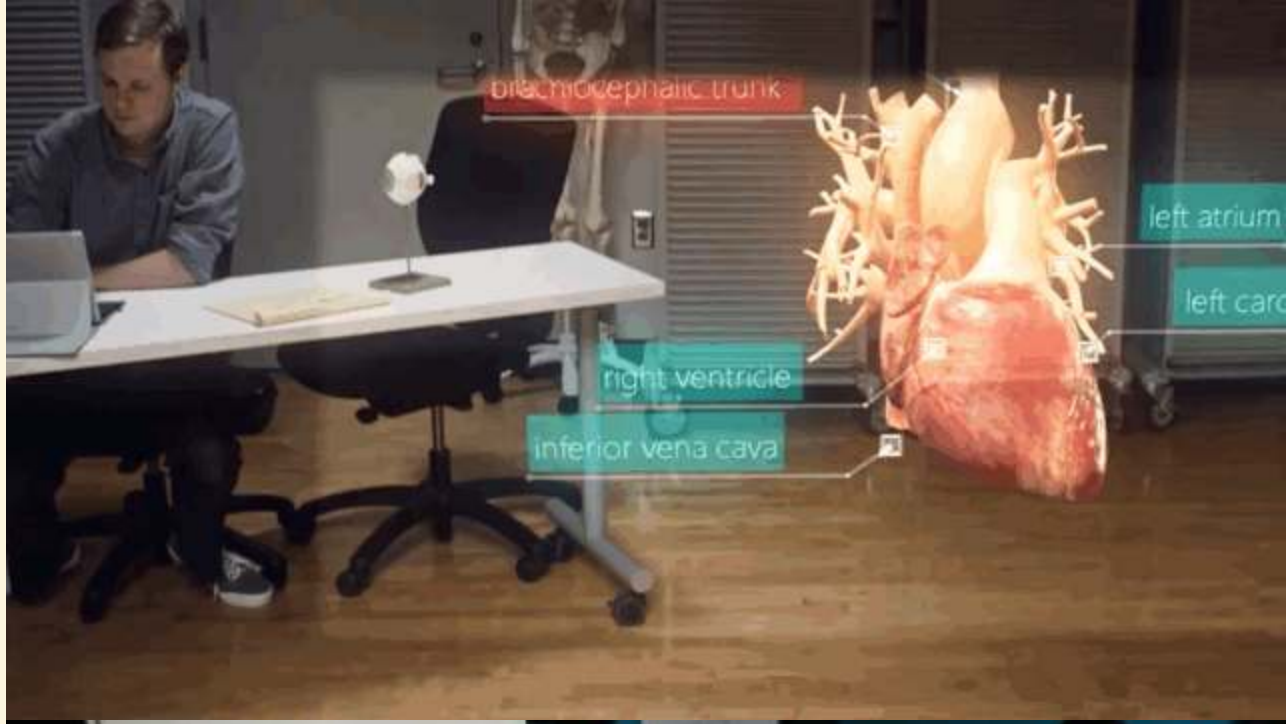
- **History and future of Web AR**
  - **Web AR: A Promising Future for Mobile Augmented Reality -** State of the Art, Challenges, and Insights.

  Qiao, Xiuquan & Pei, Ren & Dustdar, Schahram & Liu, Ling & Ma, Huadong & Junliang, Chen. (**2019**).

  Proceedings of the IEEE. 107. 1-16. 10.1109/JPROC.2019.2895105.

3 Types of AR ⭐

- **Video**
  - e.g.: smartphone, Meta Quest 3, Apple Vision Pro, Lynx-R1*
- **Optical**
  - e.g.: HoloLens
- **Projective**
  - e.g.: DIOTA ➡️



Lynx-R1: see next page ⬇️

Lynx-R1 (video)

PAUSE

30' ⏳

Required technologies for AR

Calibration
Tracking
Interactions
Rendering

Calibration

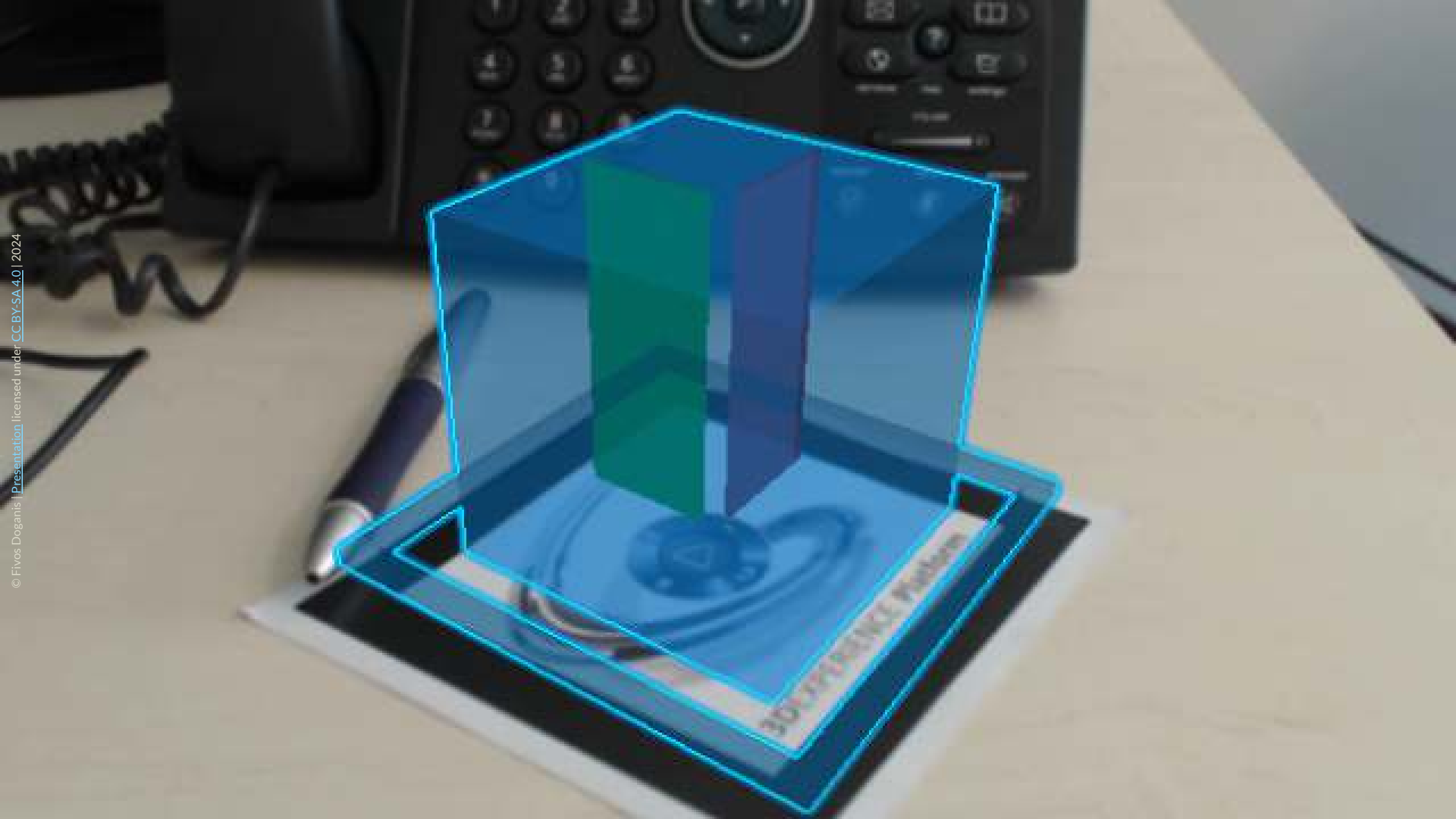
Goal: overlay accurately **the virtual rendering and the real image**

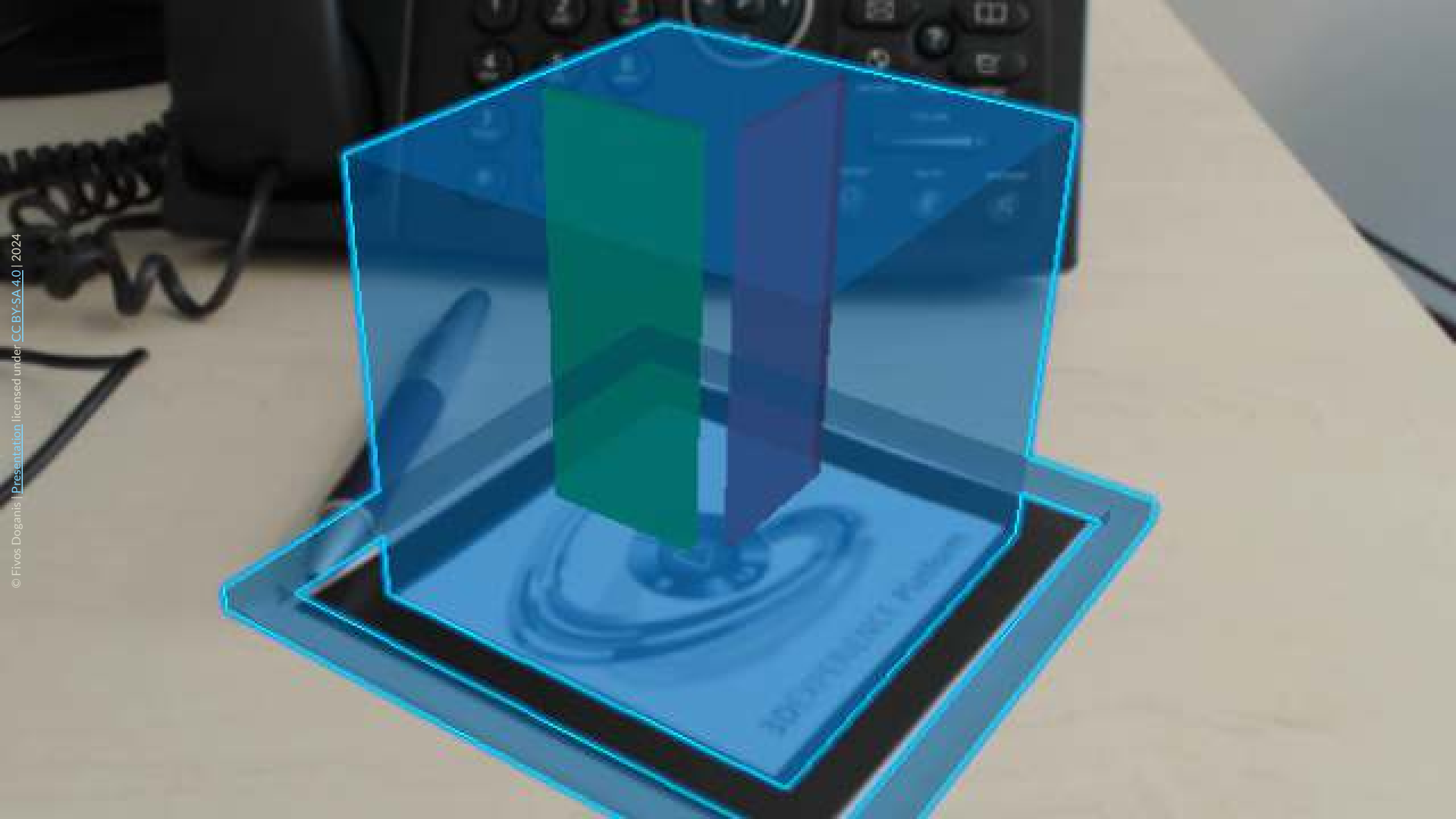
Optical AR calibration

- very complex
- hardware dependent
  - projection and image formation systems
- depends on the body metrics of the user
- **made and provided by the AR hardware manufacturer**
  - possible adjustments for each user, cf. eye calibration in HoloLens

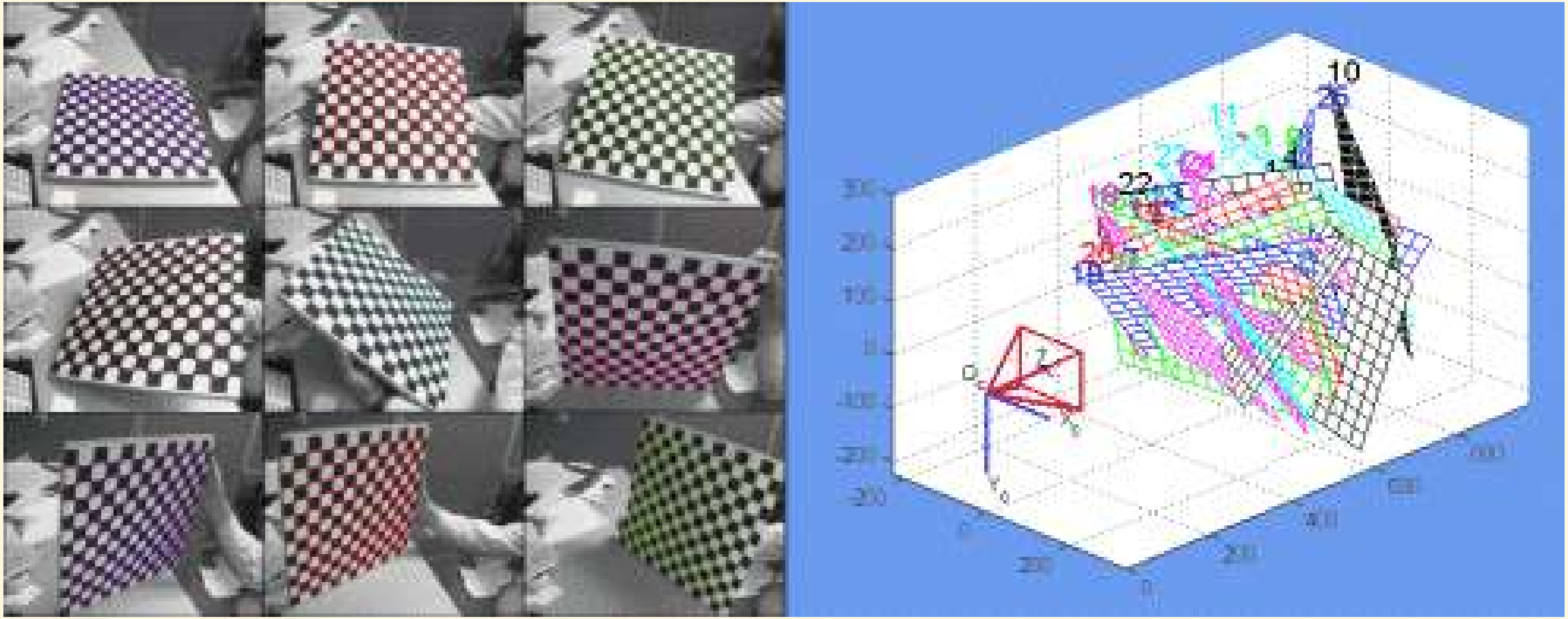
Video camera calibration

- Goal: compute the **optical parameters of the real camera**
  - **focal length**
  - radial distortion, lens imperfections
- Method:
  - capture images of known patterns (grids, **calibration patterns**) with a real camera
- ⚠️ **the focal length may be variable** (autofocus)
  - update calibration data for each frame
  - calibration data is provided by the API (ARKit, ARCore, WebXR)





Video camera calibration method



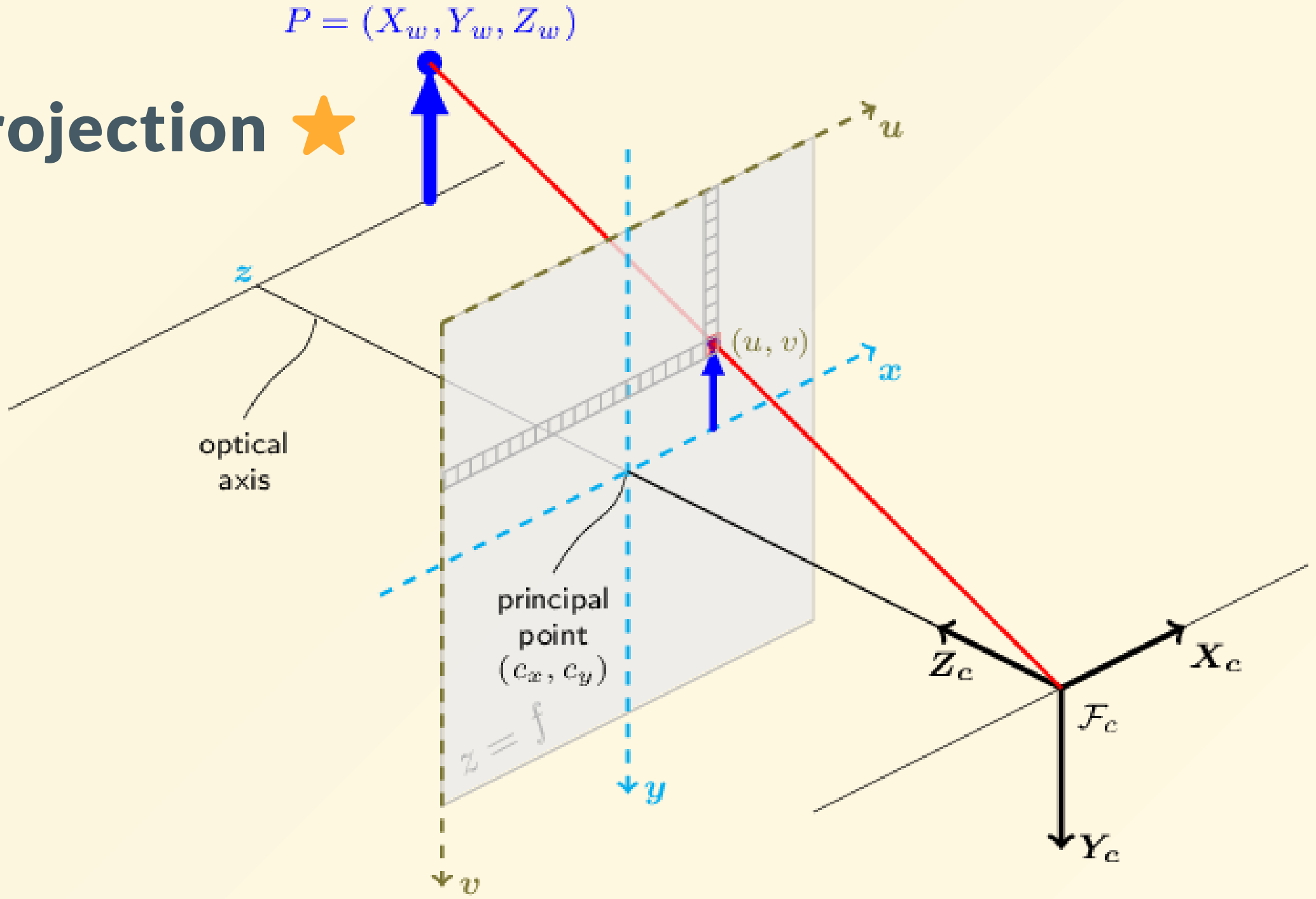
Pinhole camera model

source: https://www.mathworks.com/help/vision/ug/camera-calibration.html#buvr2qb-1

Extrinsic and intrinsic parameters

3D coordinates ➡️ Camera 3D coordinates ➡️ Image coordinates

Projection ★



$$s\ p = A[R|t]P$$

$$s \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_x \\ r_{21} & r_{22} & r_{23} & t_y \\ r_{31} & r_{32} & r_{33} & t_z \end{bmatrix} \begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix}$$

(X_w, Y_w, Z_w) 3D world coordinates O_w

(u, v) projected coordinates (pixels)

$[R|t]$ **extrinsic** matrix, A **intrinsic** matrix

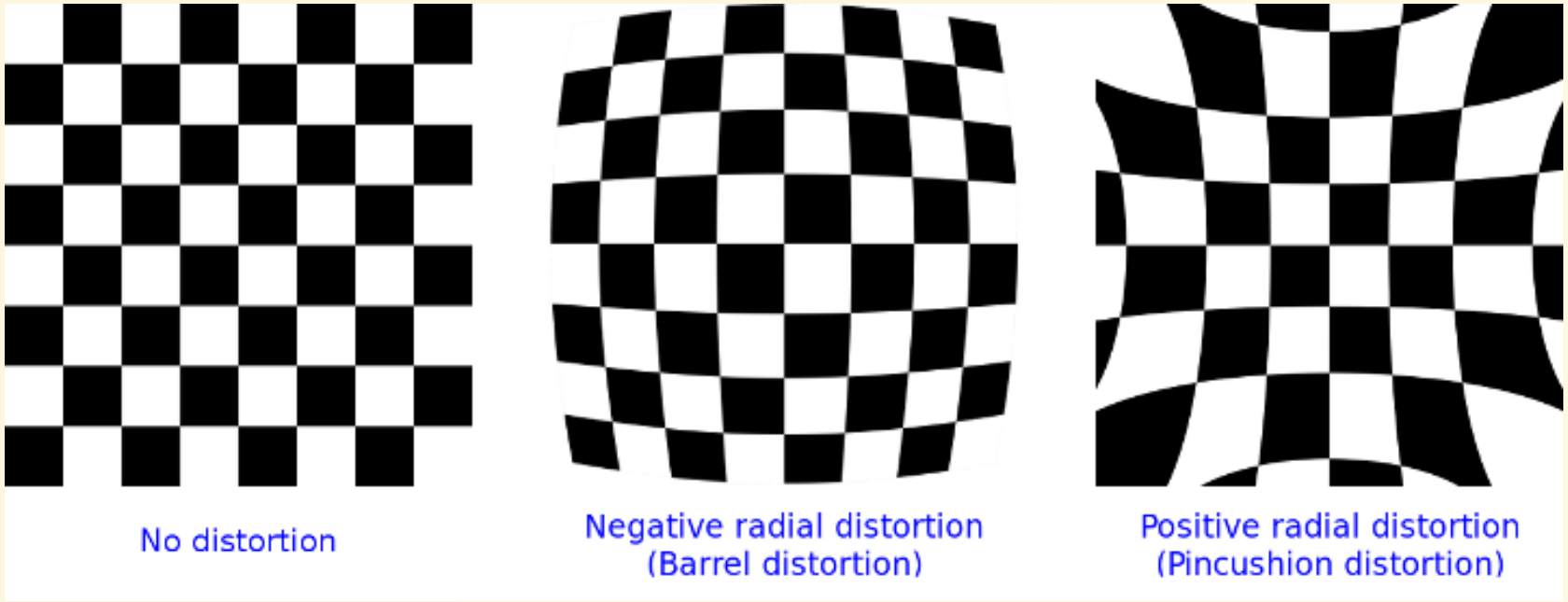
(cx, cy) principal point (pixels), **center of the image** in the ideal case

f_x et f_y focals along x and y (pixels), **equal** in the ideal case

Non linear radial distortion

- due to the lens,approximated by a polynomial expression

$$x_{distorted} = x(1 + k_1 r^2 + k_2 r^4 + k_3 r^6)$$
$$y_{distorted} = y(1 + k_1 r^2 + k_2 r^4 + k_3 r^6)$$



Registration

Goal: find the **rigid transformation** $[R|t]$ between a 3D point in the world and the center of the camera

Pose estimation

- Computed from 2D/3D pairs of points
- Optimization: projection error minmization between transformed 3D points V_i et image 2D points v_i

$$\arg\min_{R,t} \sum_i ||P(RV_i + t) - v_i||$$

P: projection function

R: rotation matrix

t: translation vector

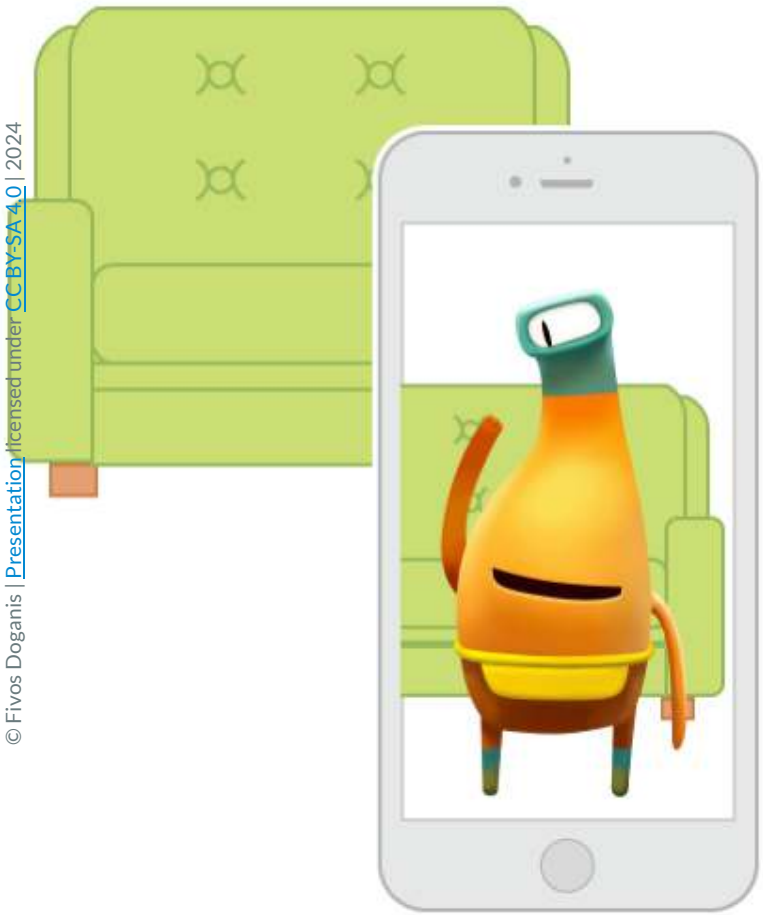
Tracking

after initial registration

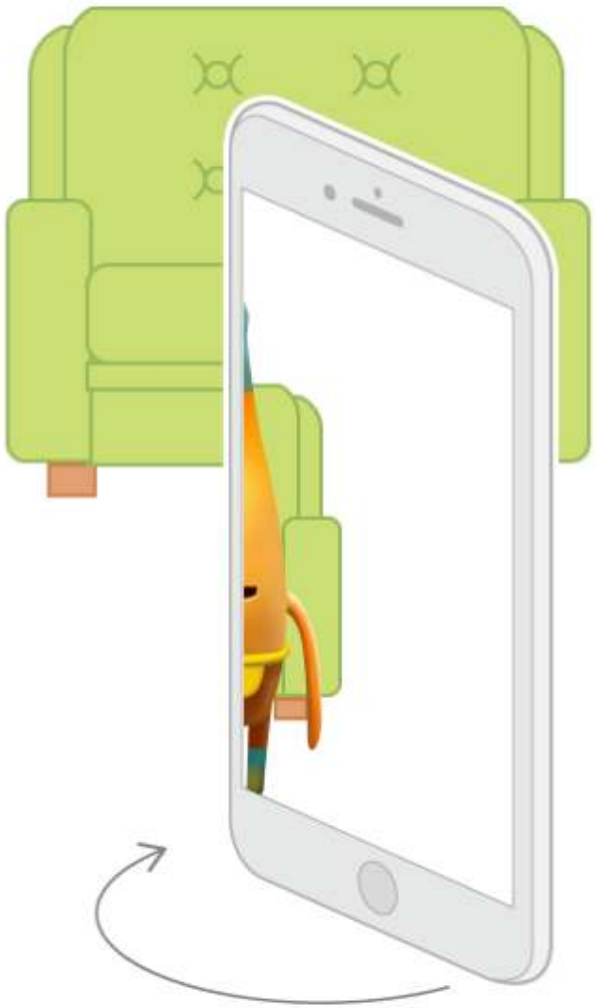
Tracking

- **D**egrees **O**f **F**reedom (**DOF**):
  - **0 DOF**
    - no tracking!
    - simple information overlay, cf. HUD
  - **3 DOF**
    - **rotation** only (gyroscope, accelerometer, compass)
      - limited experience (can be good enough, cf. planetarium)
  - **6 DOF**
    - **rotation + position**

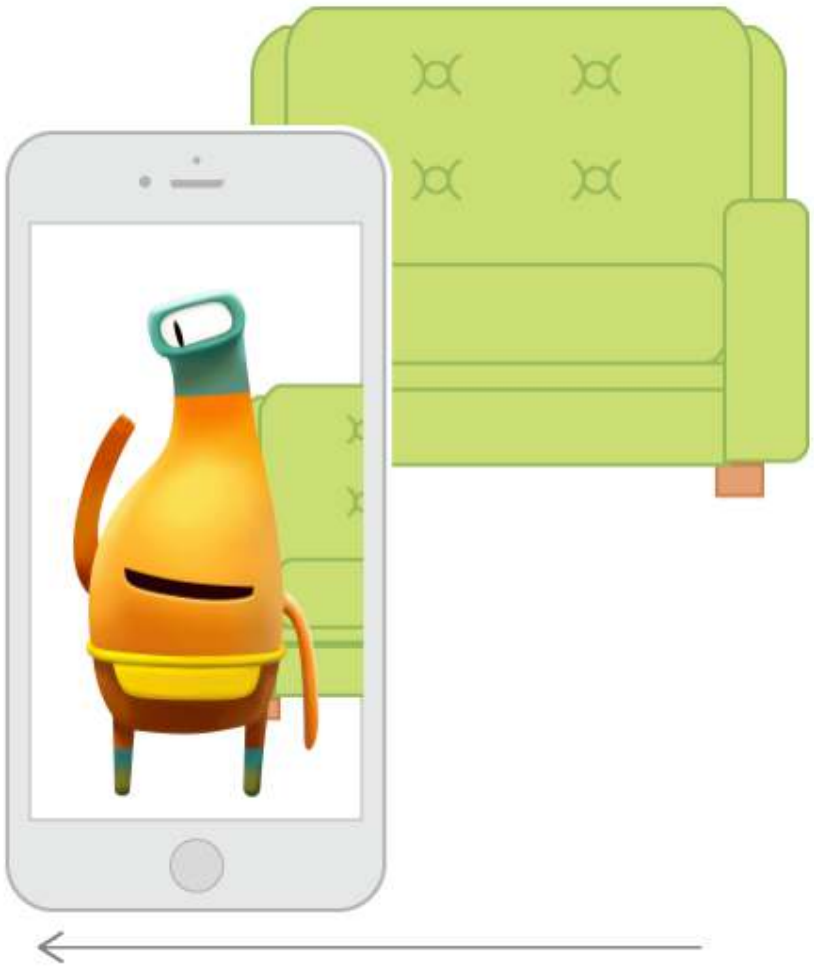
3 DOF



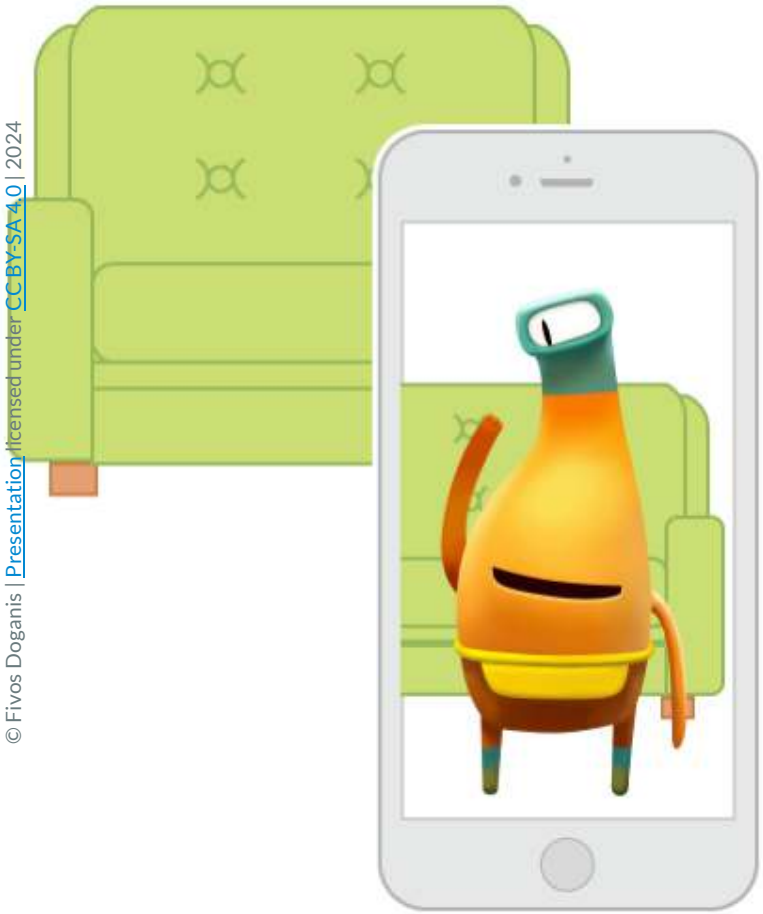
Device rotation



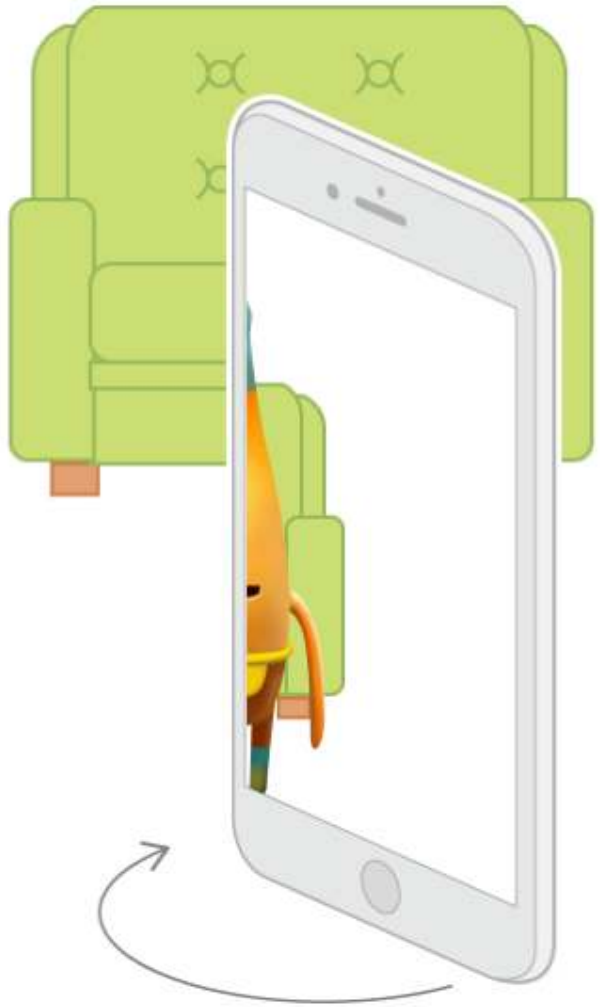
Device position



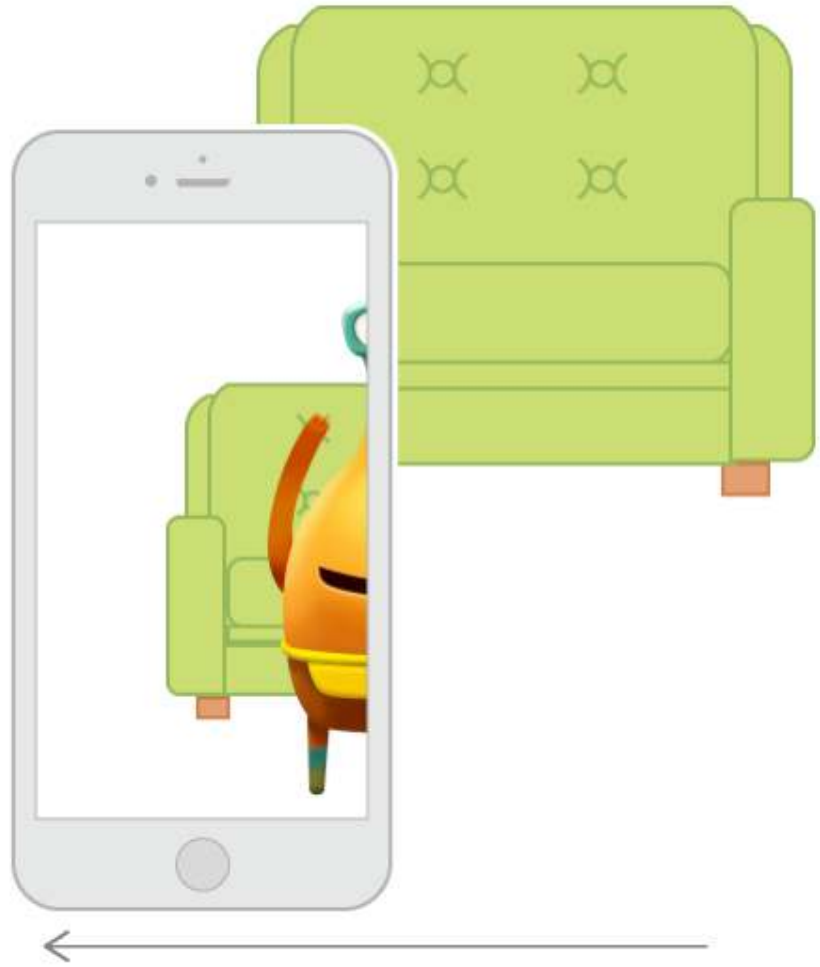
6 DOF



Device rotation



Device position



Tracking techniques ⭐

GPS
Marker
NFT
SLAM
3D

Tracking techniques

- **GPS**
  - global, satellite based, **no network connectivity required** ✅
  - **no image processing** ✅
  - **outdoors** only ❌
  - **slow** ❌
  - **not very accurate** ❌

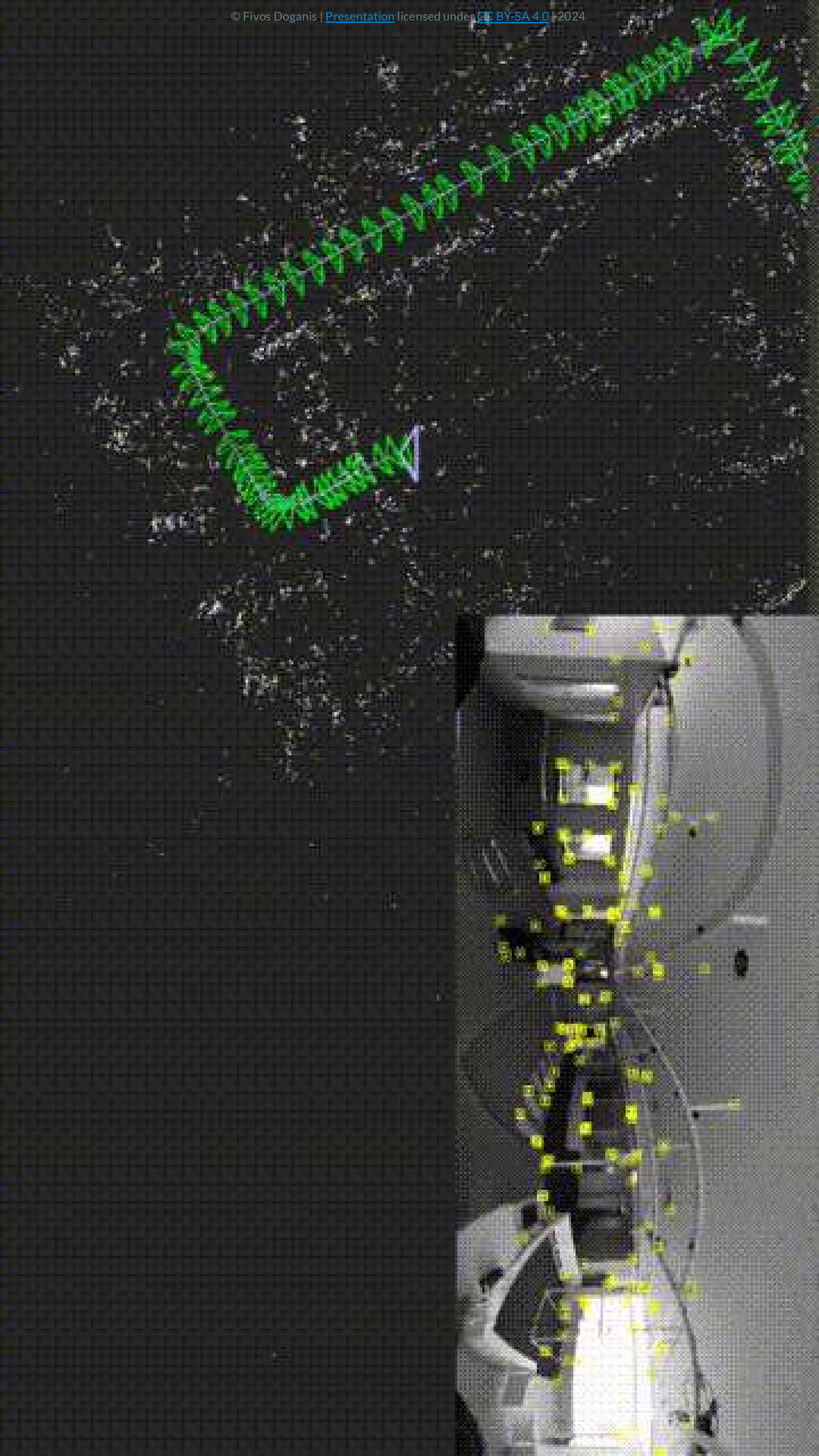
Tracking techniques

- **Marker**
  - accurate, **fast** ✅
  - **tangible**, printable ✅
  - need to display a marker to enable AR ❌
  - **non-aesthetic** ❌
  - **can be hard to detect** (low lighting, motion blur, occlusions) ❌
- **NFT**: same but
  - more **aesthetic**, easier to embed in the real world (ads) ✅
  - **more robust to occlusions** ✅

Valve VR HMD early prototype

Tracking techniques

- **SLAM** ⭐ : NFT evolution + reconstruction
  - more **natural** markerless experience ✅
  - partial **scene reconstruction** ✅
    - allows advanced functionalities (occlusions, collisions etc.)
  - not very accurate ❌
    - **drift**, loop closure
    - scene reconstructed and refined in real-time
    - difficult to define the origin of the scene
      - stable **anchor** points required



Tracking techniques

- **3D object detection** in a real scene
  - using **computer vision** (lighting, edges, silhouette)
    - generic algorithm ✅
    - but **slow**, especially during initial registration ❌
  - using **Deep Learning**
    - faster initial detection ✅
    - more robust regarding occlusions and lighting changes ✅
    - **not generic**: requires per model training ❌

Tracking techniques

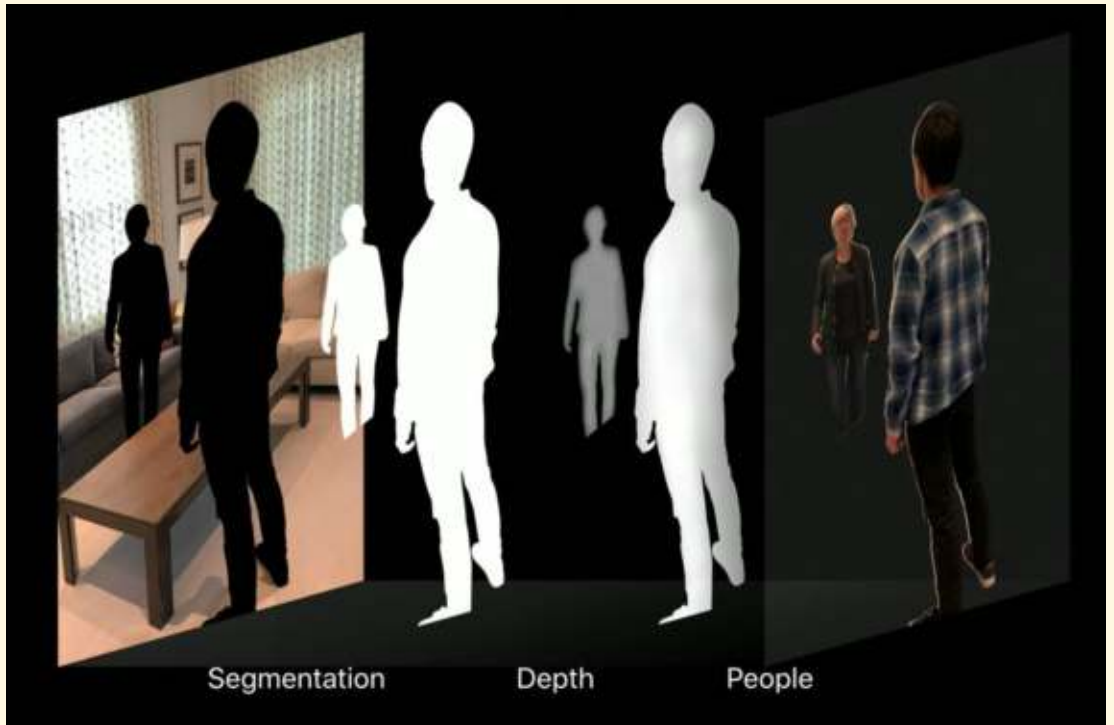
Conclusion

- No tracking technique is ideal
- Keep them all in mind and choose the right one according to:
  - the **scenario** of the AR experience
    - industrial context, consumer, generic or specific
  - **constraints**
    - indoor, outdoor, mobile

Rendering

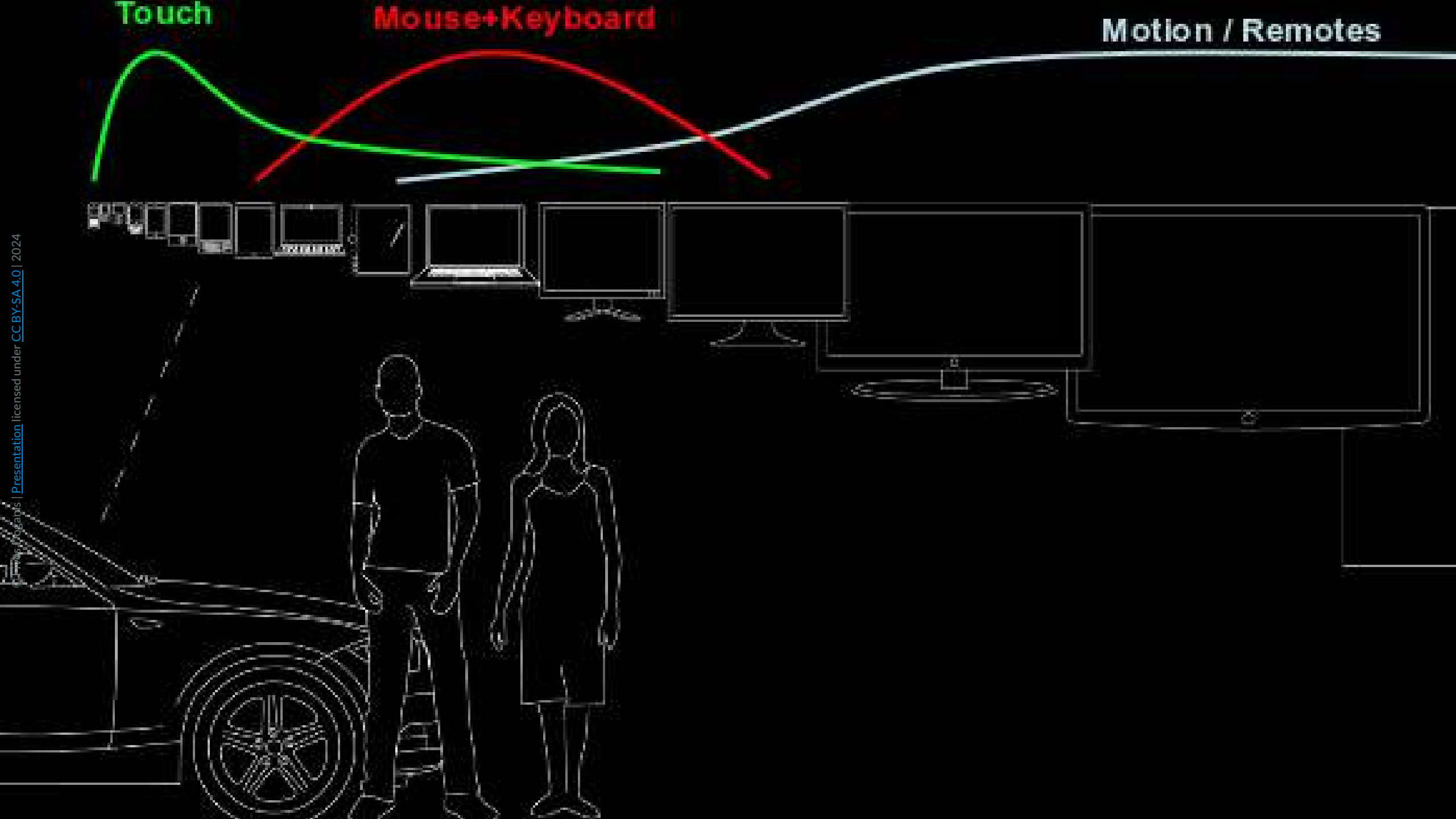
Rendering

- Realistic or not
- Lighting
  - detect the direction and intensity of real lights
  - fast environment reconstruction to simulate reflections (SLAM + AI)
- Occlusions
  - people, objects



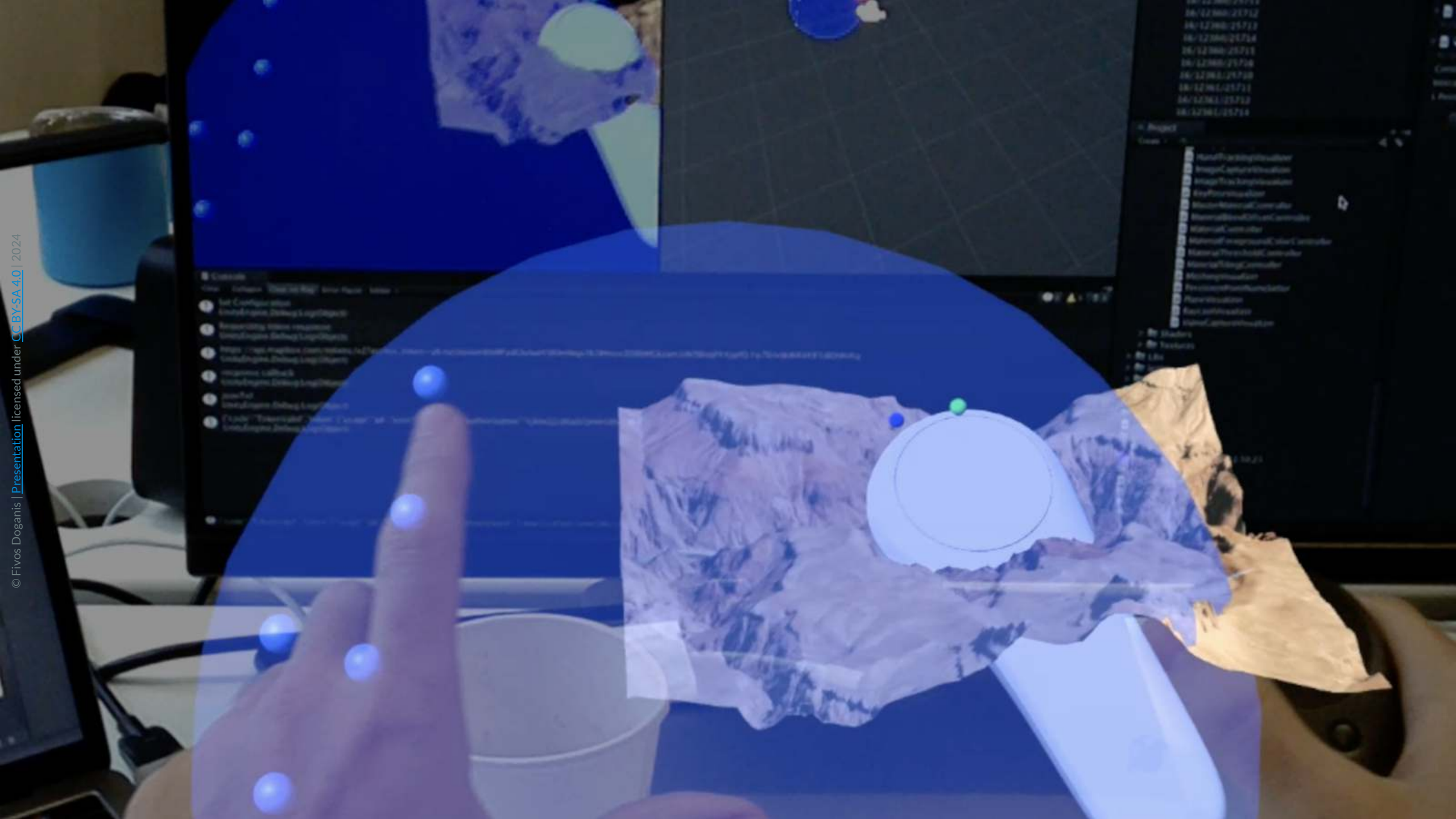
Interactions

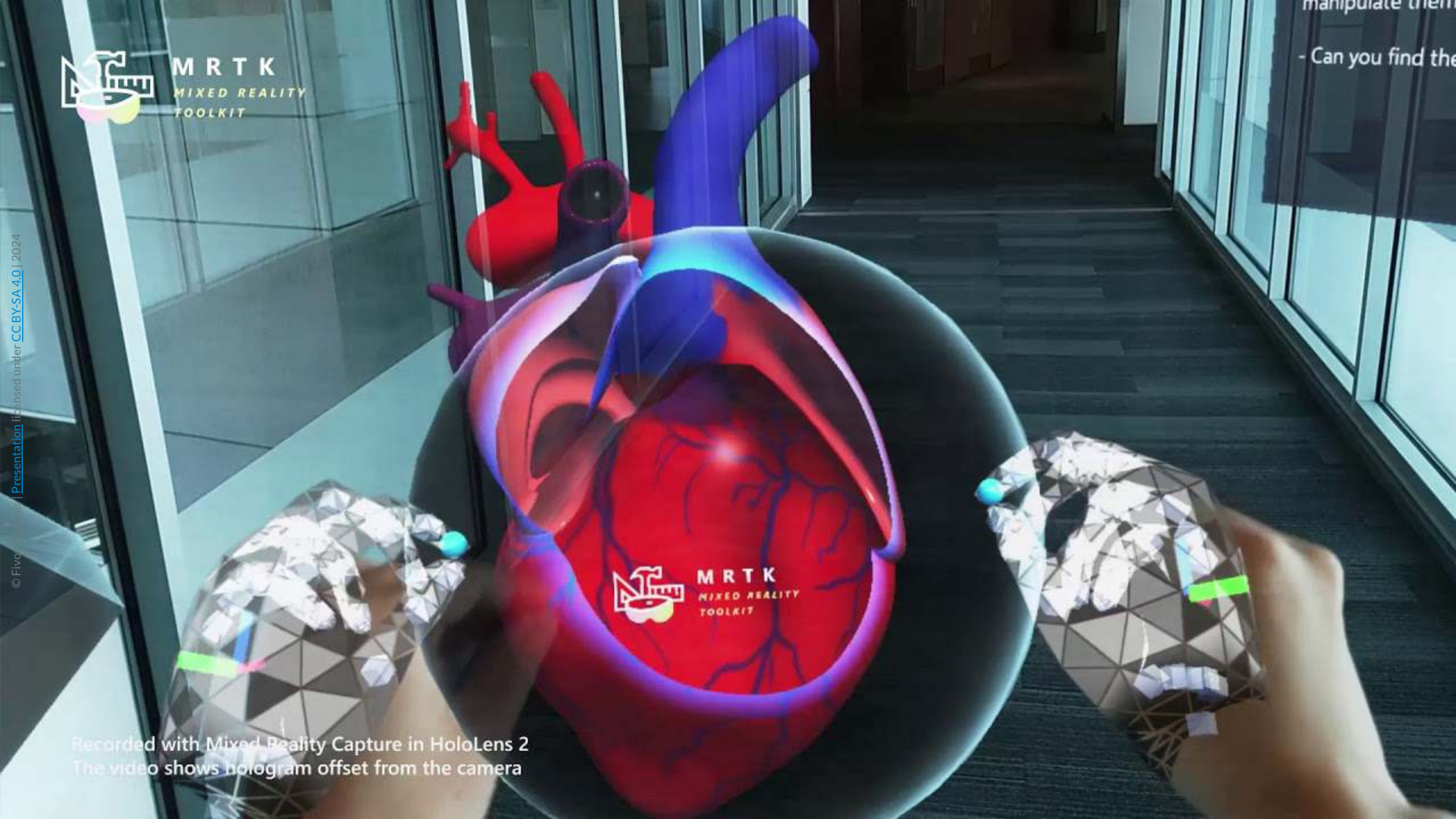
- The missing part of the equation
- Often neglected (cf. NReal)
- Myth of the dying mouse (p. 17)
  - each form factor has an optimal interaction technique
  - most headsets handle hand tracking, but also offer controller, keyboard and mouse support!
- **The XR equivalent of the mouse has not been invented yet!**

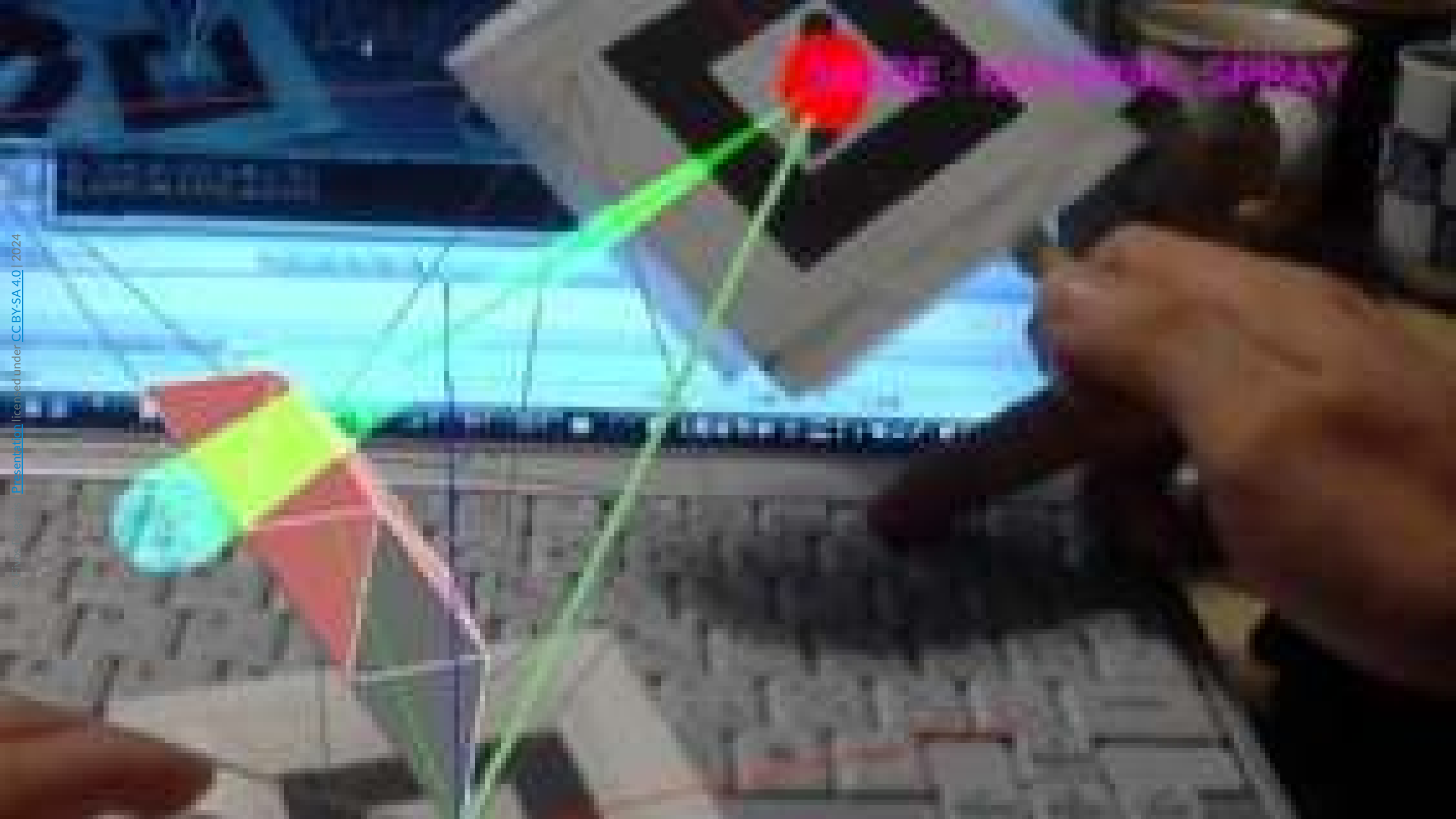


Interaction techniques

- **Screen**, when using a smartphone 📱
  - not very immersive but accurate, and provides tactile feedback
- **Controllers with buttons** 🎮
  - great haptic feedback but not immersive
- HoloLens **GGV** : **G**aze, **G**esture, **V**oice 👀 ✋ 👄
  - natural interactions, with no external hardware
  - great but tiring, lacks privacy ("hey Cortana!"), and accuracy
- **Tangible interactions** ✏️ 🔲
  - markers or accessories to add some tactile feedback ⬇️







Interactions

Conclusion

- Immersive AR interactions **have yet to be invented**!
- No interaction paradigm has become a standard yet
- We must **guide the users** and try to **understand their intent**

End

of part 1!

Questions?

LUNCH BREAK

back at 1:30 PM

Extra :)

Reconstruction 3D

- Colmap
- AliceVision
- Capturing Reality
  - RealityScan for iOS (link)
- MicMac
- **Scaniverse** ★

Links

http://www.ign.fr/institut/innovation/minecraft-a-carte

http://lsc.univ-evry.fr/~didier/home/lib/exe/fetch.php?media=cours:ra:ra.pdf

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