



JOHNS HOPKINS  
WHITING SCHOOL  
*of* ENGINEERING

# Introduction to Augmented Reality

Augmented Reality (EN.601.454/654). Fall 2022

Alejandro Martin Gomez, Dr. rer. nat.  
with slides from Prof. Nassir Navab

# Introduction to Augmented Reality

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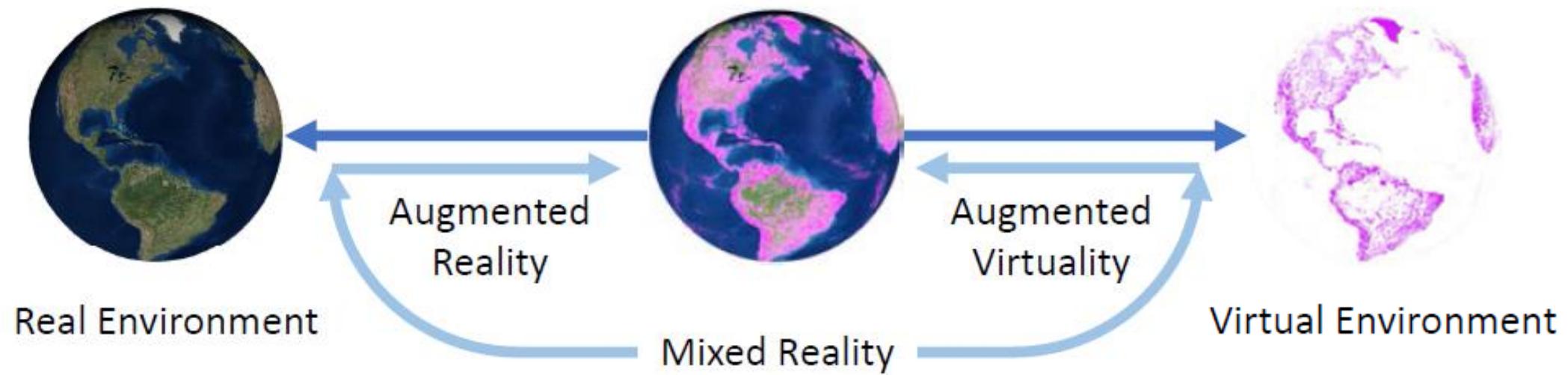
- What to expect?
  - What is the definition of augmented reality?
  - Are “augmented reality” and “mixed reality” the same?
  - How about “extended reality”?
  - What components are necessary to implement this type of applications?



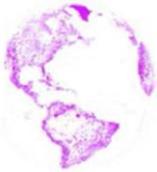
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# The Reality-Virtuality Continuum

# The Reality-Virtuality Continuum



Milgram, Paul, and Fumio Kishino. "A taxonomy of mixed reality visual displays." IEICE TRANSACTIONS on Information and Systems 77, no. 12 (1994): 1321-1329.



# Virtual Reality

- Virtual Reality (VR) immerses users inside computer-generated environments.
- Although most common virtual components are visual, these can include any other sensory input.

## Season Traveller: Multisensory Narration for Enhancing the Virtual Reality Experience

Nimesha Ranasinghe<sup>1</sup>, Pravar Jain<sup>1</sup>, Nguyen Thi Ngoc Tram<sup>1</sup>, Koon Chuan Raymond Koh<sup>2</sup>, David Tolley<sup>1</sup>, Shienny Karwita<sup>1</sup>, Lin Lien-Ya<sup>1</sup>, Yan Liangkun<sup>1</sup>, Kala Shamaiah<sup>2</sup>, Chow Eason Wai Tung<sup>1</sup>, Ching Chiuan Yen<sup>1</sup>, Ellen Yi-Luen Do<sup>1,3</sup>

Keio-NUS CUTE Center, Smart Systems Institute, National University of Singapore<sup>1</sup>

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{raymond\_k\_c\_koh, kala\_shamaiah}@ite.edu.sg

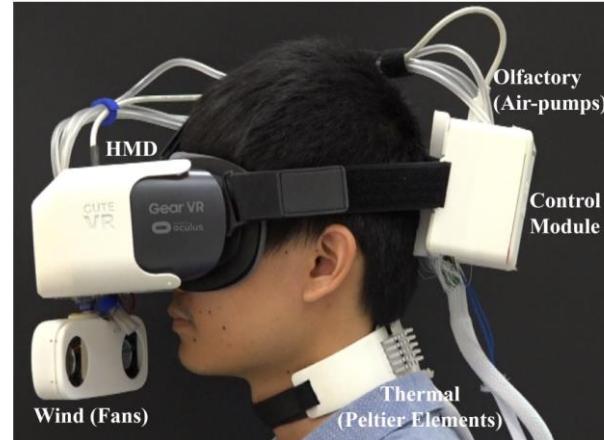


Figure 1: Season Traveller is a multisensory VR experience integrated with Samsung Gear VR HMD. It enhances participants' sense of presence using visual, auditory, wind, thermal, and olfactory stimuli.

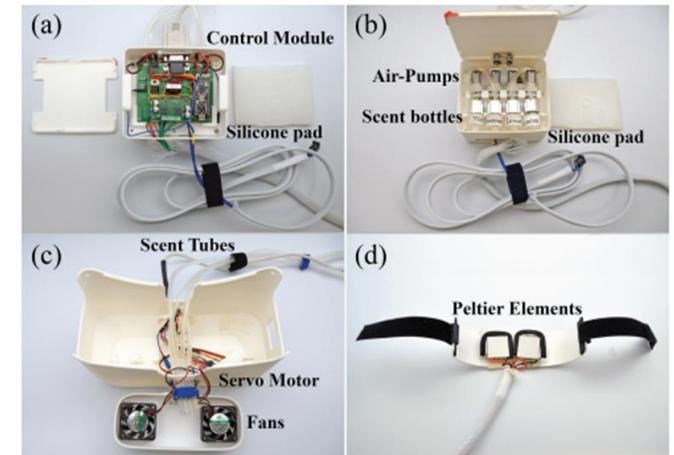


Figure 4: Main modules of Season Traveller: (a) Control Module, (b) Olfactory Simulation Module, (c) Front Casing and Wind Simulation Module, (d) Thermal Simulation Module

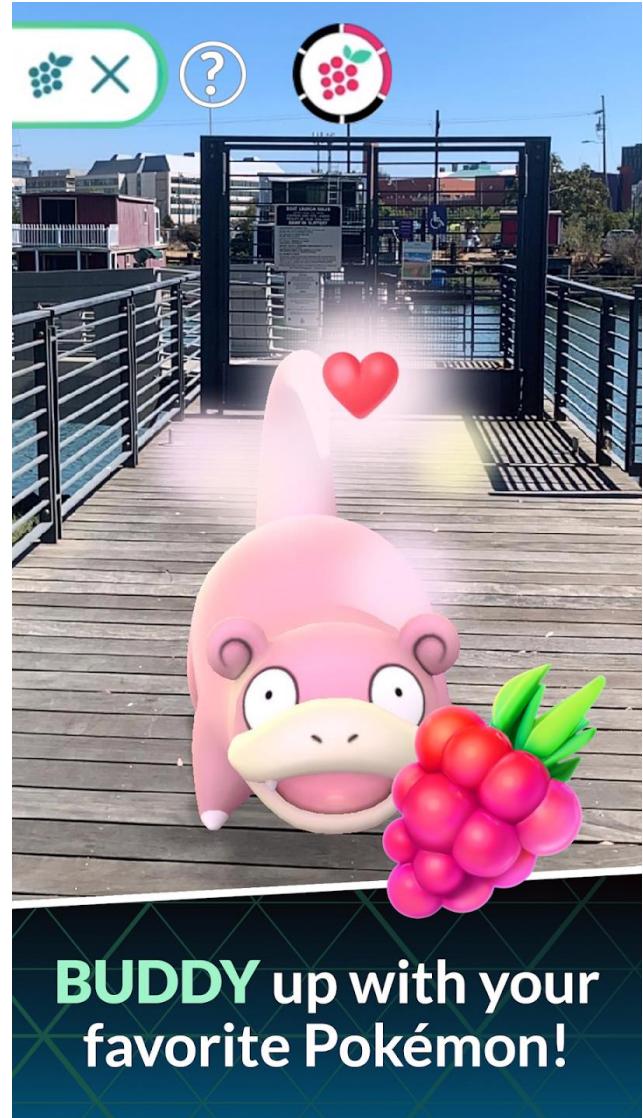
Ranasinghe, Nimesha, Pravar Jain, Nguyen Thi Ngoc Tram, Koon Chuan Raymond Koh, David Tolley, Shienny Karwita, Lin Lien-Ya et al. "Season traveller: Multisensory narration for enhancing the virtual reality experience." In *Proceedings of the 2018 CHI conference on human factors in computing systems*, pp. 1-13. 2018.



# Augmented Reality

- Augmented Reality (AR) overlays virtual content on the real world enhancing the user's perception.
- Three characteristics <sup>1</sup>:
  - Combines real and virtual
  - Interactive in real time
  - Registered in three dimensions

[1] Azuma, Ronald T. "A survey of augmented reality." *Presence: teleoperators & virtual environments* 6, no. 4 (1997): 355-385.



**BUDDY up with your favorite Pokémons!**

Image source:

[https://play.google.com/store/apps/details?id=com.nianticlabs.pokemongo&hl=en\\_US&gl=US](https://play.google.com/store/apps/details?id=com.nianticlabs.pokemongo&hl=en_US&gl=US)



# Augmented Virtuality

- Augmented virtuality (AV) enriches the virtual world using real objects with which the users interact.

## Augmented Virtuality Using Touch-Sensitive 3D-Printed Objects

Gianpaolo Palma <sup>1,\*</sup>, Sara Perry <sup>2</sup> and Paolo Cignoni <sup>1</sup>

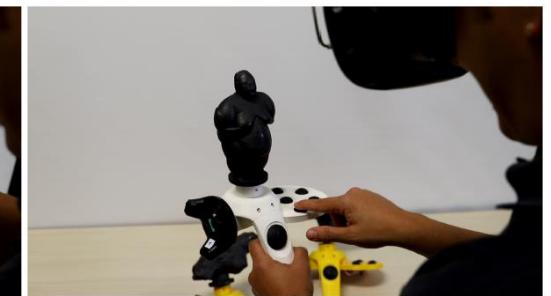
<sup>1</sup> Visual Computing Lab, Istituto di Scienza e Tecnologia dell'Informazione—CNR, 56124 Pisa, Italy; paolo.cignoni@isti.cnr.it

<sup>2</sup> MOLA (Museum of London Archaeology), London N1 7ED, UK; sperry@mola.org.uk

\* Correspondence: gianpaolo.palma@isti.cnr.it



**Figure 1.** (Left) Photos of the hardware of the system: HTC Vive, LeapMotion, Vive Tracker, the 3D-printed support with the replica that hosts the controller for capacitive touch sensing. (Right) Example of a painting session.

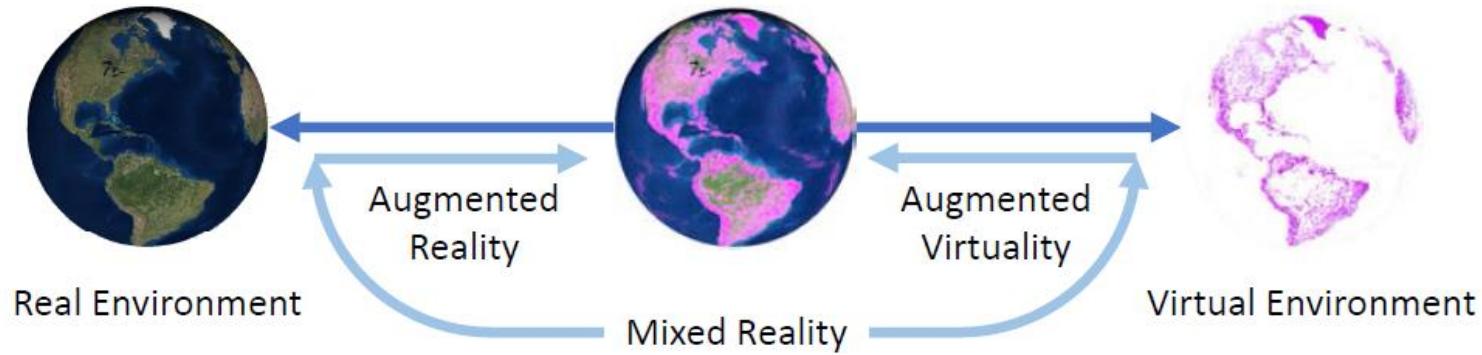


**Figure 12.** Photos of a user during the VR experience.

Palma, Gianpaolo, Sara Perry, and Paolo Cignoni. "Augmented virtuality using touch-sensitive 3D-printed objects." *Remote Sensing* 13, no. 11 (2021): 2186.

# Mixed Reality

- How about it?



Milgram, Paul, and Fumio Kishino. "A taxonomy of mixed reality visual displays." IEICE TRANSACTIONS on Information and Systems 77, no. 12 (1994): 1321-1329.

# Mixed Reality



*"...the term "Mixed Reality" is not in common use, the related term "Augmented Reality" (AR) has in fact started to appear in the literature with increasing regularity. As an operational definition of Augmented Reality, we take the term to refer to any case in which an otherwise real environment is "augmented" by means of virtual objects..."*

Milgram, Paul, and Fumio Kishino. "A taxonomy of mixed reality visual displays." IEICE TRANSACTIONS on Information and Systems 77, no. 12 (1994): 1321-1329.

# Mixed Reality



*"...a particular subclass of VR related technologies that involve the merging of real and virtual worlds, which we refer to generically as Mixed Reality (MR)...."*

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

Milgram, Paul, and Fumio Kishino. "A taxonomy of mixed reality visual displays." IEICE TRANSACTIONS on Information and Systems 77, no. 12 (1994): 1321-1329.



# Mixed Reality

CHI 2019 Paper

CHI 2019, May 4–9, 2019, Glasgow, Scotland, UK

## What is Mixed Reality?

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**Michael Nebeling**

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### ABSTRACT

What is Mixed Reality (MR)? To revisit this question given the many recent developments, we conducted interviews with ten AR/VR experts from academia and industry, as well as a literature survey of 68 papers. We find that, while there are prominent examples, there is no universally agreed on, one-size-fits-all definition of MR. Rather, we identified six

### 1 INTRODUCTION

This paper is motivated by many discussions with colleagues, researchers, professionals in industry, and students active in the HCI community, all working on Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) projects. These discussions showed that, while MR is increasingly gaining in popularity and relevance, and despite the relative

#### ★ Suggested Reading

Speicher, Maximilian, Brian D. Hall, and Michael Nebeling. "What is mixed reality?." In Proceedings of the 2019 CHI conference on human factors in computing systems, pp. 1-15. 2019.



# Mixed Reality

- So, ***what is mixed reality?***

## 10 SO, WHAT IS MIXED REALITY?

The answer is: *it depends.* MR can be many things

### ★ Suggested Reading

Speicher, Maximilian, Brian D. Hall, and Michael Nebeling. "What is mixed reality?." In *Proceedings of the 2019 CHI conference on human factors in computing systems*, pp. 1-15. 2019.

CHI 2019 Paper

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#### ABSTRACT

What is Mixed Reality (MR)? To revisit this question given the many recent developments, we conducted interviews with ten AR/VR experts from academia and industry, as well as a literature survey of 68 papers. We find that, while there are prominent examples, there is no universally agreed on, one-size-fits-all definition of MR. Rather, we identified six partially competing notions from the literature and experts' responses. We then started to isolate the different aspects of reality relevant for MR experiences, going beyond the primarily visual notions and extending to audio, motion, haptics, taste, and smell. We distill our findings into a conceptual framework with seven dimensions to characterize MR applications in terms of the *number of environments*, *number of users*, *level of immersion*, *level of virtuality*, *degree of interaction*, *input*, and *output*. Our goal with this paper is to support classification and discussion of MR applications' design and provide a better means to researchers to contextualize their work within the increasingly fragmented MR landscape.

#### CCS CONCEPTS

• Human-centered computing → Mixed / augmented reality; HCI theory, concepts and models;

#### KEYWORDS

Augmented reality; conceptual framework; expert interviews; literature review; mixed reality; taxonomy; virtual reality.

#### ACM Reference Format:

Maximilian Speicher, Brian D. Hall, and Michael Nebeling. 2019. What is Mixed Reality?. In *CHI Conference on Human Factors in Computing Systems Proceedings (CHI 2019)*, May 4–9, 2019, Glasgow, Scotland, UK. ACM, New York, NY, USA, 15 pages. <https://doi.org/10.1145/3290605.3300767>

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ACM ISBN 978-1-4503-5970-2/19/05 ... \$15.00  
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#### 1 INTRODUCTION

This paper is motivated by many discussions with colleagues, researchers, professionals in industry, and students active in the HCI community, all working on Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) projects. These discussions showed that, while MR is increasingly gaining in popularity and relevance, and despite the relative popularity of Milgram & Kishino's Reality-Virtuality Continuum [44], we are still far from a shared understanding of what MR actually constitutes. Many see MR as a synonym for AR. Some consider MR strictly according to the definition given by Milgram & Kishino [44], i.e., a superset of AR in terms of a "mix of real and virtual objects within a single display." Yet, others consider MR distinct from AR in the sense that MR enables walking into, and manipulating, a scene whereas AR does not. Some do not even attempt, or want, to specify what MR is. What adds to the confusion is that key players like Microsoft are pushing MR as a new technology, first, with HoloLens, then expanding to a range of Windows Mixed Reality devices, along with the Mixed Reality Toolkit to build applications for these devices.

*What does this paper do?* The goal of this paper is to work towards a shared understanding of the term MR, the related concepts and technologies. Many researchers base their understanding of MR on the Reality-Virtuality Continuum [44], which they consider the go-to source for a widely accepted definition of MR. Yet, as we will show with expert interviews and a literature review reported in this paper, it is not a universally agreed notion. As the authors noted themselves, the core limitation of the continuum is the fact that it is restricted to visual features. Broadly speaking, MR originated from computer graphics, hence common notions of MR are mostly restricted to graphical aspects. Yet, technological capabilities, design practices, and perceptions of MR have evolved since the continuum was first proposed in 1994, and discussions about MR have become increasingly difficult. We therefore found it necessary to identify the different working definitions of MR that are used "in the wild", how they differ and relate, and what their limitations are. We hope that our effort will allow the community to work towards a more consistent understanding of MR and apply it in different contexts, e.g., to better characterize MR experiences using such distinguishing factors as single-user or multi-user, same or different environments, different degrees of immersion and virtuality, and implicit vs. explicit interactions.



# Mixed Reality

1. Continuum. “Traditional” notion of MR in accordance with the Reality–Virtuality Continuum
2. Synonym. Many papers simply treated MR as a synonym for AR
3. Collaboration. Interaction between an AR and a VR user (potentially physically separated)
4. Combination. MR as a combination of AR and VR
5. Alignment. Synchronization between a physical and a virtual environment
6. Strong AR. Characterized by an advanced environmental understanding and interactions

★ Suggested Reading

Speicher, Maximilian, Brian D. Hall, and Michael Nebeling. "What is mixed reality?." In *Proceedings of the 2019 CHI conference on human factors in computing systems*, pp. 1-15. 2019.

## What is Mixed Reality?

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# Mixed Reality

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Technology capable of *enriching the senses* of a user by seamlessly integrating *virtual content* that interacts with the real world.

# Extended Reality

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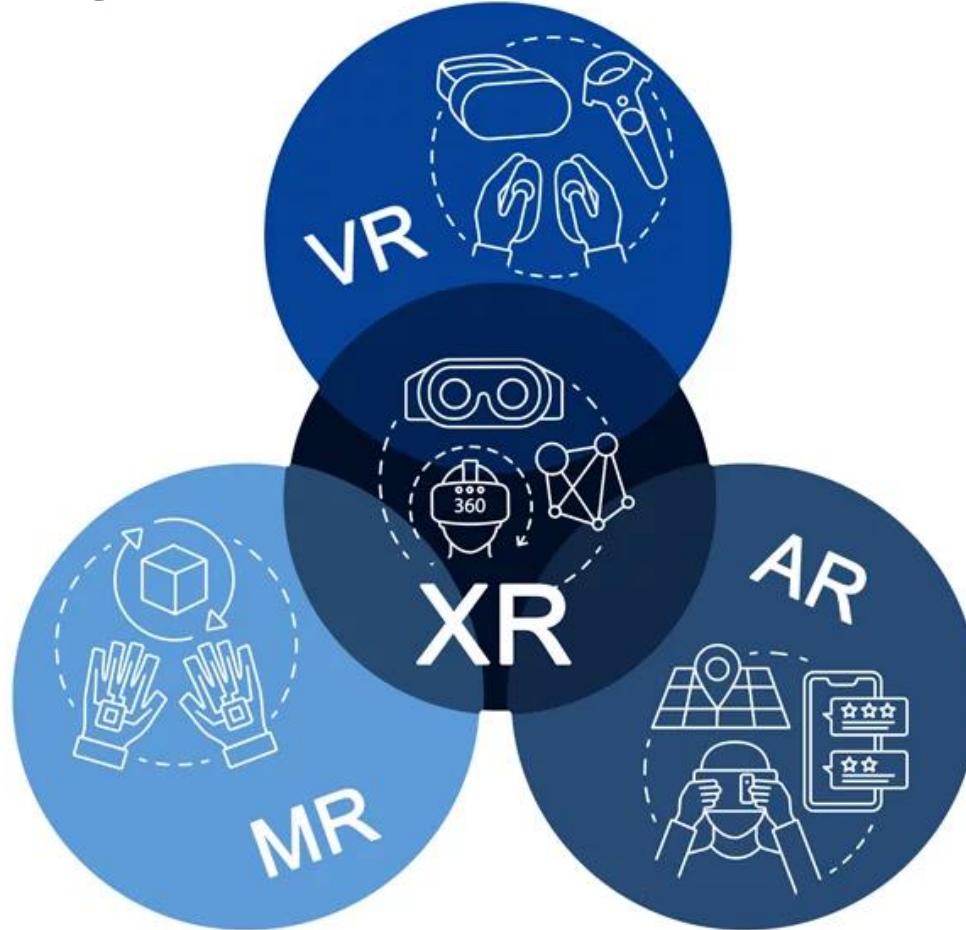


Image source: <https://envision-is.com/xr/>



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# Other Continuums?

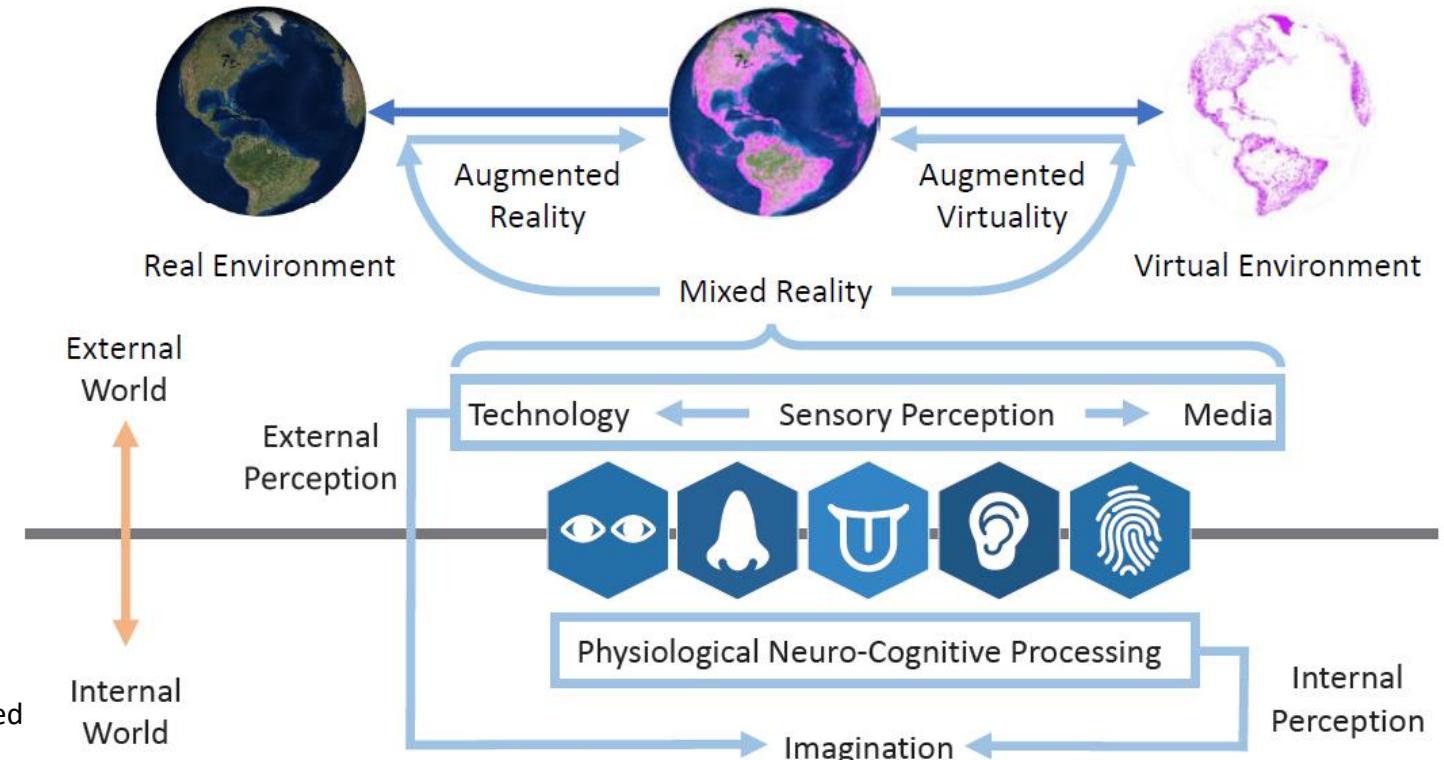
# Other Continuum?



Milgram, Paul, and Fumio Kishino. "A taxonomy of mixed reality visual displays." IEICE TRANSACTIONS on Information and Systems 77, no. 12 (1994): 1321-1329.

# Imagination: The Third Reality to the Virtuality Continuum

- The user's imagination is an essential dimension in the virtuality-reality continuum.
- Imagination enables the designer to deliver their intentions to user's.



C. Stapleton and J. Davies. "Imagination: The third reality to the virtuality continuum". In: 2011 IEEE International Symposium on Mixed and Augmented Reality-Arts, Media, and Humanities. IEEE. 2011, pp. 53–60 (cit. on p. 20).

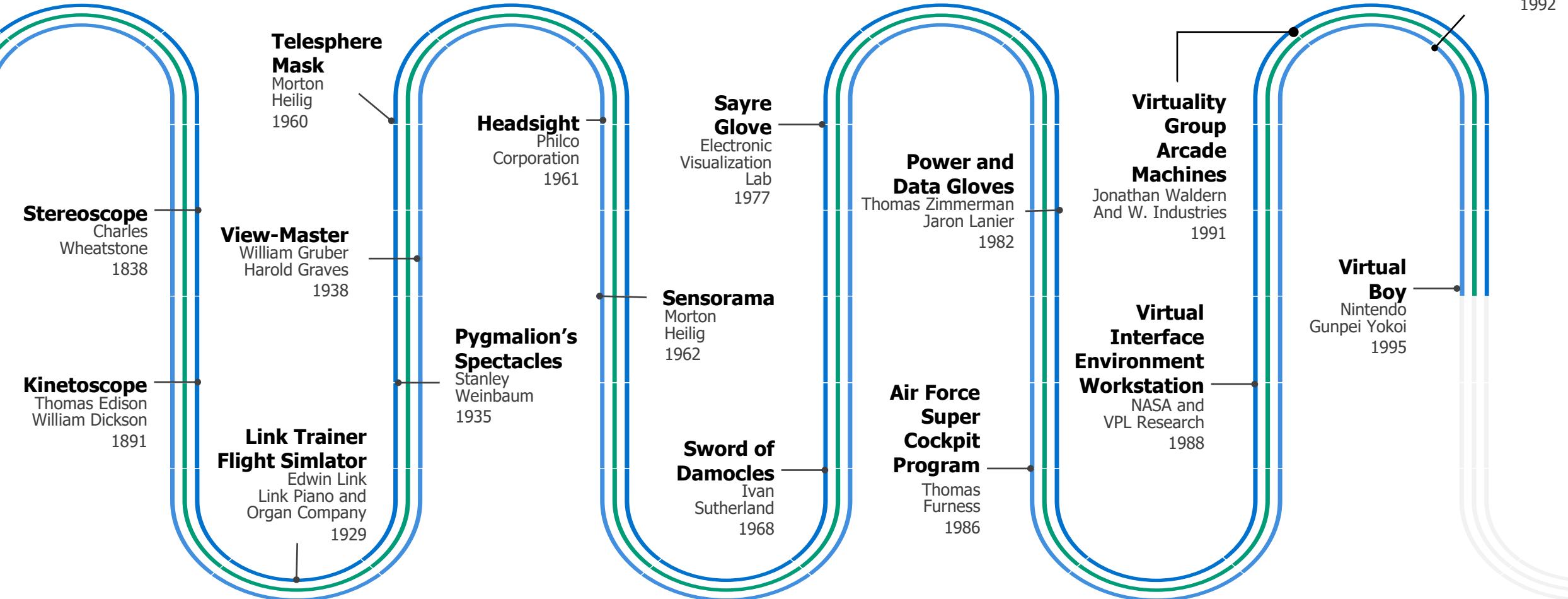


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# History of Augmented Reality

With a little of Virtual as well...

# The Road Before Augmented Reality



# Stereoscope

- Allowed users to view a pair of separate images for each eye, creating a seemingly distant and larger 3D image



—from “Stereoscopes”

**Stereoscope**  
Charles  
Wheatstone  
1838



—from “Stereoscopes”

# Kinetoscope

- Showed images in motion between a lens and a light bulb.
- Users looked at the images through a peephole.



Image source: <https://theasc.com/asc/asc-museum-kinetoscope>

Stereoscope  
Charles  
Wheatstone  
1838

**Kinetoscope**  
Thomas Edison  
William Dickson  
1891

# Link Trainer Flight Simulator

- Simulated plane movement using pneumatic pumps.
- Full degree of freedom rotation
- Force feedback and motion control
- Simulated instruments
- Modeling common flight conditions



<https://www.youtube.com/watch?v=MEKkVg9NqGM>

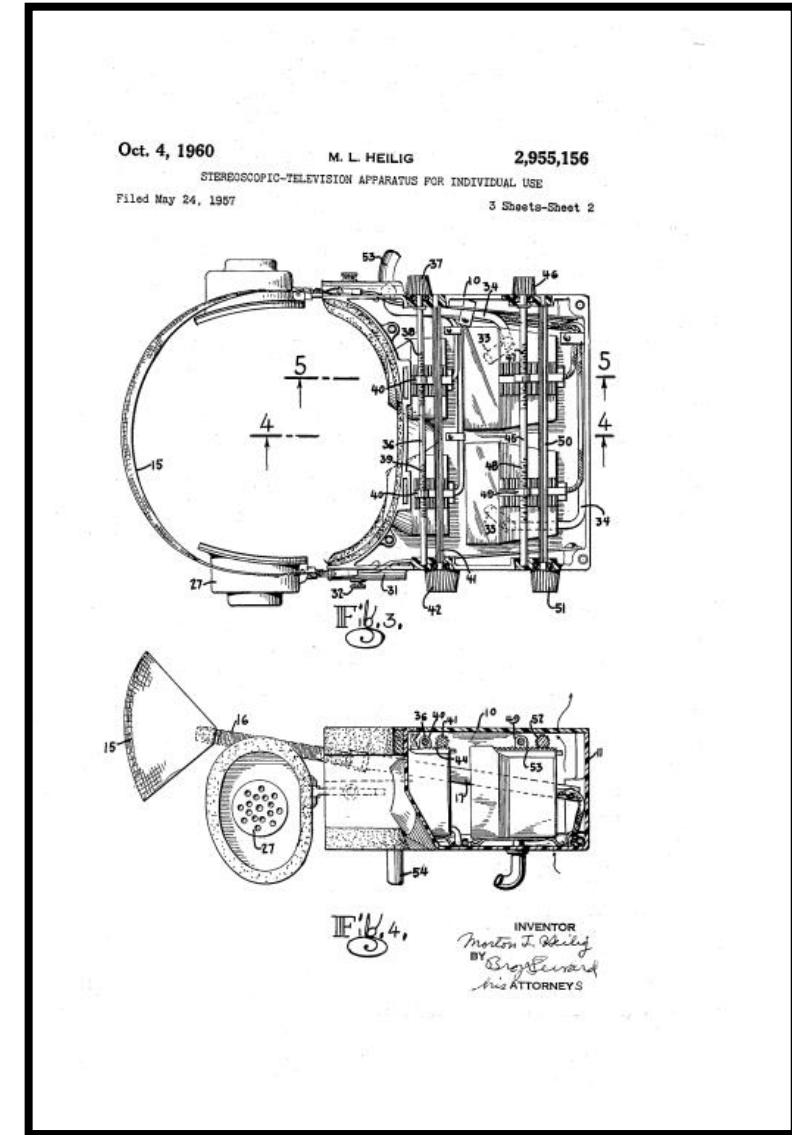
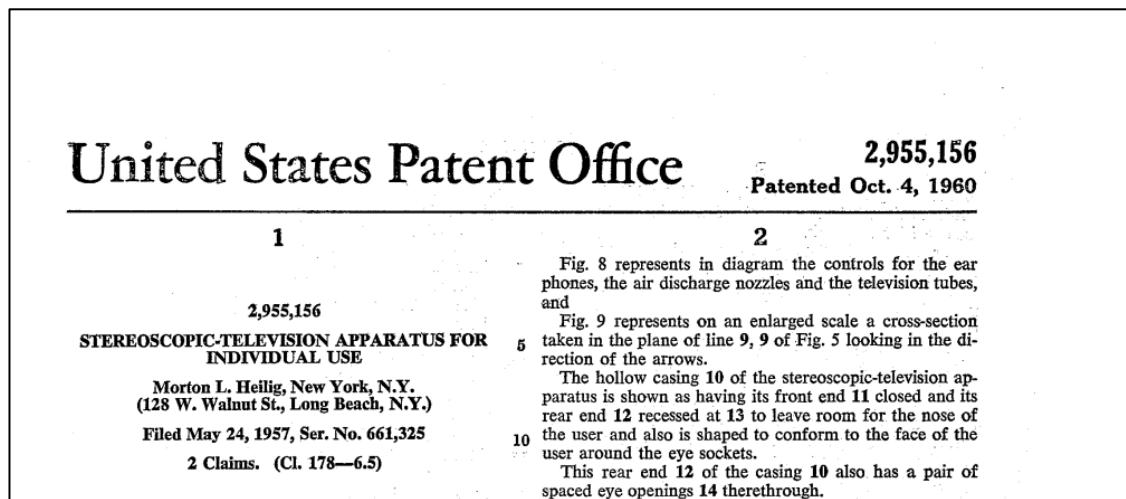
**Stereoscope**  
Charles Wheatstone  
1838

**Kinetoscope**  
Thomas Edison  
William Dickson  
1891

**Link Trainer Flight Simulator**  
Edwin Link  
Link Piano and Organ Company  
1929

# Telesphere Mask

- Integrated stereoscopic technology, widescreen vision, and stereo sound.



Stereoscope  
Charles Wheatstone  
1838

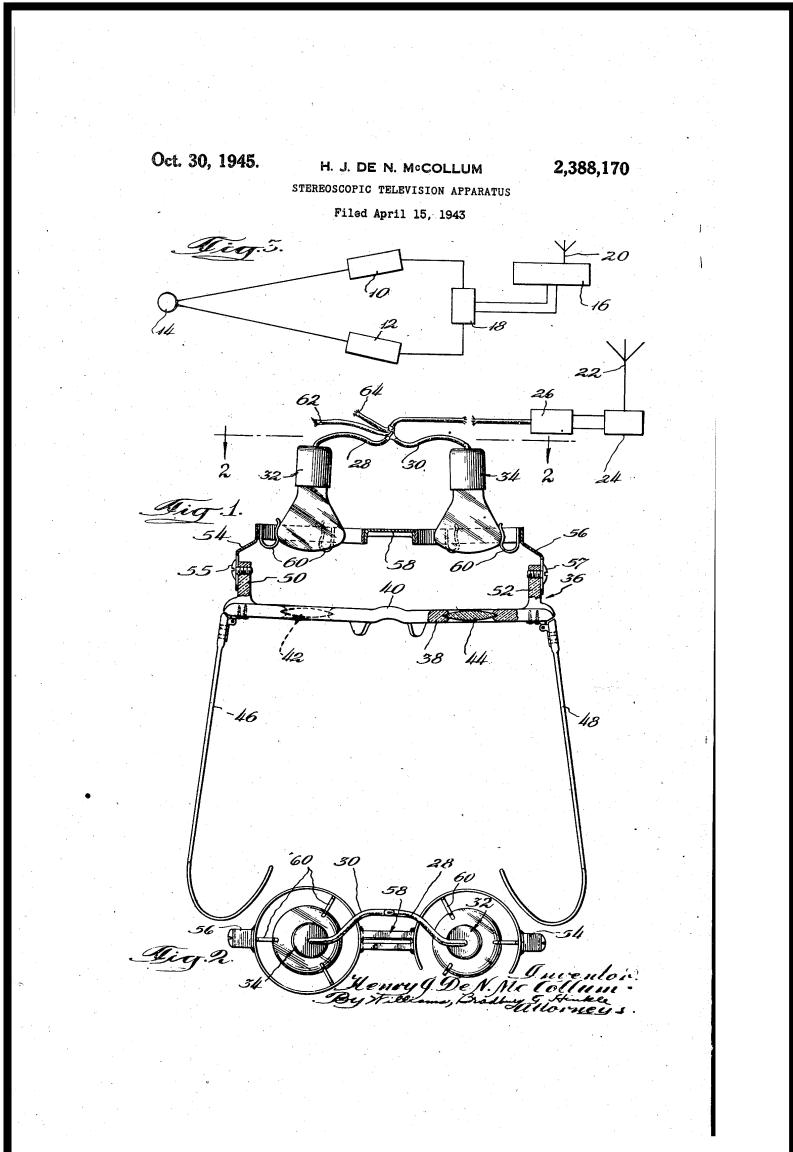
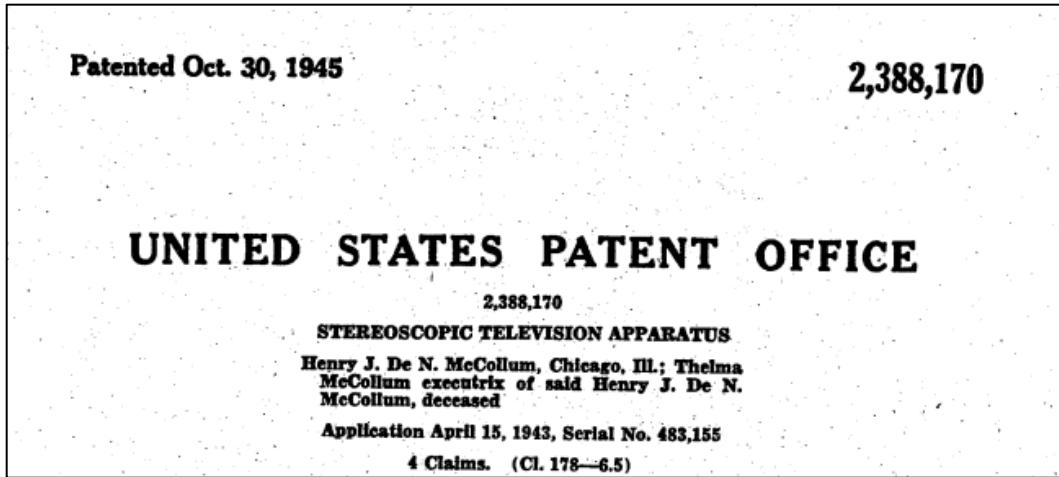
Kinetoscope  
Thomas Edison  
William Dickson  
1891

Link Trainer Flight Simulator  
Edwin Link  
Link Piano and Organ Company  
1929

Telesphere Mask  
Morton Heilig  
1960

# Other Patents for HMDs

- McCollum's Stereo TV



Stereoscope  
Charles Wheatstone  
1838

Kinetoscope  
Thomas Edison  
William Dickson  
1891

Link Trainer Flight Simulator  
Edwin Link  
Link Piano and Organ Company  
1929

Telesphere Mask  
Morton Heilig  
1960

# Headsight

- First motion-tracking HMD
- Capable of taking pictures
- Designed to allow remote viewing using a monocular HMD



Image source: <https://courses.vrtl.academy/lessons/what-is-virtual-reality-and-where-does-it-come-from/>

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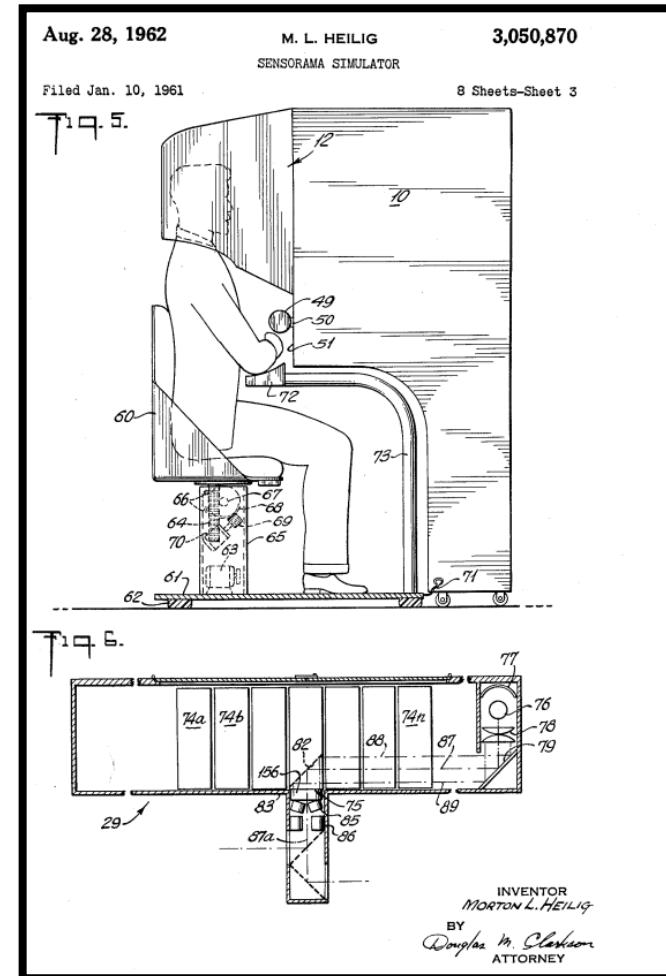
**Link Trainer Flight Simulator**  
Edwin Link  
Link Piano and Organ Company  
1929

**Telesphere Mask**  
Morton Heilig  
1960

**Headsight**  
Philco Corporation  
1961

# Sensorama

- Produced sensations to simulate real experiences.
  - In addition to visual stimulus, it included haptics (vibration) and smell.



# Stereoscope

Charles  
Wheatstone  
1838

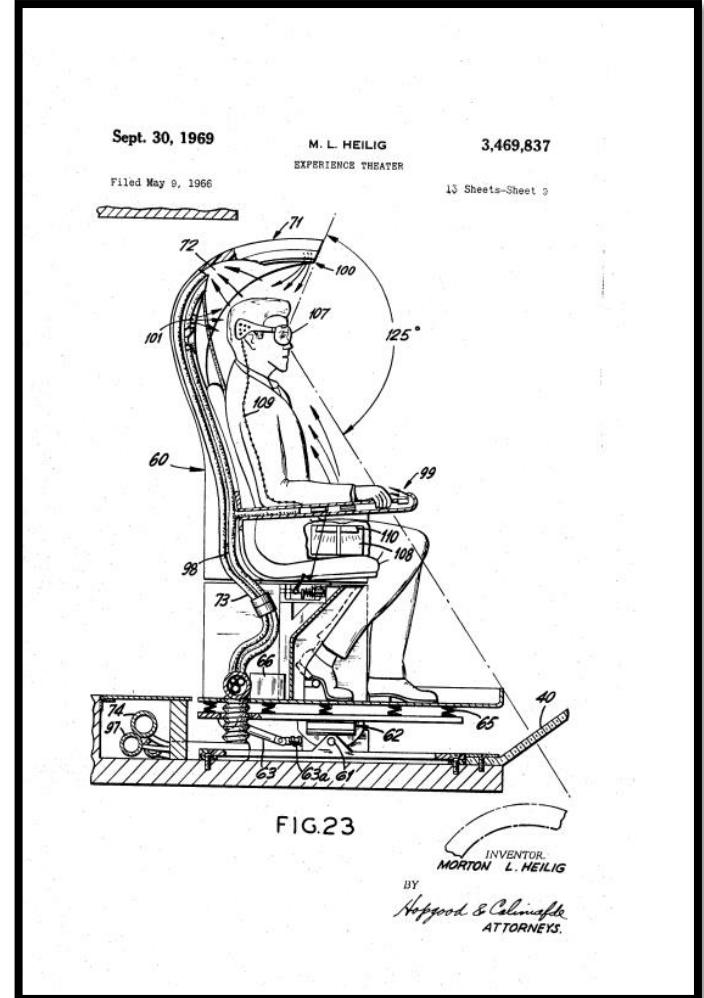
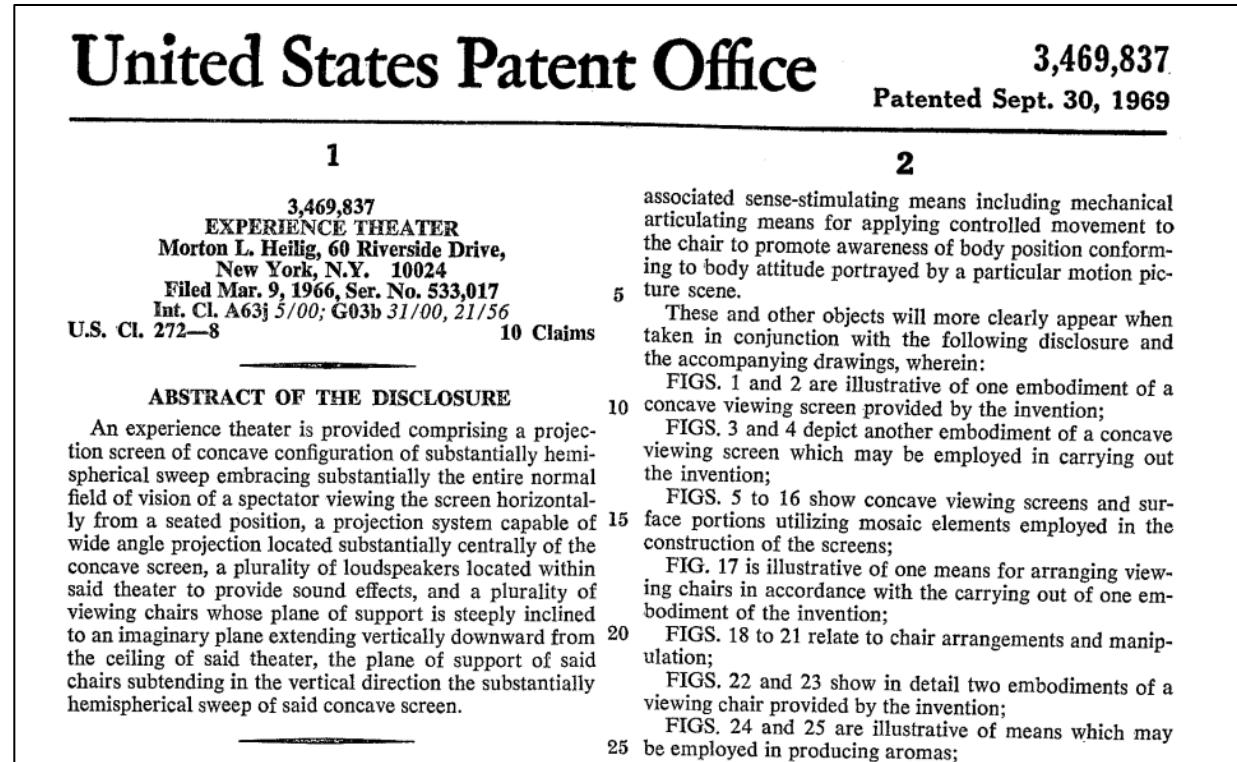
# Kinetoscope

Thomas Edison  
William Dickson  
1891

# Link Trainer Flight Simulator

**Sensorama**  
Morton  
Heilig  
1963

# More from Morton Heilig...



# Stereoscope

Charles  
Wheatstone  
1838

# Kinetoscope

Thomas Edison  
William Dickson  
1891

# Link Trainer Flight Simulator

**Telesphere Mask** Morton Heilig 1960 | **Headsight** Philco Corporation 1961

## **Sensorama**

Morton  
Heilig  
1962



# Ivan Sutherland's Headset and “*The ultimate display*”



京都賞

Kyoto Prize, 2012



Turing Award,  
1988

- Considered by many as the first augmented reality HMD
- It integrated a mechanical tracking system (a.k.a. the sword of Damocles because of the Greek myth).

Sutherland, Ivan. "The ultimate display." (1965).



<https://www.youtube.com/watch?v=MEKkVg9NqGM>



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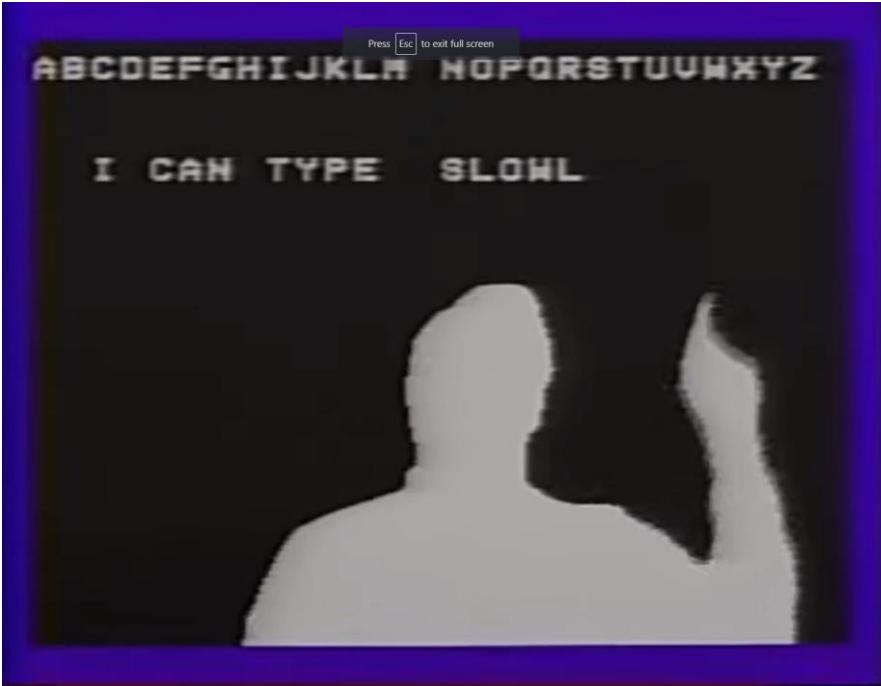
Sutherland, Ivan. "The ultimate display." (1965).



<https://www.youtube.com/watch?v=YB3saviItTI>



# Videoplace (Myron Kruger)



<https://www.youtube.com/watch?v=d4DUIeXSEpk&t=1s>



<https://www.youtube.com/watch?v=dqZyZrN3Pl0>

**Stereoscope**  
Charles  
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**Headsight**  
Philco  
Corporation  
1961

**Sensorama**  
Morton  
Heilig  
1962

**Sword of Damocles**  
Ivan  
Sutherland  
1968

**Videoplace**  
Myron  
Kruger  
1974

# Air Force Super Cockpit (Thomas Furness)

- Design a system that would integrate a headset, suit and gloves.
- Provide a multisensory input including visual, auditory, tactile, head, eye, speech, and hand input.
- Used for research only.



**Stereoscope**  
Charles Wheatstone  
1838

**Kinetoscope**  
Thomas Edison  
William Dickson  
1891

**Link Trainer Flight Simulator**  
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1962

**Sword of Damocles**  
Ivan Sutherland  
1968

**Videoplace**  
Myron Kruger  
1974

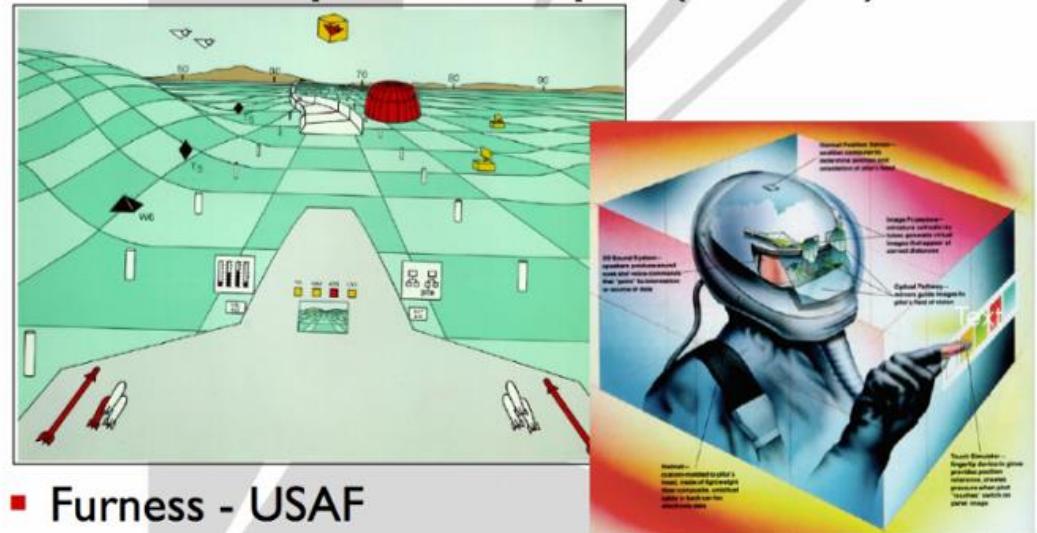
**Super Cockpit Program**  
Thomas Furness  
1986

# Air Force Super Cockpit (Thomas Furness)

Furness III, Thomas A. "The super cockpit and its human factors challenges." In *Proceedings of the human factors society annual meeting*, vol. 30, no. 1, pp. 48-52. Sage CA: Los Angeles, CA: SAGE Publications, 1986.

- A simulator allowed to project computer-generated 3D maps, and infrared and radar imagery, to simulate aircrafts operated by pilots using gestures and eye movements

The Super Cockpit (1980's)



■ Furness - USAF

Image source:

<https://medium.com/the-reality-files/the-reality-files-10-58325e3d891d>

Furness, T. A. (1986, September). The super cockpit and its human factors challenges. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 30, No. 1, pp. 48-52). SAGE Publications.

Stereoscope Charles Wheatstone 1838	Kinetoscope Thomas Edison William Dickson 1891	Link Trainer Flight Simulator Edwin Link Link Piano and Organ Company 1929	Telesphere Mask Morton Heilig 1960	Headsight Philco Corporation 1961	Sensorama Morton Heilig 1962	Sword of Damocles Ivan Sutherland 1968	Videoplace Myron Kruger 1974	Super Cockpit Program Thomas Furness 1986
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# Virtual Interface Environment Workstation

- Presented a computer-generated environment.
- Able to present real remote location captured using video cameras.
- Integrated a headset, and a DataGlove and DataSuit.



Image source: [https://www.nasa.gov/ames/spinoff/new\\_continents\\_of\\_ideas/](https://www.nasa.gov/ames/spinoff/new_continents_of_ideas/)

**Telesphere Mask**  
Morton Heilig  
1960

**Headsight**  
Philco Corporation  
1961

**Sensorama**  
Morton Heilig  
1962

**Sword of Damocles**  
Ivan Sutherland  
1968

**Videoplace**  
Myron Kruger  
1974

**Air Force Super Cockpit Program**  
Thomas Furness  
1986

**Virtual Interface Environment Workstation**  
NASA and VPL Research  
1988

# Industrial Applications

- In 1992 Tom Caudell developed the first industrial application at Boeing for wire harness assembly.



Thomas, P. C., and W. M. David. "Augmented reality: An application of heads-up display technology to manual manufacturing processes." In Hawaii international conference on system sciences, vol. 2. ACM SIGCHI Bulletin, 1992.

# Industrial Applications

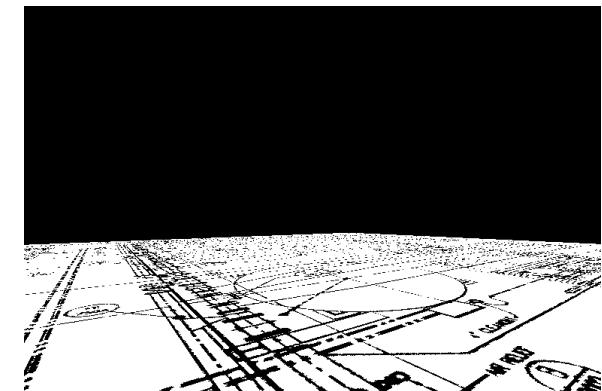
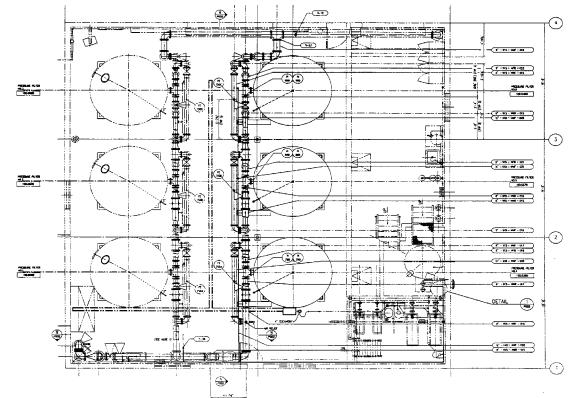
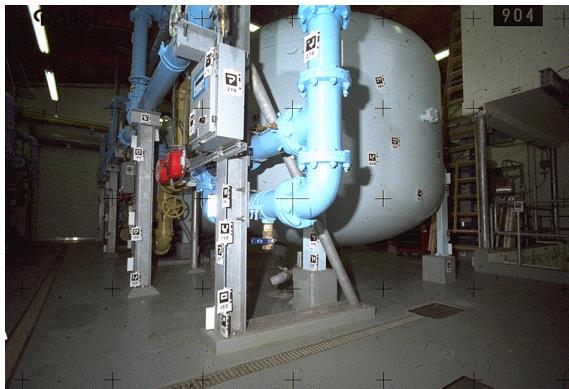
- Results:
  - Harness assembled with AR pass QA inspection
  - Productivity was no higher
  - Wide disparity of user acceptance levels

Thomas, P. C., and W. M. David. "Augmented reality: An application of heads-up display technology to manual manufacturing processes." In Hawaii international conference on system sciences, vol. 2. ACM SIGCHI Bulletin, 1992.



# Industrial Applications

- CyliCon : New Paradigm for New Practice
  - Siemens – Prof. Nassir Navab
- Create new user interaction paradigm for 3D reconstruction, design, maintenance assistance, data navigation...
- Integrate floor maps, industrial drawings, images, 3D reconstruction, in a single unique system.



Images courtesy of:  
Professor Nassir Navab

# Industrial Applications

- CyliCon : New Paradigm for New Practice – Siemens – Prof. Nassir Navab

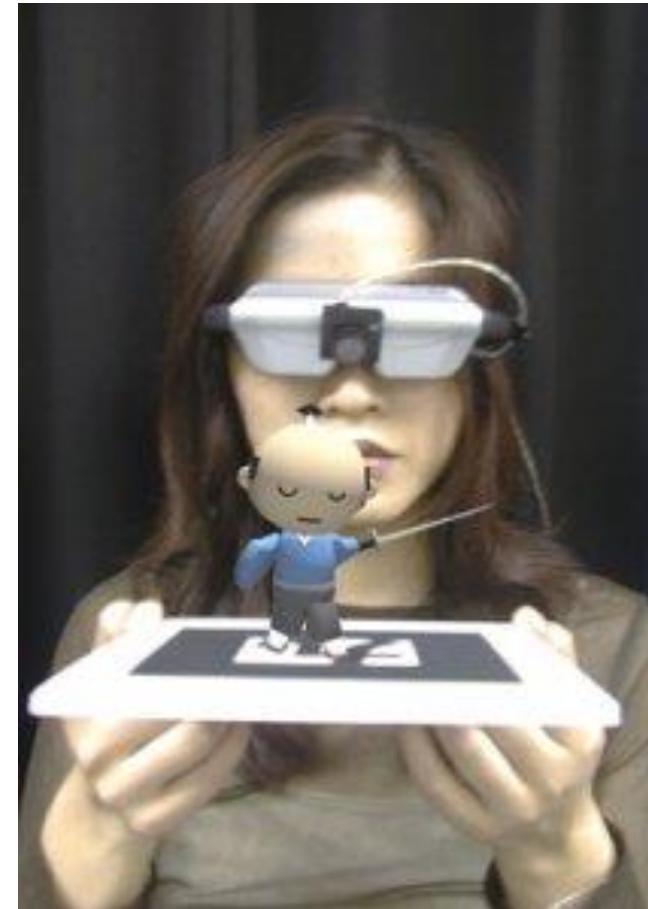


Images courtesy of: Professor Nassir Navab

Augmented Reality. Fall 2022. Introduction.  
Alejandro Martin Gomez

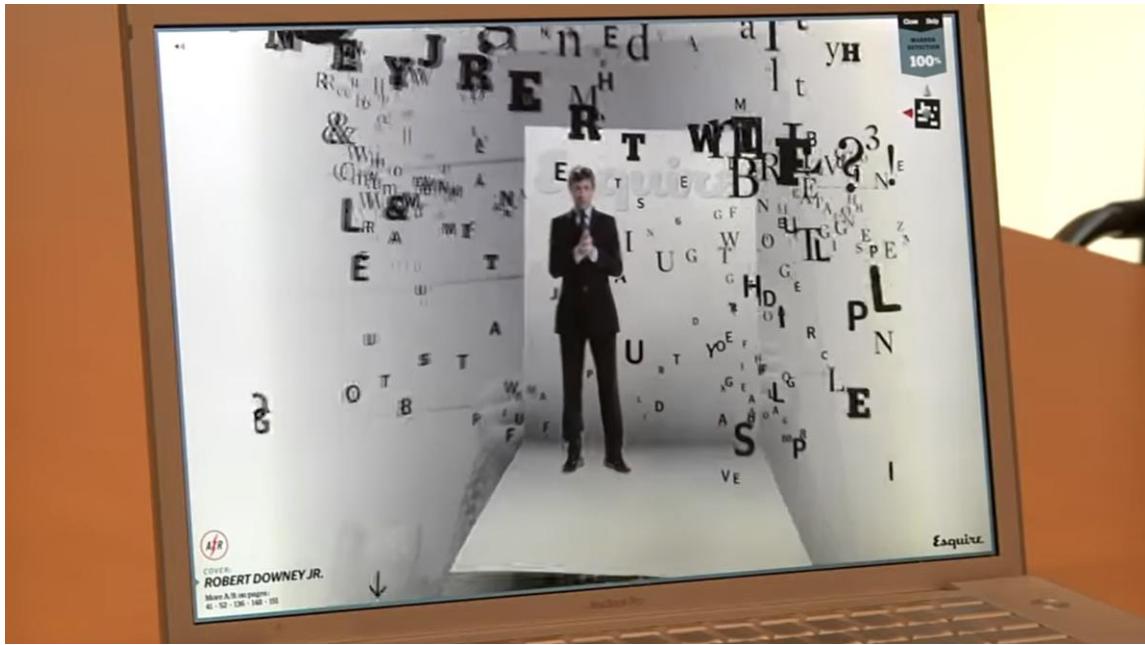
# Development of AR Tools (ARToolKit)

- Originally developed in 2000 by Dr. Hirokazu Kato and supported by:
  - The Human Interface Technology Laboratory (HIT Lab) at the University of Washington
  - The HIT Lab NZ at the University of Canterbury, New Zealand, and
  - ARToolworks, Inc, Seattle.
- Open-source library to help helps developers building augmented reality applications.



# Print Media

- In 2009, Esquire Magazine used augmented reality in print media for the first time



<https://www.youtube.com/watch?v=wp2z36kKn0s>



# Entertainment

- The “yellow yard marker” appears for the first time in 1998
- This line is overlayed on top of the field using the respective camera views to easily visualize the first down line.
- Nowadays, the system is capable to add additional graphics and has been used in other sports.

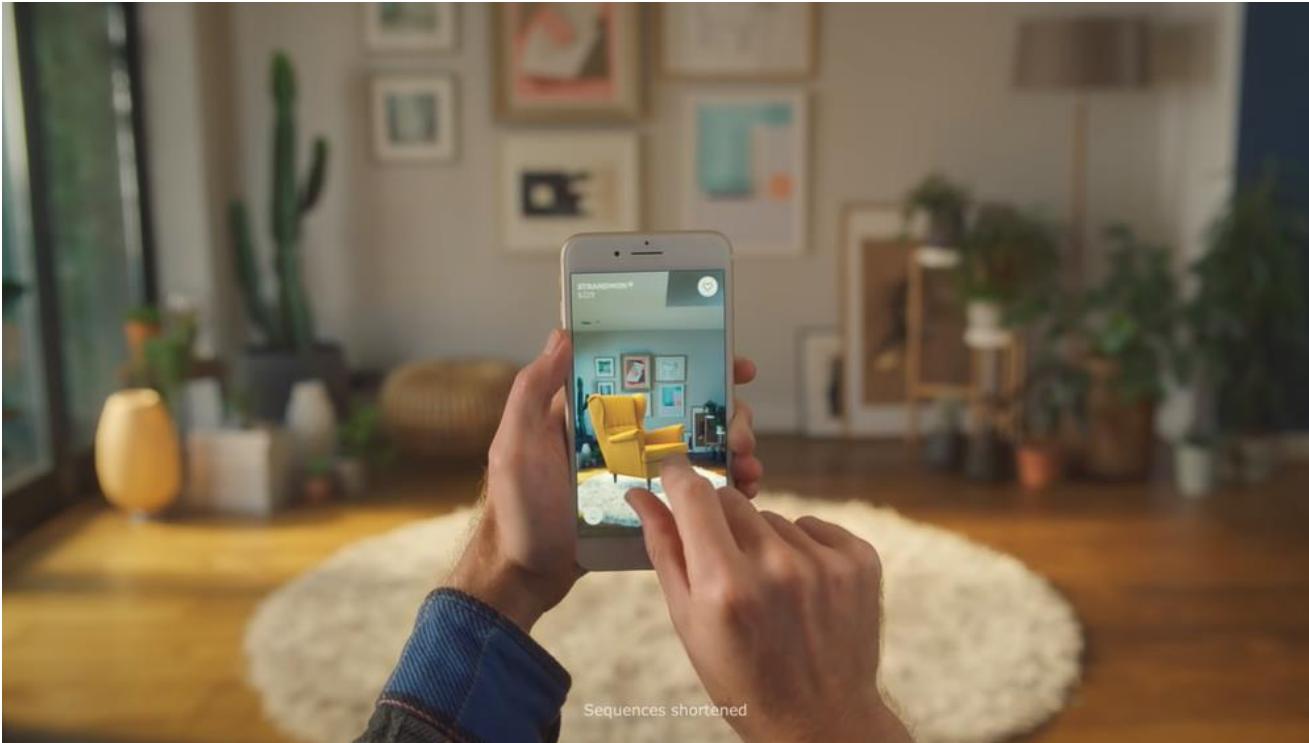


Image source: <https://ftw.usatoday.com/2022/01/nfl-on-nickelodeon-cowboys-49ers-slime>

# Commercial Applications

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- In 2017, IKEA released its augmented reality app called IKEA Place



<https://www.youtube.com/watch?v=UudV1VdFtuQ&t=1s>

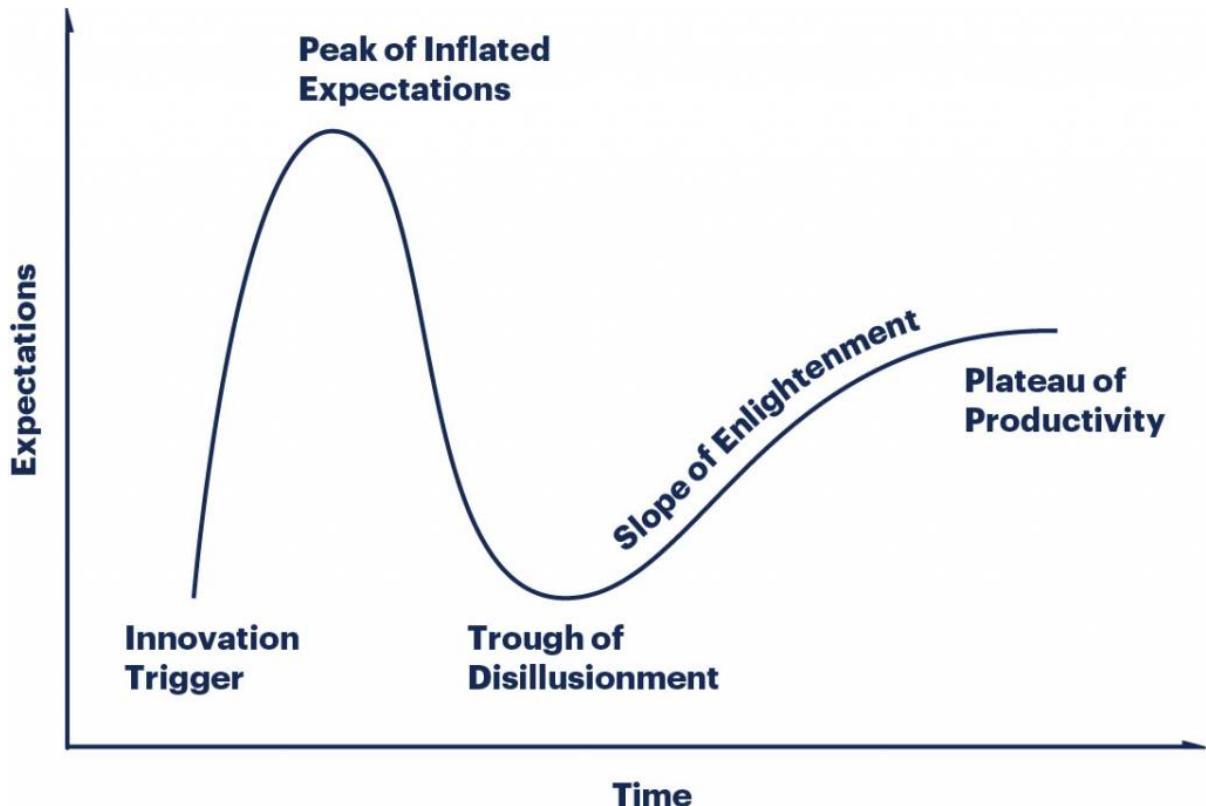


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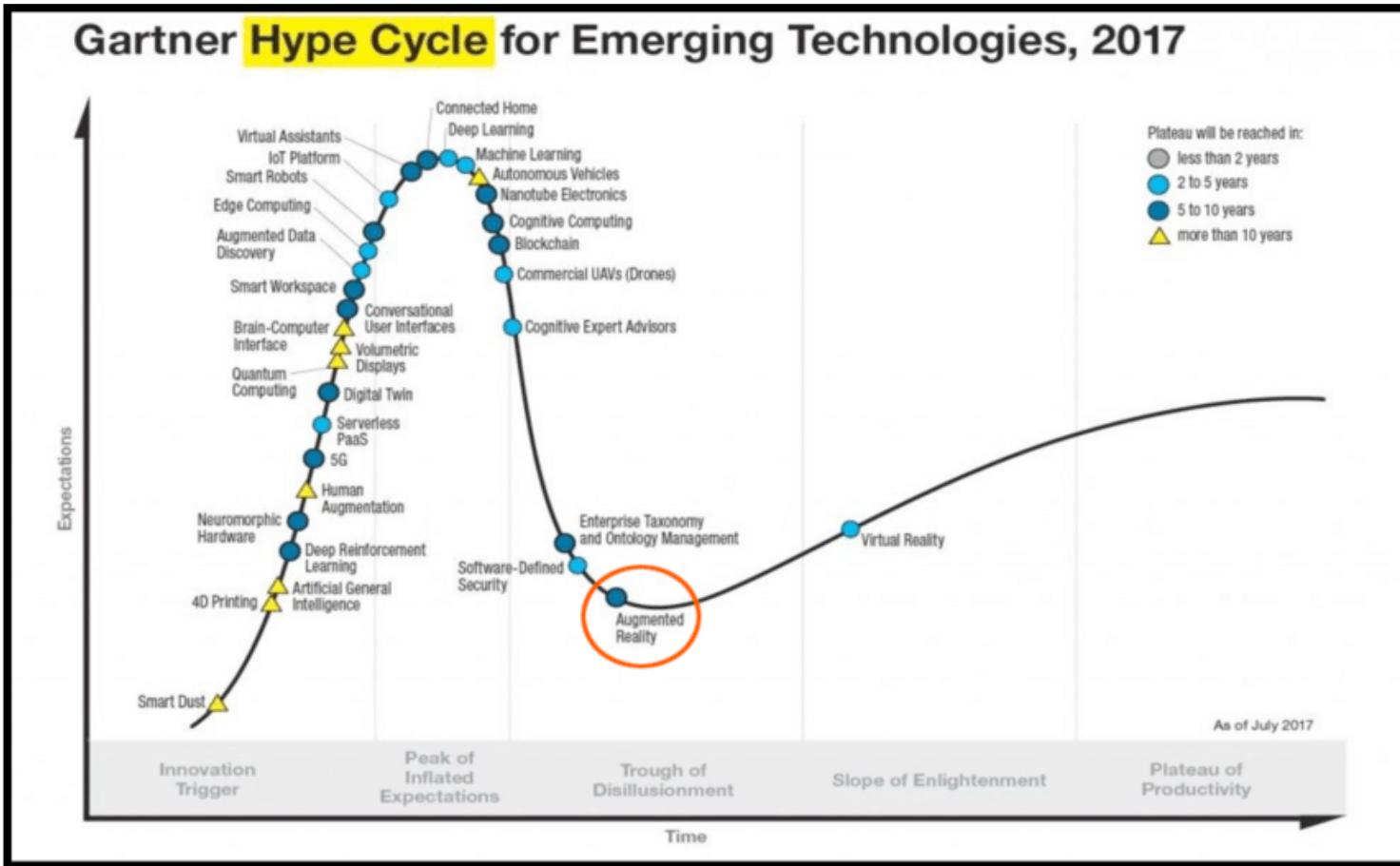
# The Gartner's Hype Cycle

# The Gartner's Hype Cycle

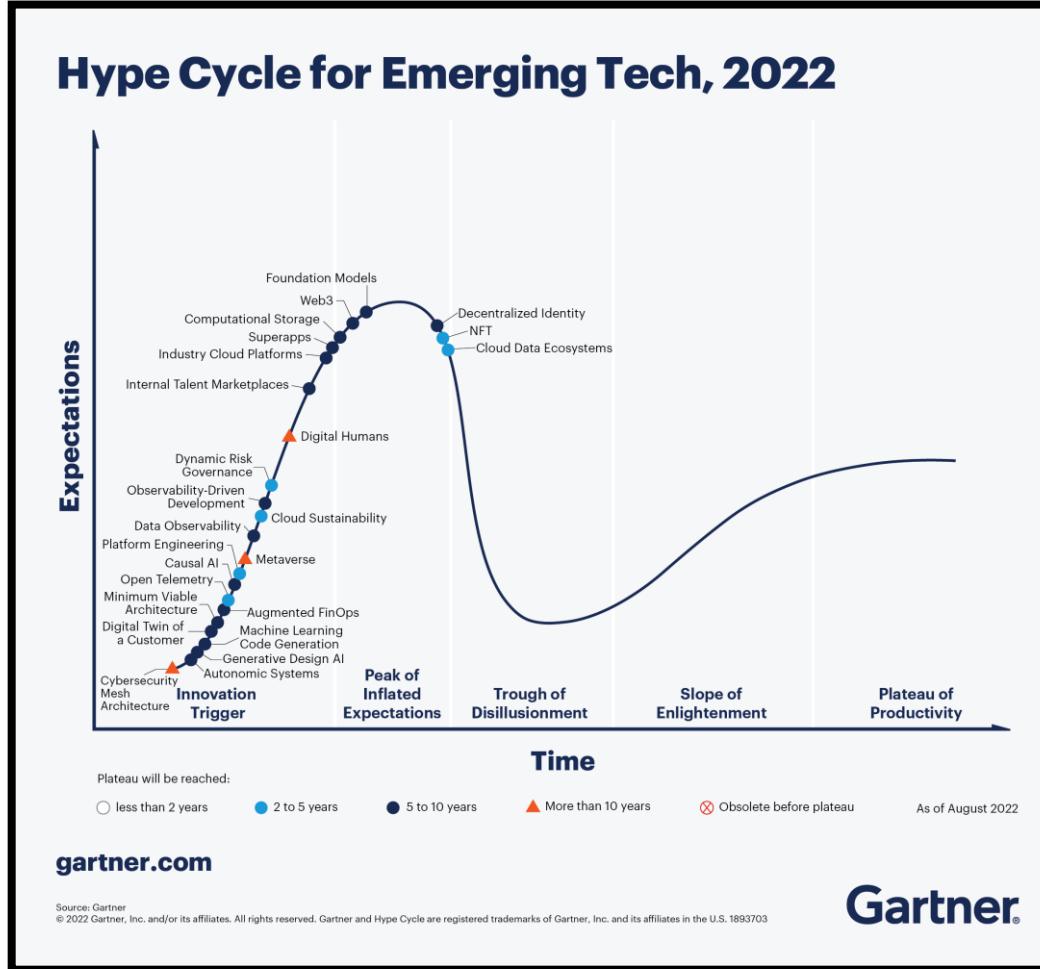
- Each Hype Cycle drills down into five key phases of a technology's life cycle:
  - Innovation Trigger
  - Peak of Inflated Expectations
  - Trough of Disillusionment
  - Slope of Enlightenment
  - Plateau of Productivity



# The Gartner's Hype Cycle (2017)



# The Gartner's Hype Cycle (2022)





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# Questions?



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# Augmented Reality (EN.601.454/654)

Fall 2022

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