CS-420 – LESSON 01 – INTRO TO VIRTUAL REALITY

GIUSEPPE TURINI

Kettering
UNIVERSITY

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STUDY GUIDE

Study Material:

- These slides.
- Your notes.
- * "Virtual Reality", chap. 1-2, pp. 1-64.

Homework:

- Complete the concept design of your course project.
- Create the Unity project for your course project.

Additional Resources:

- None.

INTRODUCTION TO VIRTUAL REALITY

Virtual Reality (VR): The technology (hardware and software) that provides realistic (believable) experiences in a synthetic (virtual) way. This goal is achieved relying on any current multimedia technology.

Note: The term "Virtual Reality" was coined by Jaron Lanier (VPL Research) in 1987.

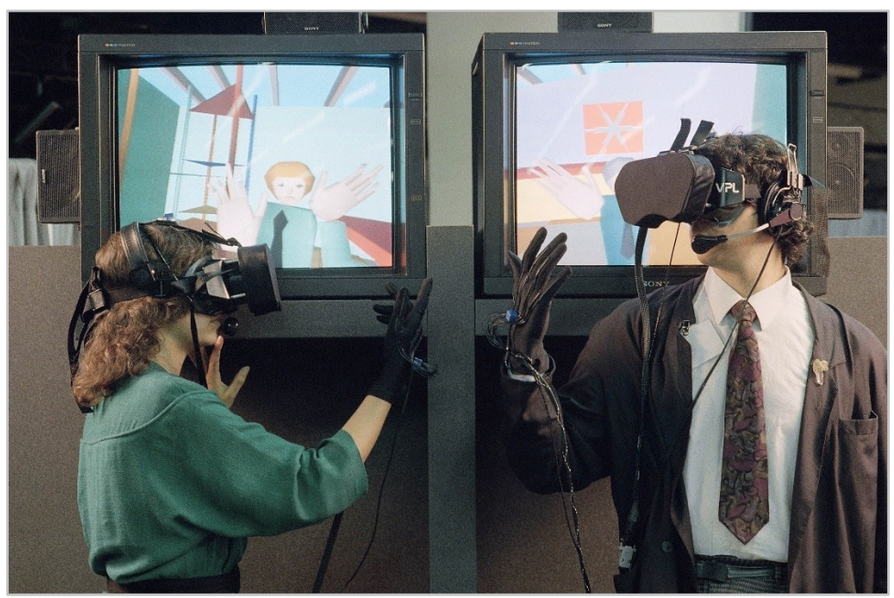

Figure 1. A demo of EyePhones (goggles) and DataGloves (gloves) developed by VPL Research in 1989.

VR VS AR VS MR VS XR

Virtual Reality (VR): Technology that infers a total immersive experience that closes out the physical world. Users can be "transported" into a realistic but not-real environment that will feel believable by most user senses.

Augmented Reality (AR): Technology that augments a live view of the real world adding digital elements. Often the virtual content is configured accordingly to the real content.

Mixed Reality (MR): Technology that combines elements of both AR and VR, focusing on interactions. The goal is to enable some of the real content to interact with some of the virtual content, and/or vice versa.

Extended Reality (XR): An umbrella term for VR/AR/MR and all other technologies that aims to extend the user senses by blending the virtual and real worlds into a unified experience.

VR VS AR VS MR VS XR (2)

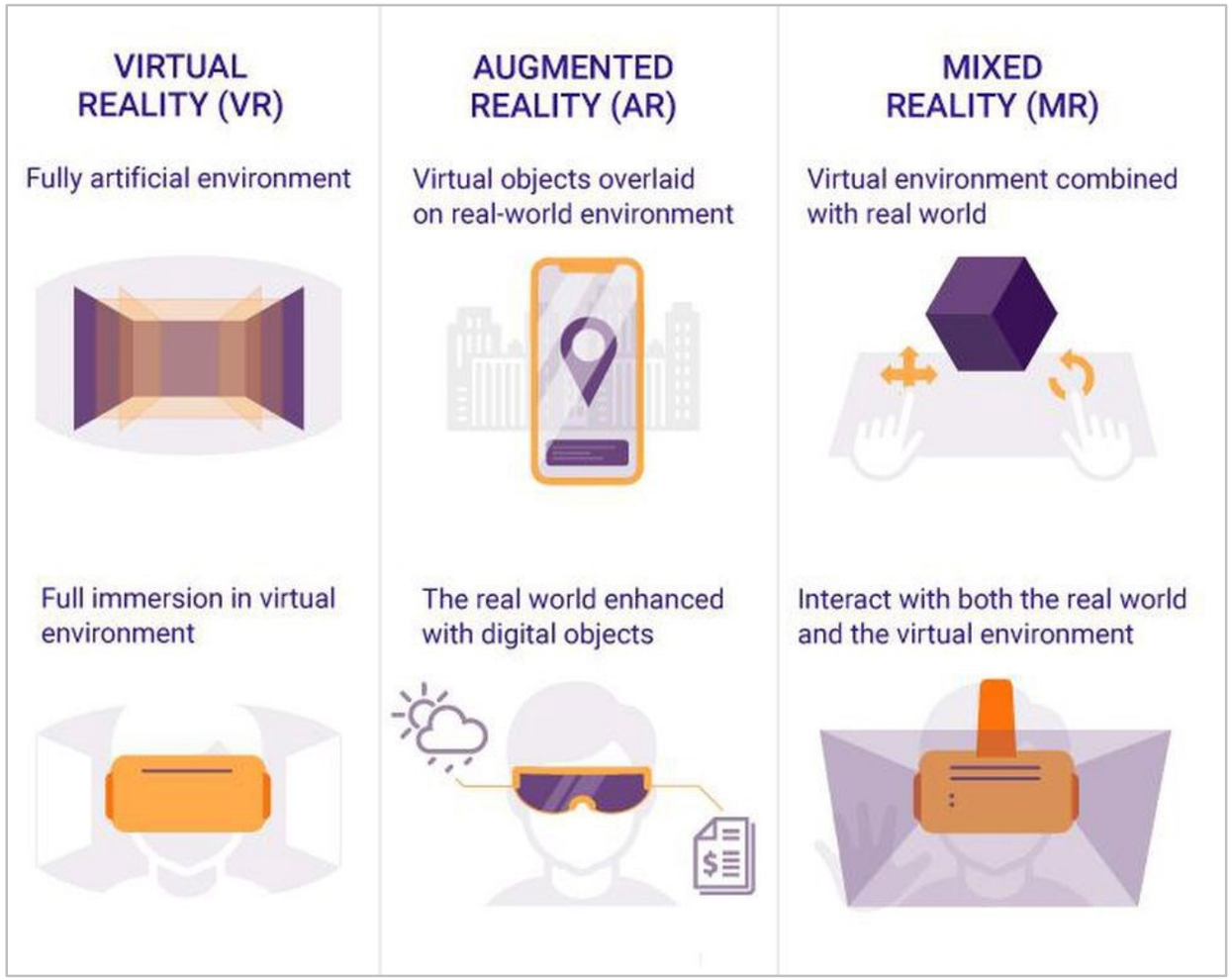

Figure 2. Main differences between VR, AR, and MR.

VR TERMINOLOGY AND IMPORTANT CONCEPTS

Reality-Virtuality Continuum: A continuous scale ranging between the completely virtual (VR) and the completely real (reality). It includes all possible variations and compositions of real and virtual content (reality, AR, augmented virtuality, VR, etc.).

Mediated Reality Continuum: A 2D plane of virtuality (X axis) and mediality/changes (Y axis). The origin (lower left) represents unmodified reality (0% virtuality, 0% mediality). The upper right represents the perfect VR (100% virtuality and 100% mediality).

Immersion: The perception of being physically present in a virtual world. It is created by surrounding the user with visual, audio, or other stimuli that make the virtual experience believable/realistic.

Presence: The subjective sensation of being there in a scene depicted by a medium. It can be achieved exploiting both technology and human factors (ergonomics).

VR TERMINOLOGY AND IMPORTANT CONCEPTS (2)

VR Avatar: The VR representation (usually a 3D model) of a user (or a user character).

Codec Avatars: Invented at Facebook Reality Labs (FRL), Pixel Codec Avatars (PiCA) are AI-models of 3D human faces optimized for reconstruction/computation.

VR Locomotion: The ability to move from place to place in VR. It relies on technology that tracks user movements and converts them into VR avatar movements.

Motion Tracking: (aka positional tracking) is the detection of precise position/orientation of elements of a VR system (HMDs, controllers, etc.) or the user.

Physiological Comfort: Body senses do not feel conflict in sensory stimulation (aural, visual, etc.). Lack of physiological comfort results in fatigue, nausea, etc.

Environmental Comfort: Discomfort depending on the environment. Lack of environmental comfort results in claustrophobia, vertigo, etc.

VR TERMINOLOGY AND IMPORTANT CONCEPTS (3)

Motion Sickness: Discomfort that occurs due to a difference between actual/real and expected/perceived motion. Common symptoms are: nausea, cold sweat, headache, sleepiness, etc.

VR Sickness: Discomfort (fatigue, nausea, etc.) caused by sensory conflicts (visual, aural, etc.) experienced by a VR user, and generated by a VR experience.

Ergonomics: "Human factors and ergonomics" is the application of psychological and physiological principles to the engineering and design of products, processes, and systems. The goals are to reduce human error, increase productivity, enhance safety and comfort, with a specific focus on human-X interactions.

VR TERMINOLOGY AND IMPORTANT CONCEPTS (4)

HMD: A head-mounted display (HMD) is a display device designed to be worn on the head. Usually, it includes a small display optic in front of one eye (monocular HMD) or each eye (binocular HMD). VR HMDs usually integrate IMUs.

IMU: An inertia measurement unit (IMU) is an electronic device that measures/reports inertia data of an object in real-time, including: applied force, angular rate, orientation, etc. The hardware includes multiple sensors: accelerometers, gyroscopes, magnetometers, etc.

OST-HMD: An optical see-through HMD (OST-HMD) is an HMD with a semi-transparend display that allows the user to see the content visualized as well as the reality (because of the transparency of the display).

VST-HMD: A video see-through HMD (VST-HMD) is an HMD integrating cameras aligned with the HMD optics so that the display can visualize in real-time the video streaming from the cameras.

VR TERMINOLOGY AND IMPORTANT CONCEPTS (5)

CAVE: A cave automatic virtual environment (CAVE) is a projector-based room-size system for VR applications. Its projectors are directed to 3-6 walls of a cube/room.

Stereopsis: The depth-perception generated by the reception in the brain of visual stimuli from both eyes (stereo image pairs) in combination (aka binocular vision).

Stereo Rendering: The computer-graphics process to visualize 3D content so that the illusion of depth perception is achieved by the viewer.

FOV: The field of view (FOV) is the extent (described as a solid angle) of the observable world that is seen by the user or a sensor.

IPD: Interpupillary distance (IPD) is the distance in mm between the eye pupil centers.

Anaglyphs: The stereoscopic effect achieved by encoding each image of a stereo pair using different color filters (usually chromatically opposite, e.g. red/cyan).

VR TERMINOLOGY AND IMPORTANT CONCEPTS (6)

Haptics: Any technology that can create an experience of touch by applying forces, vibrations, or motions to the user. Simple haptic device examples are: game controllers integrating vibrations, steering wheels with torque feedback, etc. Haptic feedback includes both force/kinesthetic feedback and tactile feedback.

Force Feedback: Also called kinesthetic feedback, it refers to the feelings provided by sensors in your muscles, joints, etc. Humans use this feedback to estimate properties (sizes, weights, etc.) of objects we touch.

Tactile Feedback: It refers to the feelings provided by the sensors in your skin tissue. Humans use this feedback to estimate vibration, texture, etc.

Gesture Recognition: Algorithms designed to detect/interpret gestures relying on different hardware (markers, cameras, etc.) to track body parts (hands, fingers, etc.).

BRIEF HISTORY OF VIRTUAL REALITY

Most of current VR technology is built upon original ideas that date back to the 1800s.

A brief overview of the history of VR-AR technology can help to:

- Understand future trends and predict failures in the current market.
- Get inspiration to design novel VR-AR systems from past technology.
- Identify advantages and limitations of different elements of a VR-AR system.

BRIEF HISTORY OF VIRTUAL REALITY – 1800-1850

1801: Robert Barker designs and builds the Leicester Square Rotunda in London, displaying 2 360-degree panorama paintings of London.

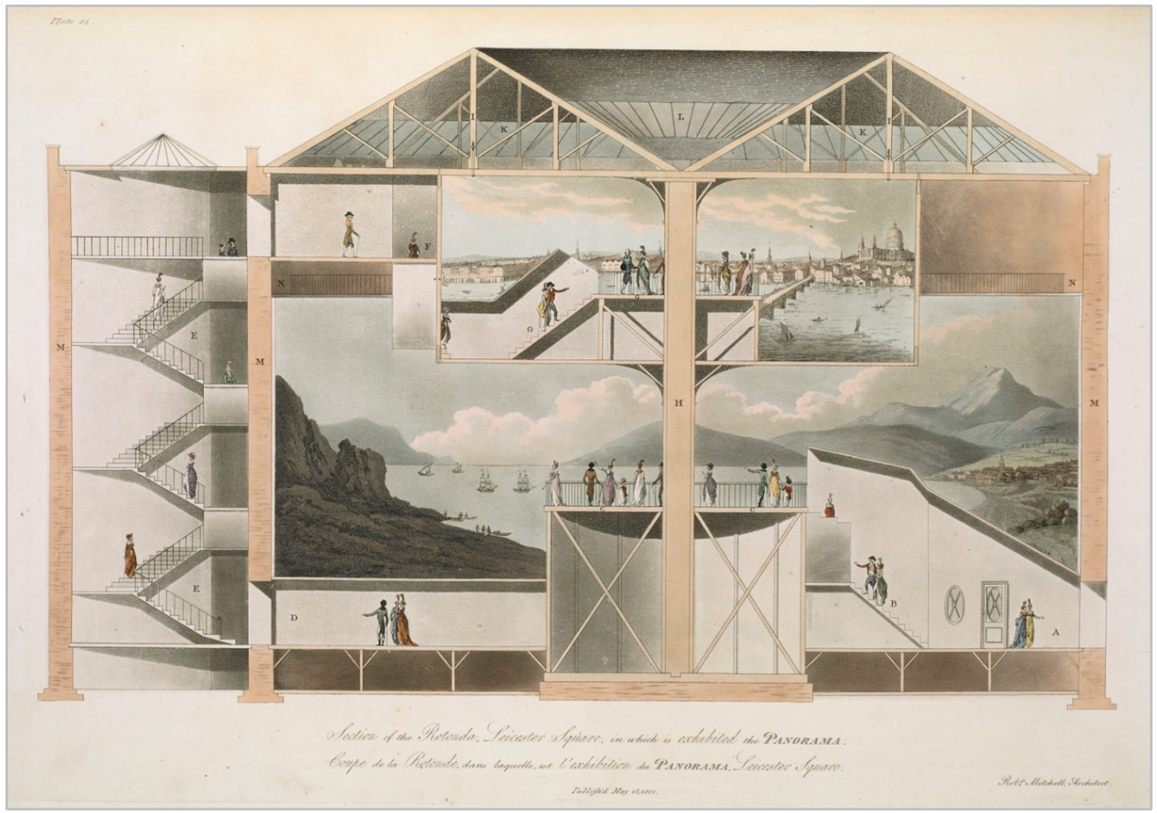

Figure 3. The Leicester Square Rotunda designed by Robert Barker in 1801 to display panorama paintings.

BRIEF HISTORY OF VIRTUAL REALITY – 1800-1850 (2)

1812: First panoramic paintings (360-degree) designed to fill the entire viewer FOV.

Figure 4. Panoramic painting "Battle of Borodino" by Franz Roubaud (1812).

Figure 5. Panoramic painting "Siege of Sevastopol" by Franz Roubaud (1855).

BRIEF HISTORY OF VIRTUAL REALITY – 1800-1850 (3)

1838: Charles Wheatstone demonstrates stereopsis inventing first reflective stereoscope.

1849: David Brewster invents the first lenticular stereoscope.

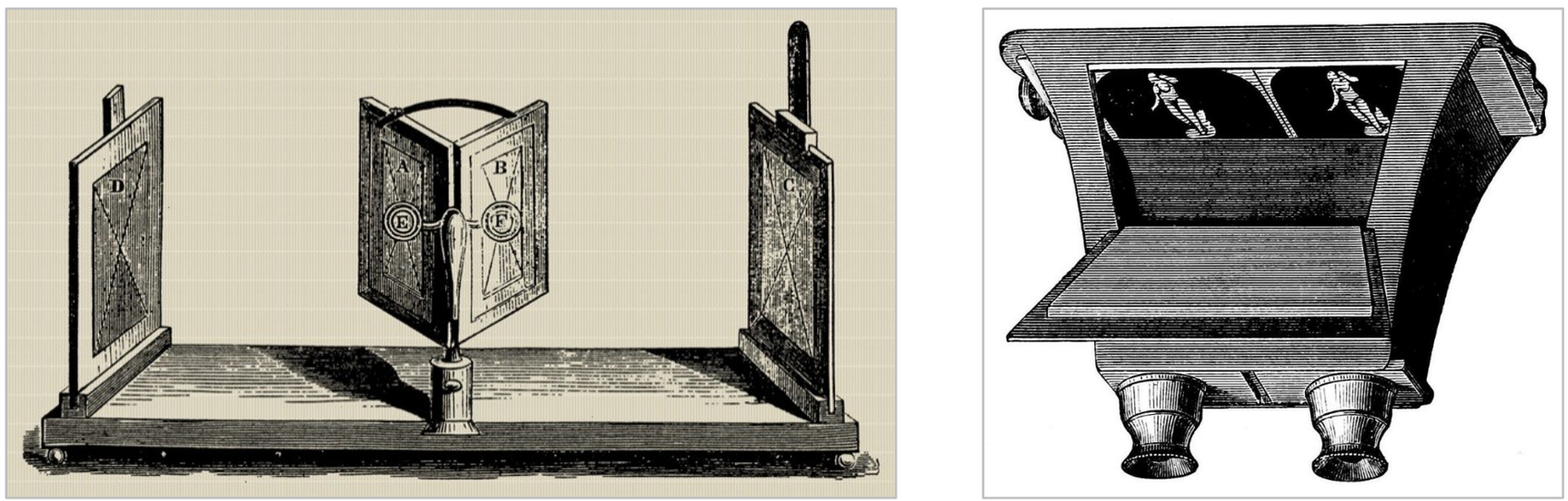

Figure 6. The 1st reflective stereoscope by Charles Wheatstone in 1838 (left), and the 1st lenticular stereoscope by David Brewster in 1849 (right).

BRIEF HISTORY OF VIRTUAL REALITY – 1800-1850 (4)

1853: First description of anaglyphs by W. Rollmann, using Y/B drawing with R/B glasses.

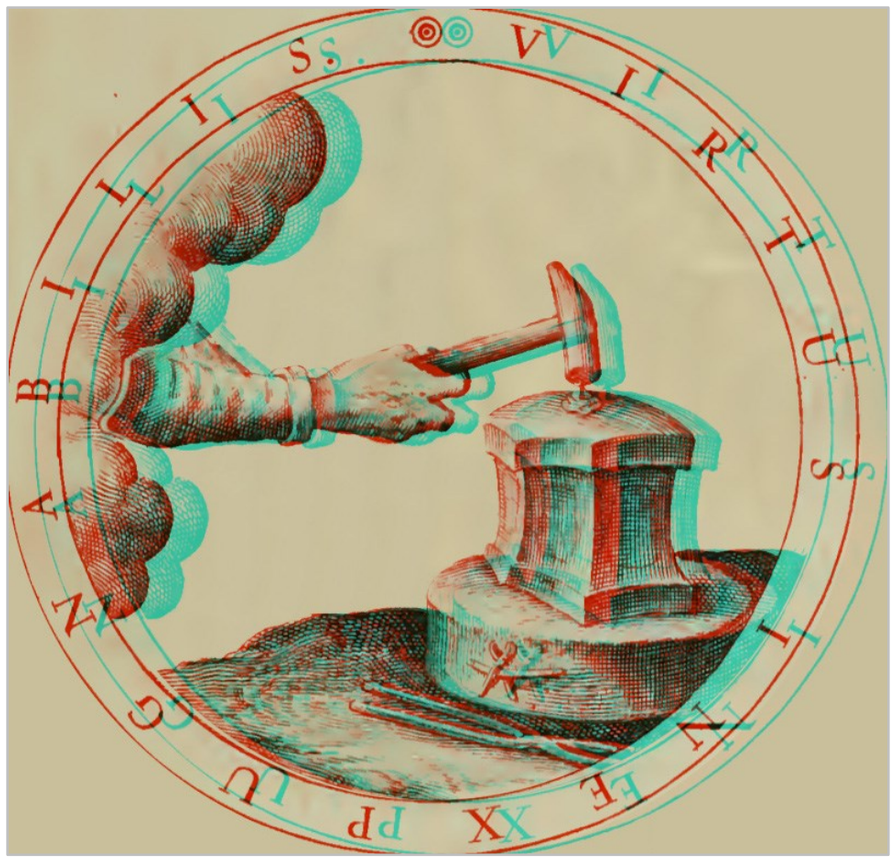

Figure 7. An example of red/cyan anaglyph.

BRIEF HISTORY OF VIRTUAL REALITY – 1900-1950

1922: First commercial 3D movie "The Power of Love" is released using anaglyph glasses.

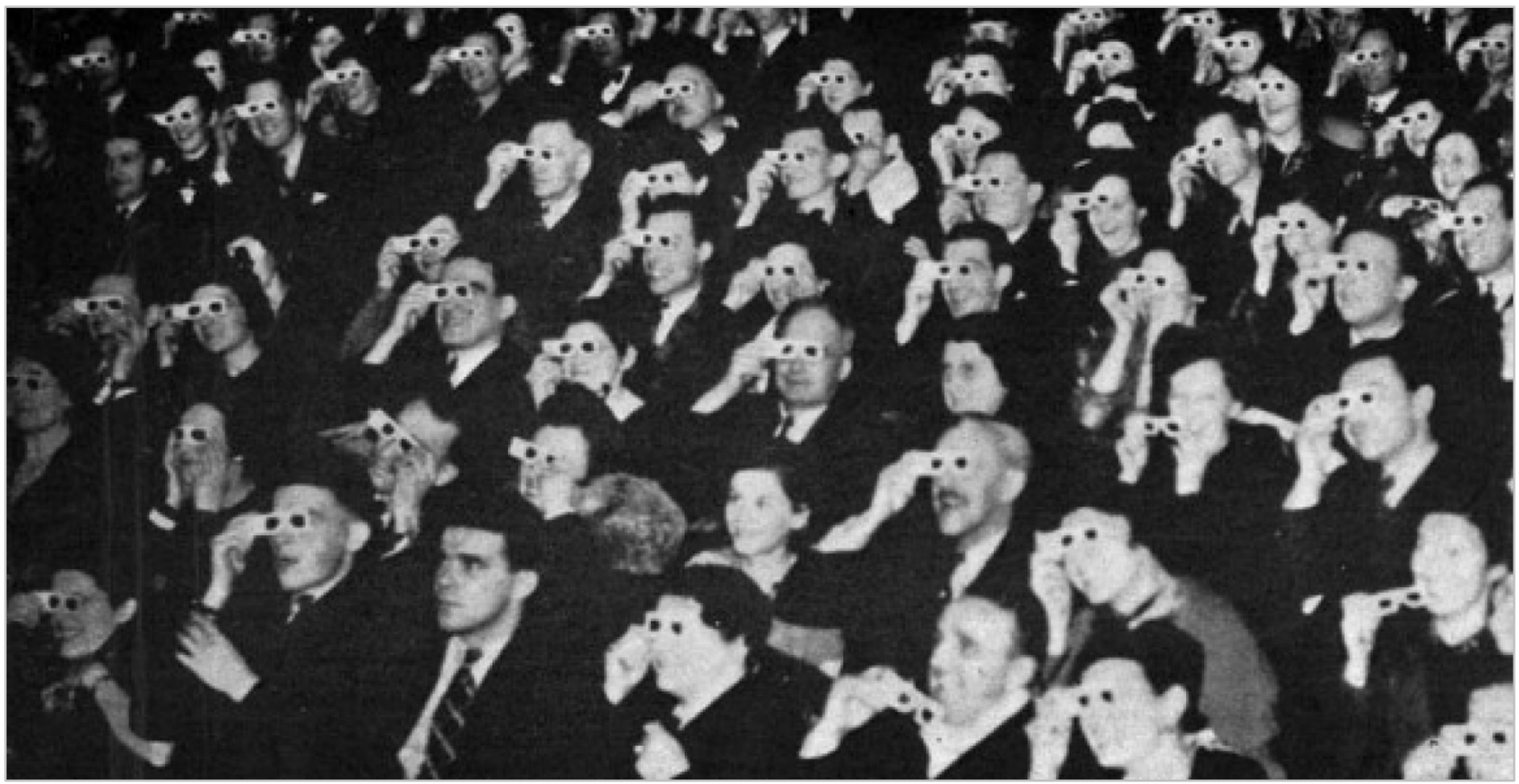

Figure 8. The audience of a 3D movie using anaglyph glasses in early 1900.

BRIEF HISTORY OF VIRTUAL REALITY – 1900-1950 (2)

1929: Edward Link creates the first flight simulator (the "Link Trainer", patented in 1931).

Figure 9. First flight simulator invented by Edward Link in 1929.

BRIEF HISTORY OF VIRTUAL REALITY – 1900-1950 (3)

1935: Stanley G. Weinbaum writes a sci-fi novel ("Pygmalion's Spectacles") inventing the idea of VR goggles (allowing the user to experience a virtual world through holographics, smell, taste and touch).


PYGMALION'S SPECTACLES

By STANLEY G. WEINBAUM

Author of "The Black Flame," "A Martian Odyssey," etc.

Unbelieving, still gripping the arms of that unseen chair, Dan was staring at a forest

Figure 10. VR goggles idea appears in sci-fi novel "Pygmalion's Spectacles" by S.G. Weinbaum in 1935.

BRIEF HISTORY OF VIRTUAL REALITY – 1900-1950 (4)

1939: The View-Master stereoscope is patented by William Gruber (only stereo vision).

Figure 11. Original View-Master stereoscope patented by William Gruber in 1939, and manufactured by Sawyers.

BRIEF HISTORY OF VIRTUAL REALITY – 1950-1970

1956: The Sensorama system was invented by Morton Heilig (a virtual city the user can visit riding a virtual motorbike with stereovision, audio, vibrations, and smells)(see video).

1960: The Telesphere Mask (HMD) was invented by Morton Heilig (designed for non-interactive films with stereo wide-vision and audio, but no motion tracking).

Figure 12. The Sensorama system invented by Morton Heilig in 1956 (left), and the Telesphere Mask system invented by Morton Heilig in 1960 (right).

BRIEF HISTORY OF VIRTUAL REALITY – 1950-1970 (2)

1961: The Headsight system (HMD) invented by Philco Corporation (was non-portable and included magnetic motion tracking, but computer graphics were not integrated).

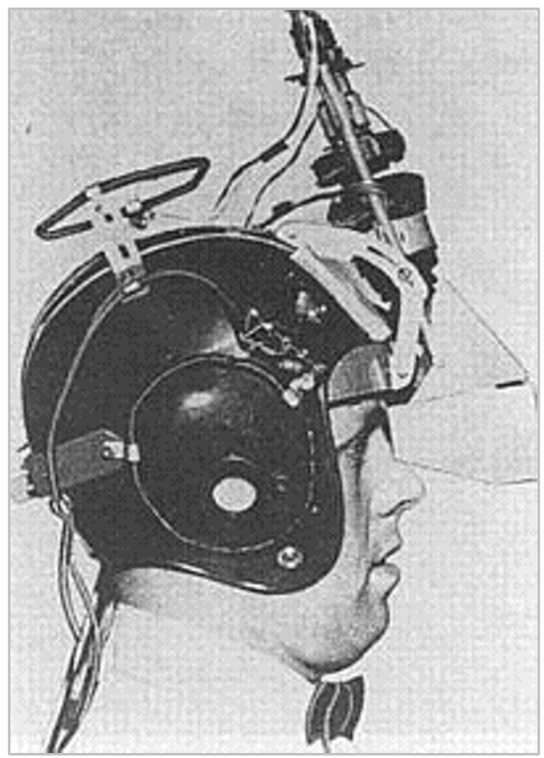

Figure 13. Headsight HMD invented by Philco Corporation in 1961, and integrating magnetic motion tracking.

BRIEF HISTORY OF VIRTUAL REALITY – 1950-1970 (3)

1965: The "Ultimate Display" (HMD) was invented by Ivan Sutherland (non-portable and connected only to cameras, with no computer graphics)(see paper).

1968: The "Sword of Damocles" (VR-AR HMD) was invented by Ivan Sutherland and Bob Sproull (non-portable but integrating computer graphics (see video).

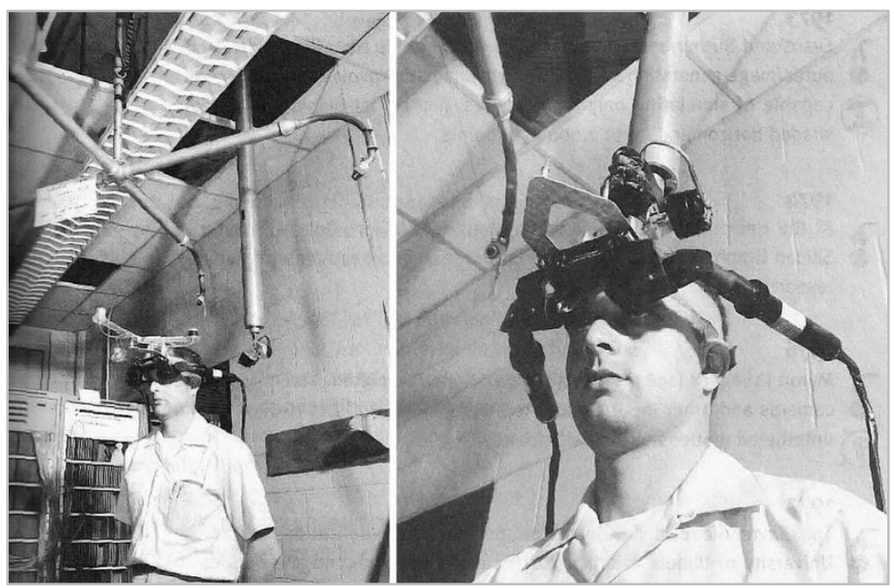

Figure 14. The "Ultimate Display" (first HMD) invented by Ivan Sutherland in 1965.

BRIEF HISTORY OF VIRTUAL REALITY – 1970-1990

1969: Virtual artistic experiences ("Artificial Reality") designed by Myron W. Krueger, including computer-generated environments interacting to internal users.

1975: The first interactive VR (AR) system (the "VIDEOPLACE") is designed by Myron W. Krueger, using a mix of CG, projectors, cameras, and screens (included tracking of user position, but did not include any headset).

Figure 15. An "Artifical Reality" experience designed by Myron Krueger in 1969.

BRIEF HISTORY OF VIRTUAL REALITY – 1970-1990 (2)

1971: The "Visually Coupled Airborne Systems Simulator" (VCASS) co-developed by Tom Furness (engineered for the military and considered the first modern flight simulator).

Figure 16. The VCASS flight simulator codeveloped by Tom Furness in 1971.

BRIEF HISTORY OF VIRTUAL REALITY – 1970-1990 (3)

1972: A fully digital (CG-based) flight simulator is designed by General Electric (GE), including 3-screens in a 180-degree setup arranged in a training cockpit.

Figure 17. The digital flight simulator designed by GE in 1972.

BRIEF HISTORY OF VIRTUAL REALITY – 1970-1990 (4)

1977: A VR interactive map (the "Aspen Movie Map") is designed at MIT, allowing users to visit Aspen (CO) in VR (using video filmed from a car, with no HMD) (see video).

Figure 18. The VR interactive map "Aspen Movie Map" designed by MIT in 1977.

BRIEF HISTORY OF VIRTUAL REALITY – 1970-1990 (5)

1979: The first non-research VR HMD (the VITAL helmet) is designed by McDonnell-Douglas, including a head tracker and basic computer-generated virtual content.

Figure 19. The VITAL helmet (VR HMD) designed by McDonnell-Douglas in 1979.

BRIEF HISTORY OF VIRTUAL REALITY – 1970-1990 (6)

1980: Steve Mann creates the Eye Tap HMD, a backpack-PC connected to a helmet-camera including a beam splitter allowing the overlay of real-time data (for AR).

Figure 20. The prototype of the "Eye Tap" HMD designed by Steve Mann in 1980.

BRIEF HISTORY OF VIRTUAL REALITY – 1970-1990 (7)

1982: The first VR gloves ("Sayre Gloves") invented by Daniel Sandin and Thomas DeFanti, connected to a PC and using optical sensors to detect finger movement.

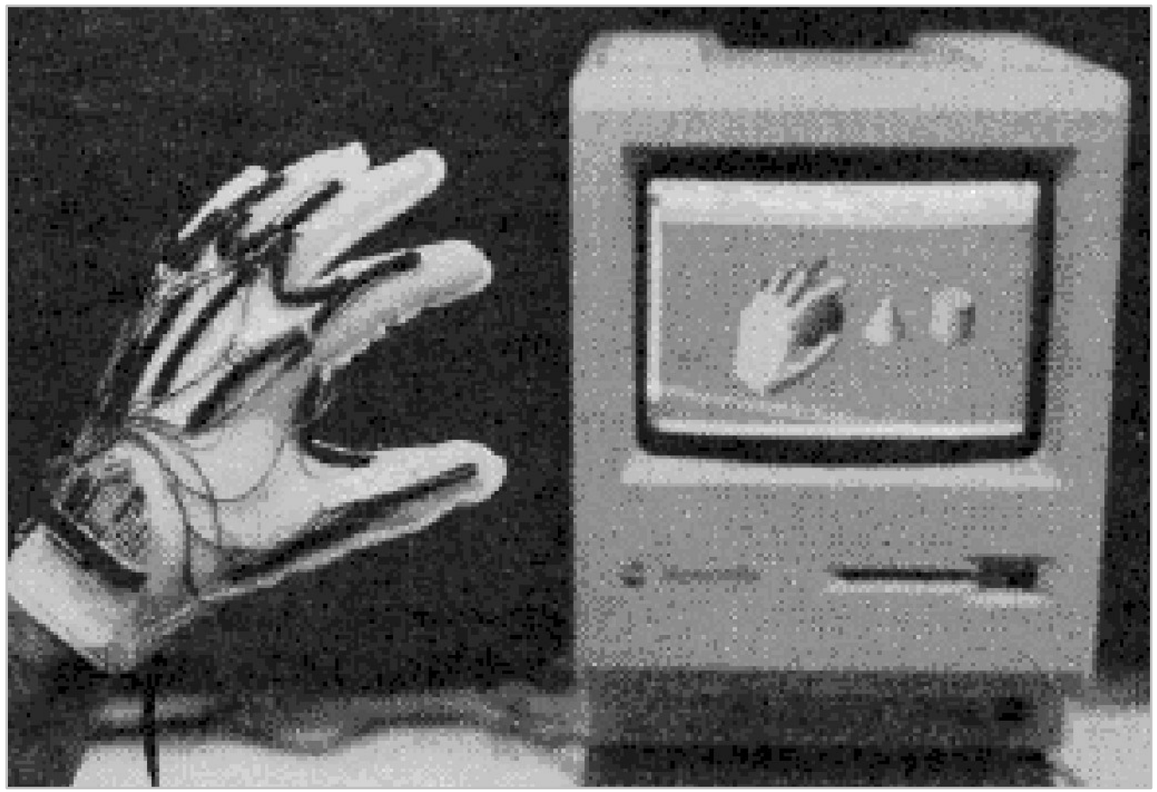

Figure 21. The "Sayre Gloves" to track fingers for VR invented by Daniel Sandin and Thomas DeFanti in 1982.

BRIEF HISTORY OF VIRTUAL REALITY – 1970-1990 (8)

1982: The movie “Tron” introduces characters involved in a videogame/VR adventure.

Figure 22. Poster of the movie “Tron” released in 1982.

BRIEF HISTORY OF VIRTUAL REALITY – 1970-1990 (9)

1985: The VIEW (modern HMD) was invented at NASA (including haptic gloves).

Figure 23. The VIEW system (research HMD with haptic gloves) invented by Scott Fisher at NASA in 1985.

BRIEF HISTORY OF VIRTUAL REALITY – 1970-1990 (10)

1986: The 3D movie "Transitions" is released using full-color 3D IMAX technology, including polarized glasses to refract anaglyph images to the proper eye.

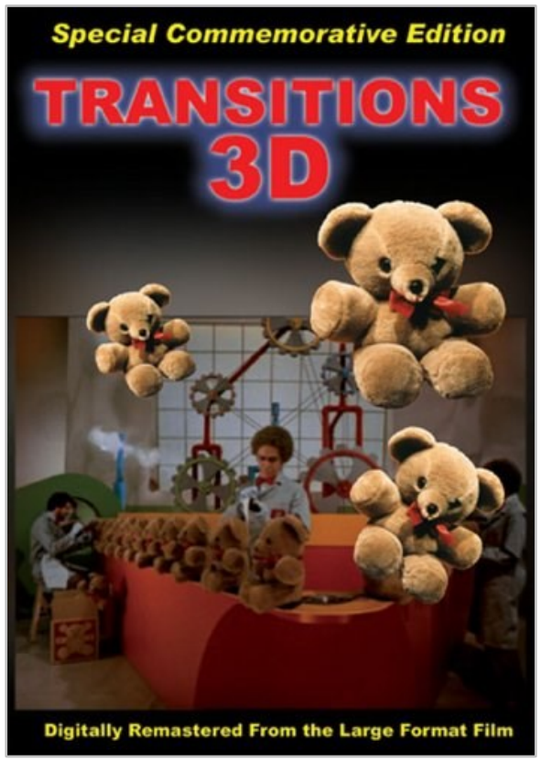

Figure 24. The poster of the movie "Transitions" using 3D IMAX technology and released in 1986.

BRIEF HISTORY OF VIRTUAL REALITY – 1970-1990 (11)

1986: The "Super Cockpit" is invented by Tom Furness (a flight simulator designed for VR training including CG, real-time interactivity, motion tracking, and aircraft control).

Figure 25. The "Super Cockpit" flight simulator invented by Tom Furness in 1986.

BRIEF HISTORY OF VIRTUAL REALITY – 1970-1990 (12)

1985: VPL Research is founded by Jaron Lanier and Thomas Zimmerman. It is the first VR company manufacturing consumer-grade HMDs and VR gloves (data gloves).

1987: First use of the term "virtual reality" and "data gloves" (Jaron Lanier, VPL Research).

Figure 26. A demo of EyePhones (goggles) and DataGloves (gloves) developed by VPL Research in 1989.

BRIEF HISTORY OF VIRTUAL REALITY – 1970-1990 (13)

1989: The same technology of the NASA VIEW system (i.e., its gloves) is used to design the Nintendo Power Glove.

Figure 27. The Nintendo NES Power Glove designed in 1989, using the same technology of the NASA VIEW system.

BRIEF HISTORY OF VIRTUAL REALITY – 1990-2000

1991: The Virtuality Group launches multiple VR arcade games/machines with VR goggles, real-time immersive stereoscopic 3D graphics, and networked multiplayer.

Figure 28. An example of the VR arcade machines launched by the Virtuality Group in 1991.

BRIEF HISTORY OF VIRTUAL REALITY – 1990-2000 (2)

1991: A NASA engineer (Antonio Medina) develops a VR system to pilot a Mars rover in teleoperation (i.e., a computer-simulated teleoperation).

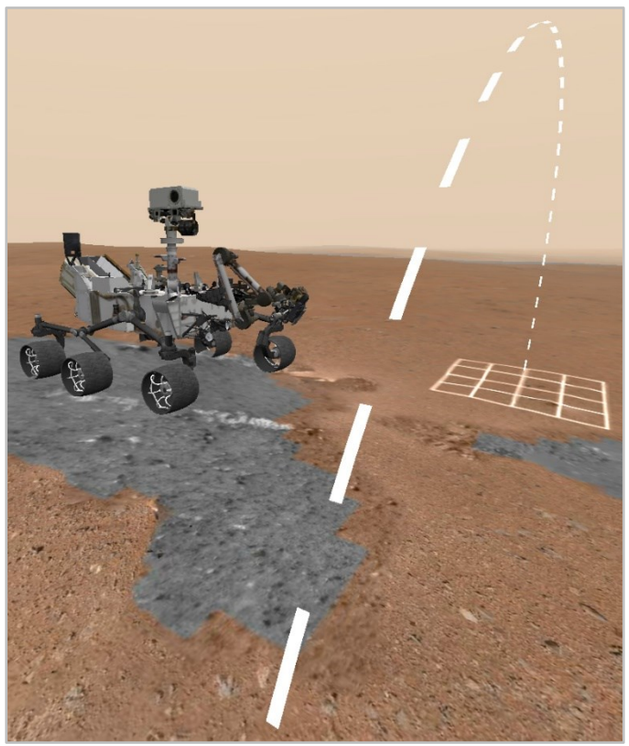

Figure 29. A modern VR Mars rover inspired by the system designed by Antonio Medina at NASA in 1991.

BRIEF HISTORY OF VIRTUAL REALITY – 1990-2000 (3)

1992: The movie "The Lawnmower Man" introduces the concept of VR to a wider audience.

Figure 30. Poster of the movie "The Lawnmower Man" released in 1992.

BRIEF HISTORY OF VIRTUAL REALITY – 1990-2000 (4)

1993: Sega announces the new Sega VR headset for the Sega Genesis console, including head tracking, stereo sound, and LCD screens.

1994: Sega releases the VR-1 arcade motion simulator, including HMDs.

Figure 31. The Sega VR headset for the Sega Genesis console (left), and the Sega VR-1 arcade motion simulator (right).

BRIEF HISTORY OF VIRTUAL REALITY – 1990-2000 (5)

1995: Nintendo releases the Virtual Boy (aka VR-32) the first 3D gaming portable console.

Figure 32. The Nintendo Virtual Boy released in 1995.

BRIEF HISTORY OF VIRTUAL REALITY – 1990-2000 (6)

1995: CAVE Automatic Virtual Environment is invented at the University of Illinois, including stereoscopic LCD shutter glasses and wall projections allowing multi-user VR.

Figure 33. The CAVE system invented at the University of Illinois in 1995.

BRIEF HISTORY OF VIRTUAL REALITY – 1990-2000 (7)

1997: Georgia Tech and Emory University use a VR system (Virtual Vietnam) to research/treat PTSD in war veterans.

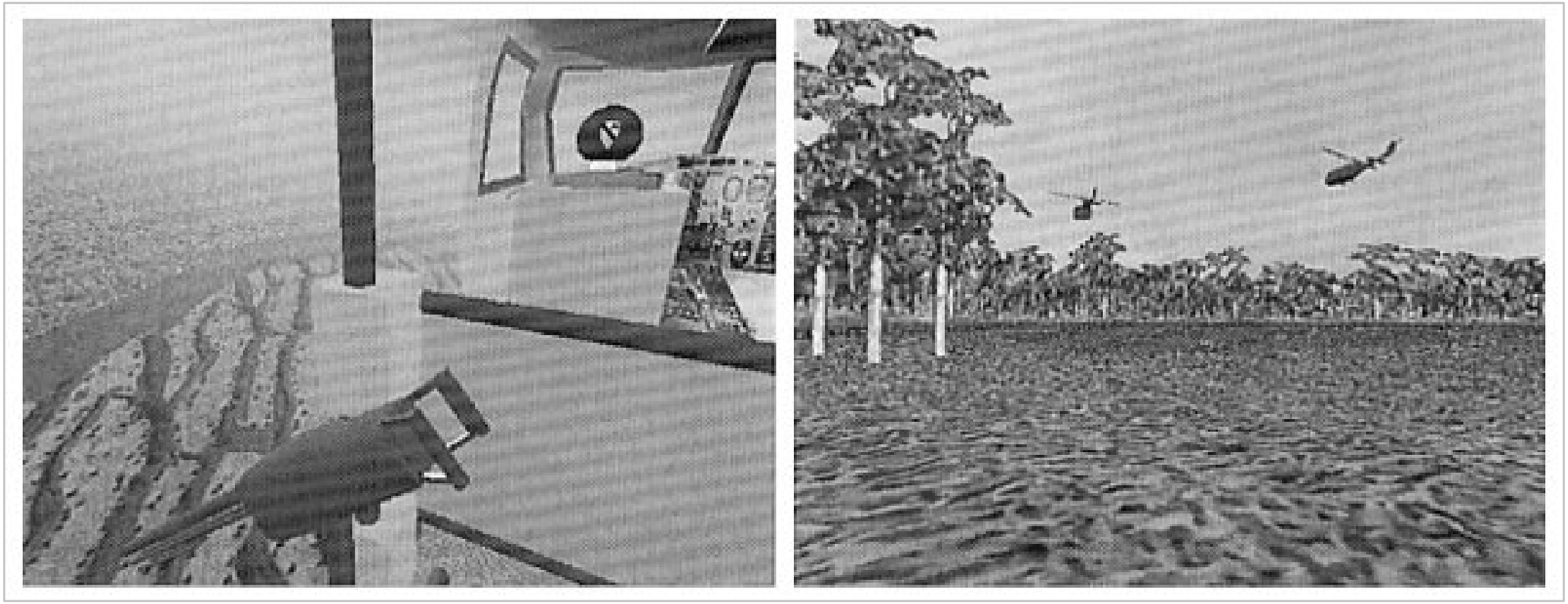

Figure 34. The "Virtual Vietnam" VR system invented at Georgia Tech and Emory University to study PTSD in 1997.

BRIEF HISTORY OF VIRTUAL REALITY – 1990-2000 (8)

1999: The movie "The Matrix" is released featuring characters living in a fully simulated world.

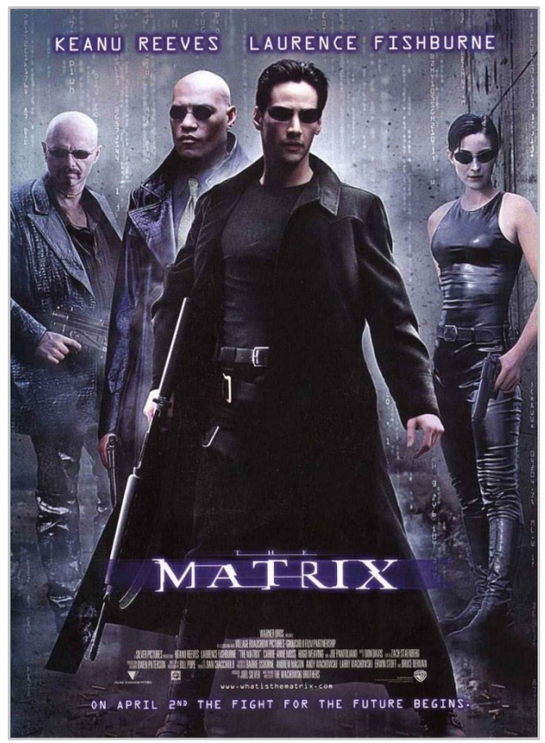

Figure 35. Poster of the movie "The Matrix" released in 1999.

BRIEF HISTORY OF VIRTUAL REALITY – 2000-2010

2001: SAS Cube is commercialized by Z-A Production, a PC-based cubic room (CAVE).

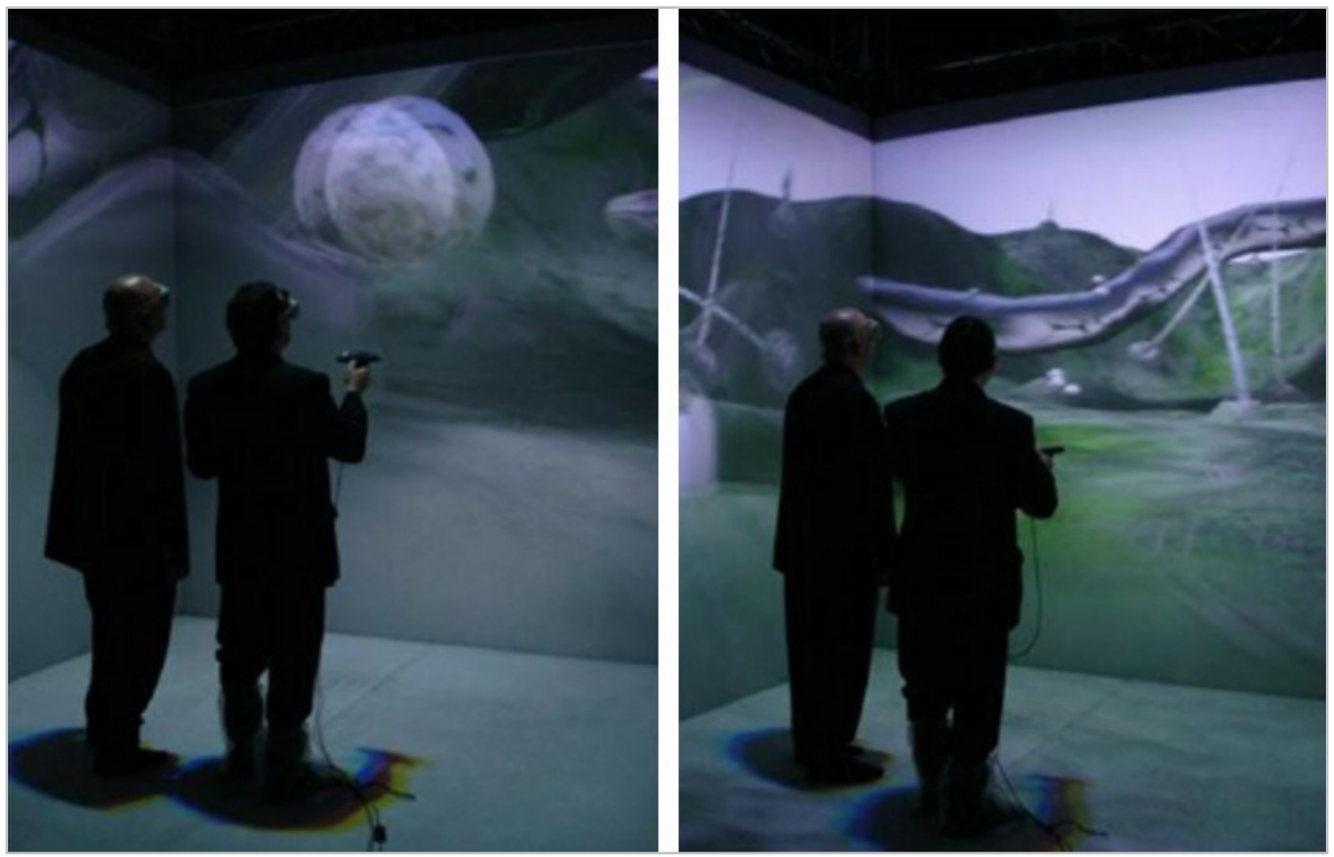

Figure 36. A SAS Cube system designed by Z-A Production in 2001.

BRIEF HISTORY OF VIRTUAL REALITY – 2000-2010 (2)

2007: Google releases Street View for its Maps service, including street-level 360-degree images captured by custom dodecahedral cameras mounted on cars roofs.

Figure 37. Development details of the Google Street View service integrated in Google Maps in 2007: a Google car used to acquire images (left), the dodecahedral camera used (center), and the stitching pattern used to assemble multiple camera photos into a 360-degree view.

BRIEF HISTORY OF VIRTUAL REALITY – 2000-2010 (3)

2009: The 3D movie "Avatar" is released, filmed with custom-built stereo cameras and 3D software represents the most expensive movie ever made because of this new tech.

Figure 38. Poster of the movie "Avatar" released in 2009.

BRIEF HISTORY OF VIRTUAL REALITY – 2000-2010 (4)

2010: Palmer Lucky invents the first prototype of the Oculus Rift HMD (later commercialized collaborating with John Carmack.

Figure 39. The very first prototype of the Oculus Rift HMD invented by Palmer Lucky in 2010.

BRIEF HISTORY OF VIRTUAL REALITY – 2010-2020

2012: Palmer Lucky launches a Kickstarter to fund the product development of his Oculus Rift HMD prototype (the campaign raises ~2.5 million $.

2014: Facebook buys Oculus, Sony releases the PlayStation VR, Google launches the Google Cardboard, and Samsung markets the Samsung Gear VR.

2016: Every tech company releases its own VR products (Oculus Rift and HTC Vive leading).

2018: The Oculus Half-Dome HMD is announced, including varifocal lenses, a wide FOV (140 degrees), face-tracking, eye-tracking, hand-tracking, etc. (see video).

2019: "Beat Saber" (VR) is the first SW app to sell over 1 million copies in less than 1 year.

2020: Standalone VR (non-wired) is leading the market with the Oculus Go and the Oculus Quest, while mobile VR is declining rapidly.

BRIEF HISTORY OF VIRTUAL REALITY – 2010-2020 (2)

2020: The current VR-AR market includes multiple different headsets designed for various targets (consumer, research etc.) and marketed with different prices.

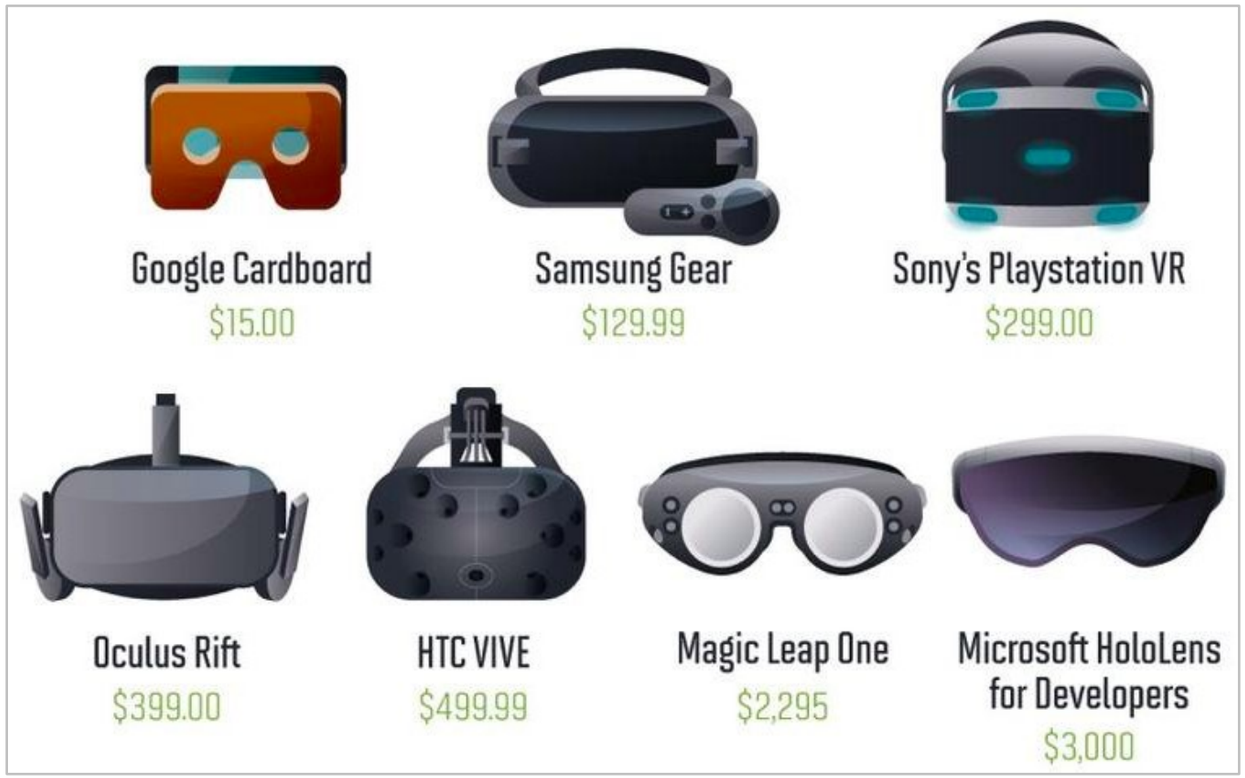

Figure 40. A summary of the VR-AR headset market in 2020.

VIRTUAL REALITY ECOSYSTEM

This is a short list of the main components of a VR system:

- **VR Game Engines:** software development frameworks.
- **Display Devices:** HMDs, CAVEs, etc.
- **VR Controllers:** wands, data gloves, haptic interfaces, etc.
- **VR Tracking Systems:** integrated in VR devices, and external tracking systems.

VR GAME ENGINES

A VR game engine provides software developers with a framework for creating a VR app. Current VR game engines are game engines supporting VR devices (with some VR game engines supporting also AR-MR app development).
Usually, a VR game engine should provide:

- Functionality to **design/develop/test VR apps**.
- Functionality to **design/create/edit 3D content** for immersive VR experiences.
- Functionality to **integrate VR hardware** (HMDs, controllers, etc.).

At the moment (2021), the main VR game engines on the market are:

- **Unity:** coding in C#.
- **Unreal Engine:** coding in C++.

HMD TECHNICAL SPECS

This is a summary of the main specs of current HMDs on the market:

- **Cost:** from ~20 $ (e.g., Google Cardboard) to ~500 $ (e.g., Oculus Quest 2).
- **Display Type:** from mobile phone to OLED.
- **Display Resolution:** from mobile phone (split-screen) to 1920×1080 each eye.
- **FOV:** from ~60 degrees to ~120 degrees.
- **Audio:** from mobile audio to 360 degrees noise-cancelling headphones.
- **Refresh Rate:** from 60Hz to 120 Hz.
- **Latency:** from ~20 ms (smartphones) to ~ 0.01 ms (high-end HMD).
- **Optics:** from fixed lenses to adjustable IPD and focus.

CAVE TECHNICAL SPECS

This is a summary of the main specs of current CAVE systems on the market:

- **Cost:** starting at 50000 $.
- **Dimensions:** starting at 3×3×3 m.
- **Displays:** 4-5 projection screens, used with stereoscopic glasses (shutter glasses).
- **Users:** up to 5 users simultaneously.
- **Interactions:** using VR controllers (wands, data gloves, joysticks, etc.).

VR CONTROLLERS

Standard input devices (mouse, keyboard etc.) are not user-friendly during a VR session.
So, VR controllers are the standard input devices used to interact with the virtual world.

This is a short list of the most common VR controllers:

- **Wand:** a hand-held joystick (see Nintendo Wii), often including a tracker.
- **VR Gloves (Data Gloves):** special gloves able to track hand-finger movements, often including basic tactile feedback (vibrations).
- **Hand-Finger Trackers:** trackers designed to track hand-finger movements (see Leap Motion), often integrated on HMDs to implement touch-less gestural interactions.
- **VR Controllers:** a pair of hand-held joysticks (see Oculus Controllers), always integrating both 6-DOF tracking and basic tactile feedback.
- **Haptic Stylus:** a stylus-like joystick attached to a simple robotic arm (see Sensable Phantom Omni), always integrating both 6-DOF tracking and haptic feedback.

VR TRACKING SYSTEMS

The goal of a VR tracking system is to measure the pose of an object in 3D: the 3-DOF pose (only position) or the 6-DOF pose (position and rotation).

In most VR systems the main tracking targets are the HMD and the controllers.
Depending on the target, different tracking performance requirements may be needed.
For example: the head tracker must run at > 20 Hz with a latency < 50 ms.

VIRTUAL REALITY APPLICATIONS

There are numerous application fields in which VR can provide enormous benefits:

- Healthcare (medicine, rehabilitation, psychology, surgery, etc.).
- Military (army, air force, navy, etc.) and other armed forces (police, fire fighters, etc.).
- Architecture and industrial/civil engineering (e.g., virtual design, virtual testing, etc.).
- Art and entertainment.
- Education and training (e.g., geography, history, etc.).
- Business.
- News and media.
- Sports (e.g., analyzing tactics on the virtual field during a virtual match).

This list is just a summary, and the actual list of application fields is endless.

VR IN SURGERY

Surgery is a popular VR application fields with the development of virtual surgery simulation:

- To train novice surgeons on new surgical techniques performing operations on virtual patients.
- To let surgical staff familiarize with novel surgical tools (e.g., surgical robots, etc.).
- To improve surgical education facilitating the learning of human anatomy.
- To assess the performance of resident surgeons as they age.
- To perform preoperative planning using a fully virtual surgical environment (e.g., surgical room, tools, and patient).

VR IN AVIATION

Aviation is another popular VR application field, using VR to design a virtual aircraft allowing the testing of the prototype during the design process (involving multiple prototype versions).

VR IN ARCHITECTURE

Architecture and industrial/civil engineering often use VR to design and test new buildings:

- Enabling the navigation in a virtual building to evaluate the architectural design.
- Inspect safety hazards in a virtual building before starting the actual construction.
- Simulate lighting, materials, volumes, before construction begins.