VIRTUAL REALITY: THEORY AND PRACTICE

LESSON 1: INTRO AND VR SYSTEM DESIGN

GIUSEPPE TURINI - FRI 2 FEB 2024 - UNIVERSITY OF PISA

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PART 0: COURSE INTRODUCTION

This section includes:

- My **acknowledgements** to the institutions and colleagues that supported this course.
- A brief **bio** to summarize by background, including my professional **contacts**.
- Some **warnings** on the course content and information on the intended audience.
- An overview of the **syllabus**, including attendance policy and student assessment.

See: github.com/turinig/vrphd

ACKNOWLEDGEMENTS

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- The Dept. of Information Engineering (DII) of the University of Pisa, for the support and organization and dissemination of the course.
- Prof. Vincenzo Ferrari for the initial invitation.
- The EndoCAS Research Center of the University of Pisa, for the collaboration and support in my research activities in this field.
- Kettering University for the support of my regular academic activity.

BIO AND CONTACTS

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Ph.D. in Health Technologies (Comp. Eng.) @ University of Pisa

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Teaching: Comp. and Algs. 1/2/3, Prog. Paradigms, CG, VR, Game Development

Research: Computer-Assisted Surgery, VR-AR, HCI-HMI

CONTENT WARNINGS

Intended Audience: This Ph.D. course has been designed considering Ph.D. students with an engineering/computing/technological background, and a basic knowledge of computer programming object-oriented.

Content Warning: All course material on *"VR app development"* is based on: Unity (2022.3.17), Visual Studio 2022, and Windows (11 Pro).

This course will **not** include the deployment of a VR app on an actual VR HMD because of both lack of hardware and time constraints.
However, VR testing/evaluation will be discussed using the *"XR Device Simulator"* included in the *"XR Interaction Toolkit"* for Unity.

Note: All course material is available on: github.com/turinig/vrphd

Note: Some of the course material has been enhanced by using AI (Microsoft Copilot LLM).

SYLLABUS OVERVIEW

The course syllabus includes the following information:

- Instructor and course information.
- Teaching method (lesson structure).
- Course schedule (tentative).
- References and software tools used.
- Student assessment (attendance policy and final exam information).

PART 1A: INTRO TO VR

Virtual Reality (VR): Technology (HW/SW) capable of providing realistic experiences artificially, by exploiting any existing multimedial technology.

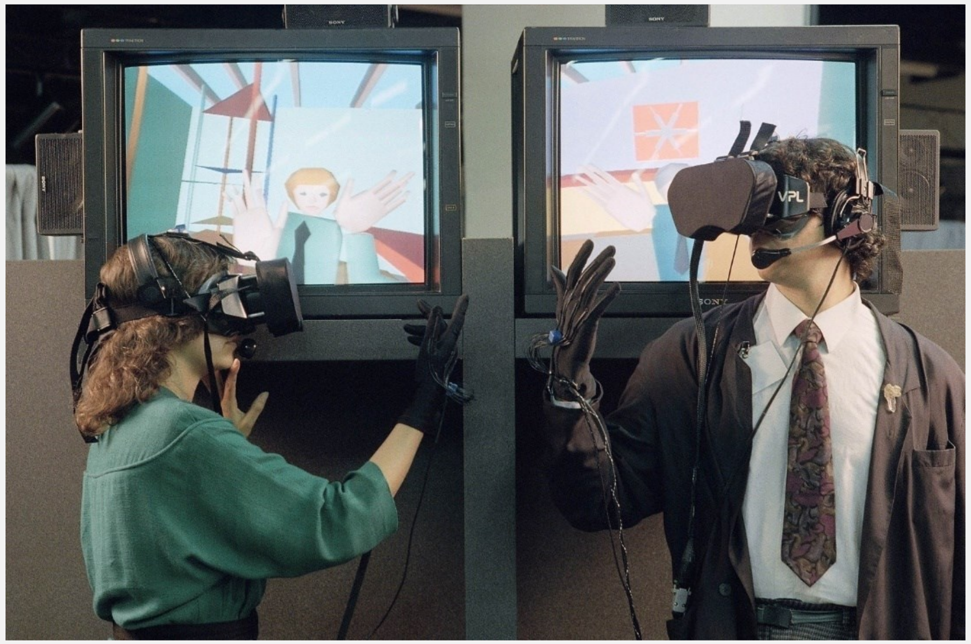
VR technology can provide a total immersive experience excluding the physical world, and "transporting" the user in a realistic but not-real environment that is perceived as credible by the user's main senses.

The term *"virtual reality"* was invented by Jaron Lanier (VPL Research) in 1987.

Jaron Lanier is a founder of the field of VR.

In 1985 he founded VPL Research, and in 1989 he commercialized 2 products: the VR goggles *"EyePhones"*, and the VR gloves *"DataGloves"* della VPL Research.

See: [www.hollywoodreporter.com]



BASICS: AR, MR, AND XR

Augmented Reality (AR): Tecnologia capace di aumentare una visualizzazione dal vivo del mondo reale aggiungendo (aumentandola con) elementi digitali.

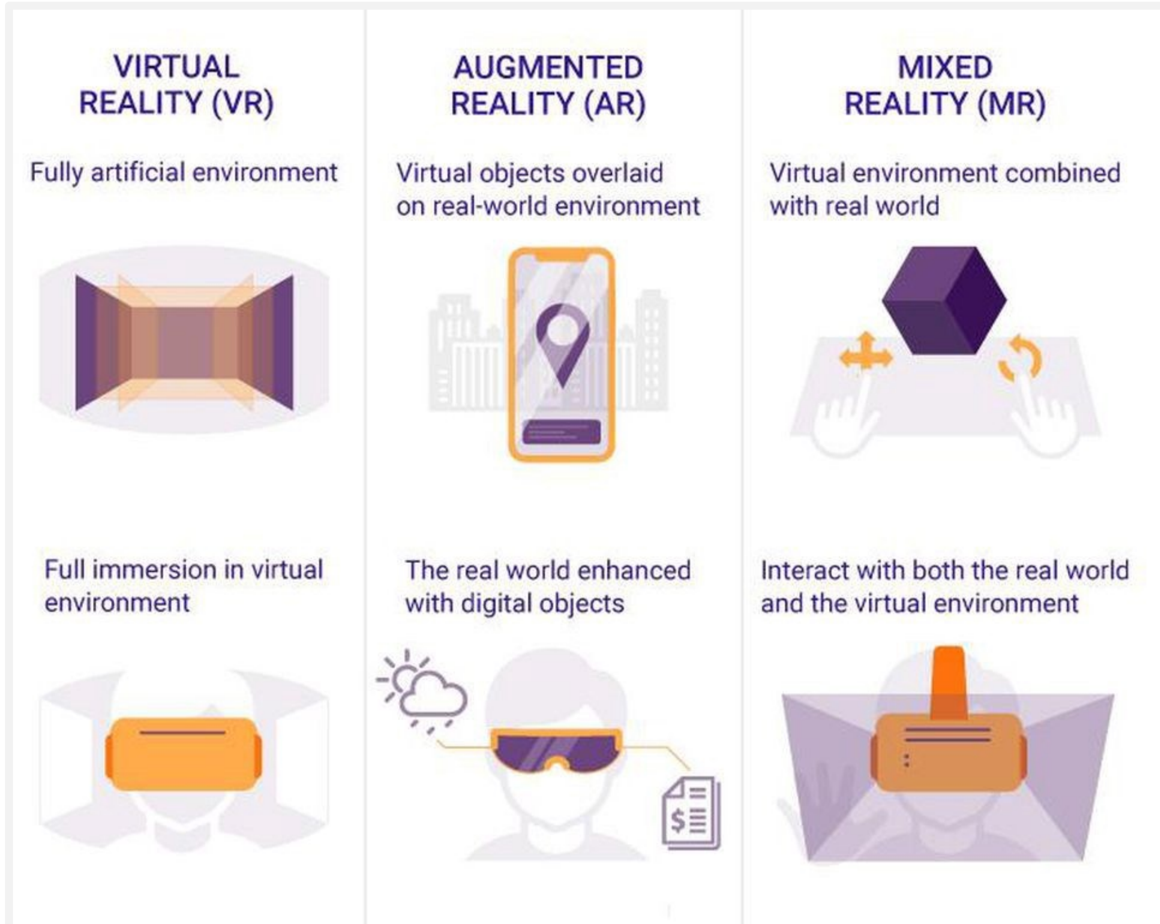
Spesso gli elementi digitali aggiunti sono configurati considerando l'ambiente reale.

Mixed Reality (MR): Tecnologia che combina elementi sia della VR che della AR, ma focalizzata sulle interazioni reale-virtuale.

L'obiettivo e' abilitare parte del contenuto reale ad interagire con parte del contenuto digitale, e/o viceversa.

Extended Reality (XR): Termine ombrello per VR/AR/MR e tutte le altre tecnologie che hanno come obiettivo l'estensione dei sensi dell'utente mischiando il virtuale con il reale in una esperienza unificata.

BASICS: VR VS AR VS MR



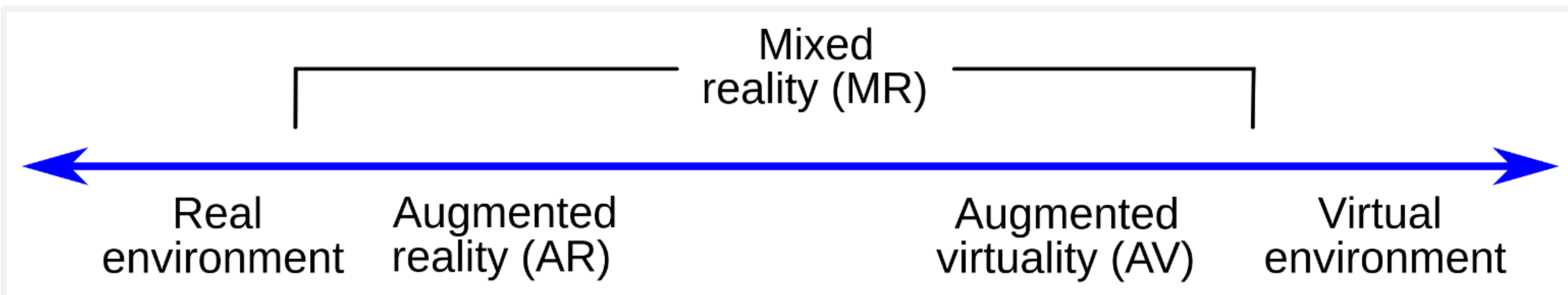
See: rubygarage.org/blog/difference-between-ar-vr-mr

BASICS: REALITY-VIRTUALITY CONTINUUM

Reality-Virtuality Continuum

A continuous scale between an environment/experience completely virtual (VR) and an environment/experience completely real (physical world).

It includes all possible variations and compositions of real content mixed with virtual content, including: VR, AR, *"Augmented Virtuality"*, etc.



See: en.wikipedia.org/wiki/Reality-virtuality_continuum

BASICS: REALITY-VIRTUALITY-MEDIALITY CONTINUUM

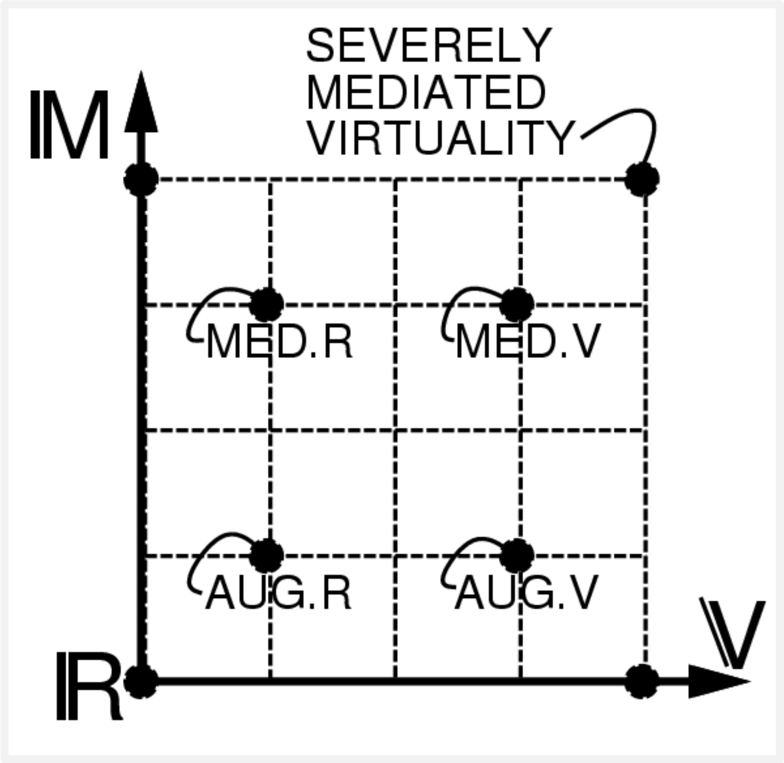
Mediated Reality/Virtuality: Reality/virtuality including artificial modifications of human perception by using devices that alter sensory input.

Reality-Virtuality-Mediality Continuum

The origin R denotes unmodified reality.

The Virtuality axis V represents the amount of virtual content in the environment, and includes: AR as well as Augmented Virtuality.

The Mediality axis M represents environments including modifications of sensory input, including: mediated reality, mediated virtuality, etc.



See: en.wikipedia.org/wiki/Reality-virtuality_continuum

BASICS: IMMERSION

Immersion: The objective level of sensory fidelity provided by a VR system.

Immersion is achieved by surrounding the user with accurate artificial sensory inputs (audio, visual, etc.) making the VR experience realistic and believable.

Immersion mainly depends on ***"sensory immersion"***: the degree to which the range of sensory channels is engaged by the VR simulation.

Sensory Immersion: Sensory immersion includes all sensory inputs: olfactory, visual, auditory, and haptics; relying on advanced technology (e.g., computer graphics, high-resolution displays, multi-channel sound systems, seat movements and force feedback controllers, etc.).

See: en.wikipedia.org/wiki/Immersion_(virtual_reality)

BASICS: PRESENCE

Presence: The subjective psychological response of a user experiencing a VR environment. In other words: the user sense of being in the virtual world.

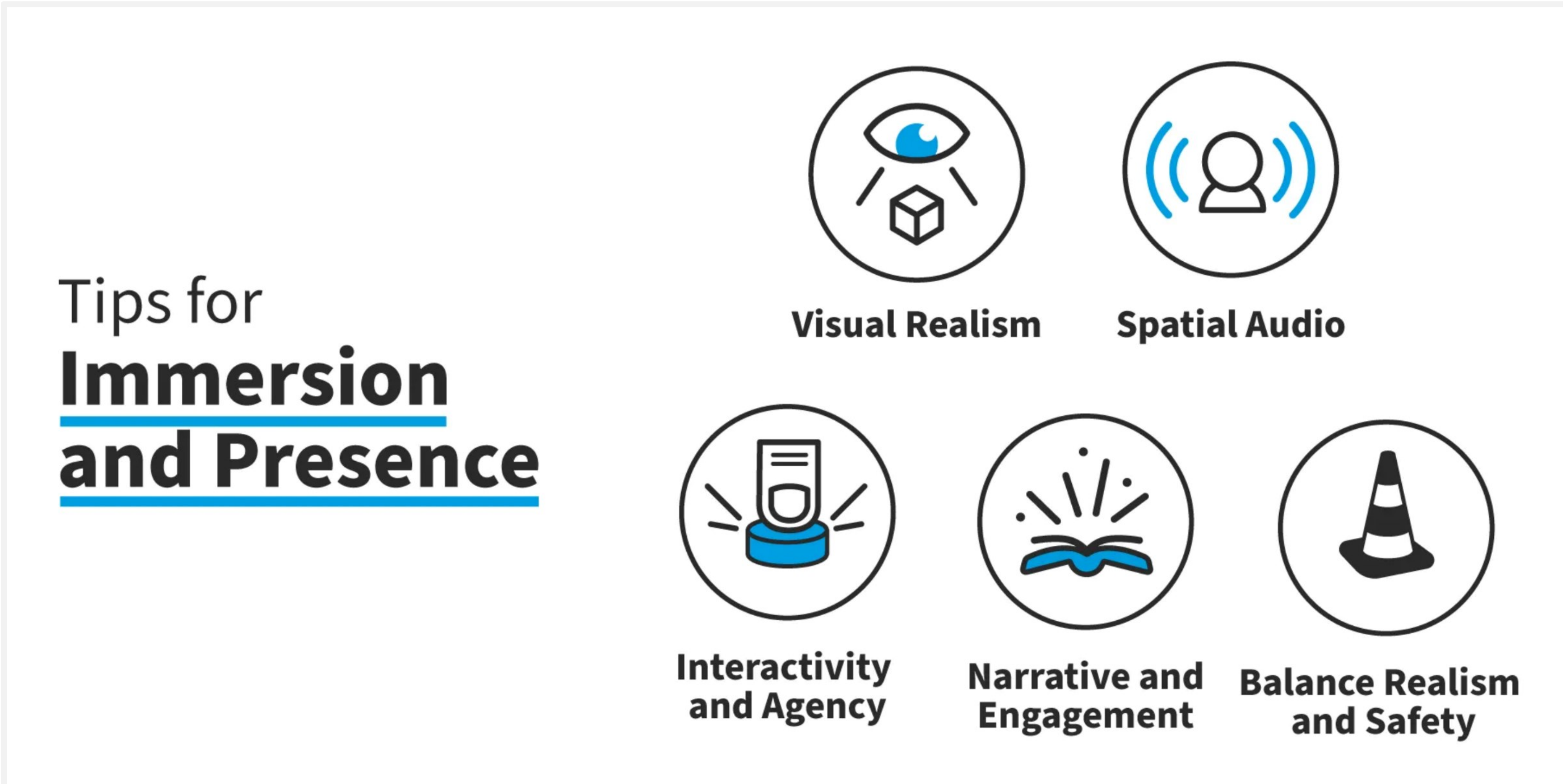
Presence is a perceptual illusion, not a cognitive one: the perceptual system identifies the events and objects and the brain-body system automatically reacts to the changes in the environment, while the cognitive system slowly responds with a conclusion of what the person experiences is an illusion.

Presence is achieved exploiting: technology, psichology, ergonomics, etc.

See: en.wikipedia.org/wiki/Immersion_(virtual_reality)

Note: Sometimes, the terms *"presence"* and *"immersion"* are used interchangeably, but remember that they refer to different aspects of the VR experience!

BASICS: ACHIEVE IMMERSION AND PRESENCE



See: www.interaction-design.org/literature/topics/presence

BASICS: ACHIEVE IMMERSION AND PRESENCE (2)

In 2014 Michael Abrash stated that **all of the following are needed to establish presence:**

- Wide field of view (FOV) of 80 degrees or more.
- Adequate display resolution of 1080p (1920x1080) or better.
- Low pixel persistence (3 ms or less).
- High refresh rate (60 Hz or more).
- Global display with all pixels on simultaneously (rolling display only with eye tracking).
- VR optics with max 2 lenses per eye with trade-offs (ideal optics not practical).
- Optical calibration considering inter-pupillary distance (IPD) etc.
- Solid tracking (accuracy of 1 mm on trans and 0.25 deg on rot, volume 1.5x1.5x1.5 m^3).
- Low latency (25 ms motion to last photon or less).

See: en.wikipedia.org/wiki/Immersion_(virtual_reality)

THEORY: BINOCULAR VISION

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.

Binocular Vision: A type of vision system of a human/animal that includes 2 eyes capable of facing the same direction (share the FOV) to perceive a single 3D image of the virtual/real world.

Monocular Vision: A type of vision system of a human/animal that includes only 1 eye or multiple eyes not facing the same direction (do not share the FOV).

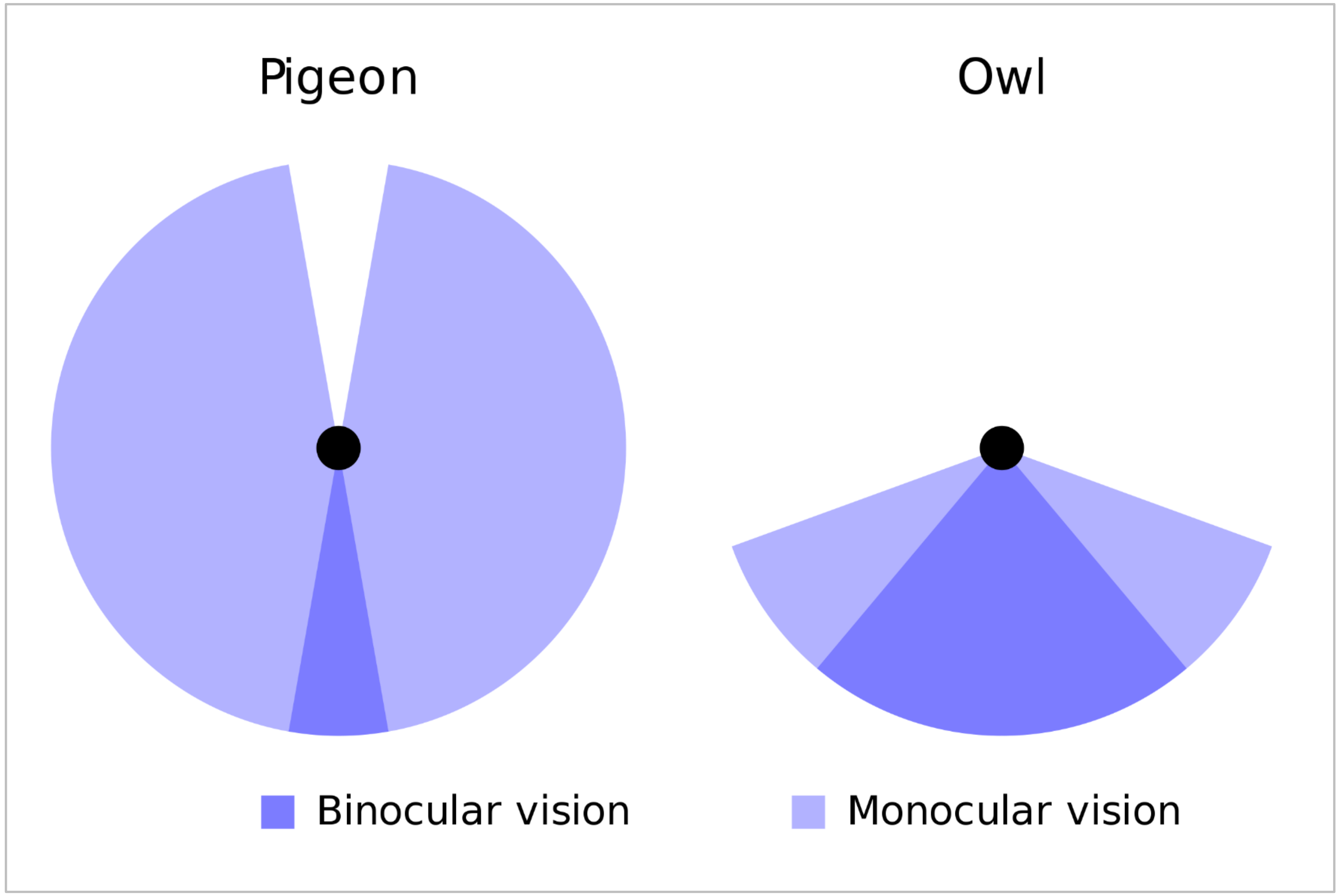
Example: The vision system of a horse is mainly monocular, its eyes are positioned laterally on its head, this arrangement provides the horse with increased field of view, but poor depth perception.

THEORY: BINOCULAR VISION (2)

The FOV of a pigeon (left) and of an owl (right).

Pigeons have 2 eyes arranged laterally on their head, whereas owls have 2 eyes positioned frontally on their head.

Different colors show FOV areas where binocular vision is enabled and where only monocular vision is available.



THEORY: DEPTH PERCEPTION

Depth Perception: The human ability to perceive distance (depth) to objects in the real/virtual world using a visual system. It is a major factor in perceiving the real/virtual world in 3D.

Depth Sensation: The animal (non-human) ability to perceive distance (depth) to objects in the real/virtual world using a visual system.

Note: It is known that non-human animals can perceive depth, but it is not known if it it the same perception as humans (vision systems could be different, etc.).

Stereopsis: The process performed by the human brain (visual cortex) allowing the depth perception when a scene is viewed with both eyes (binocular vision).

THEORY: DEPTH CUES

Depth perception is essential in VR systems,
and it is based on the correct generation of stereo pairs!

To understand how depth perception works we must consider that there are several *"depth cues"* utilized by our brain. These are the **(monocular) depth cues available in 2D graphics:**

- **Perspective:** objects (projections) become smaller if the distance from the point of view increases.
- **Relative Dimensions:** we expect certain dimensions of familiar objects.
- **Detail:** we can see more details of closer objects in respect to distant targets.
- **Occlusion:** occluding objects appear on the foreground in respect to occluded objects.
- **Illumination:** near objects are brighter than distant objects.
- **Relative Movement:** distant objects move slower than near objects.

THEORY: DEPTH CUES (2)

These are the **(binocular) depth cues only available in 3D graphics:**

- **Binocular Disparity:** difference between the left and right images of a stereo pair.
- **Accomodation:** muscular tension needed by our eyes to focus on a target.
- **Convergence:** muscular tension needed to rotate our eyes toward the focal point.

Binocular disparity is considered the dominant depth cue dominante!

All other depth cues, if incorrect, can have a severe detrimental effect!

THEORY: DEPTH CUES (3)

To achieve a correct depth perception, the stereo pair must be properly visualized so that the visual cortex can *"fuse"* it.

If a stereo pair is generated with conflicting depth cues:

- Any depth cue could become dominant (accidentally).
- Depth perception could be exaggerated or diminish (in respect to the correct one).
- The 3D content could be uncomfortable to view.
- The visual cortex could fail *"fusing"* the stereo pair (resulting in double vision).

If a stereo pair is generated correctly:

- Both binocular disparity and convergence are correct!
- Accomodation will always be inconsistent, but usually this issue is tolerated…

THEORY: STEREOSCOPY

Stereopsis: Depth perception produced by the reception in the brain (visual cortex) of visual stimuli (stereo images) from both eyes in combination (binocular vision).

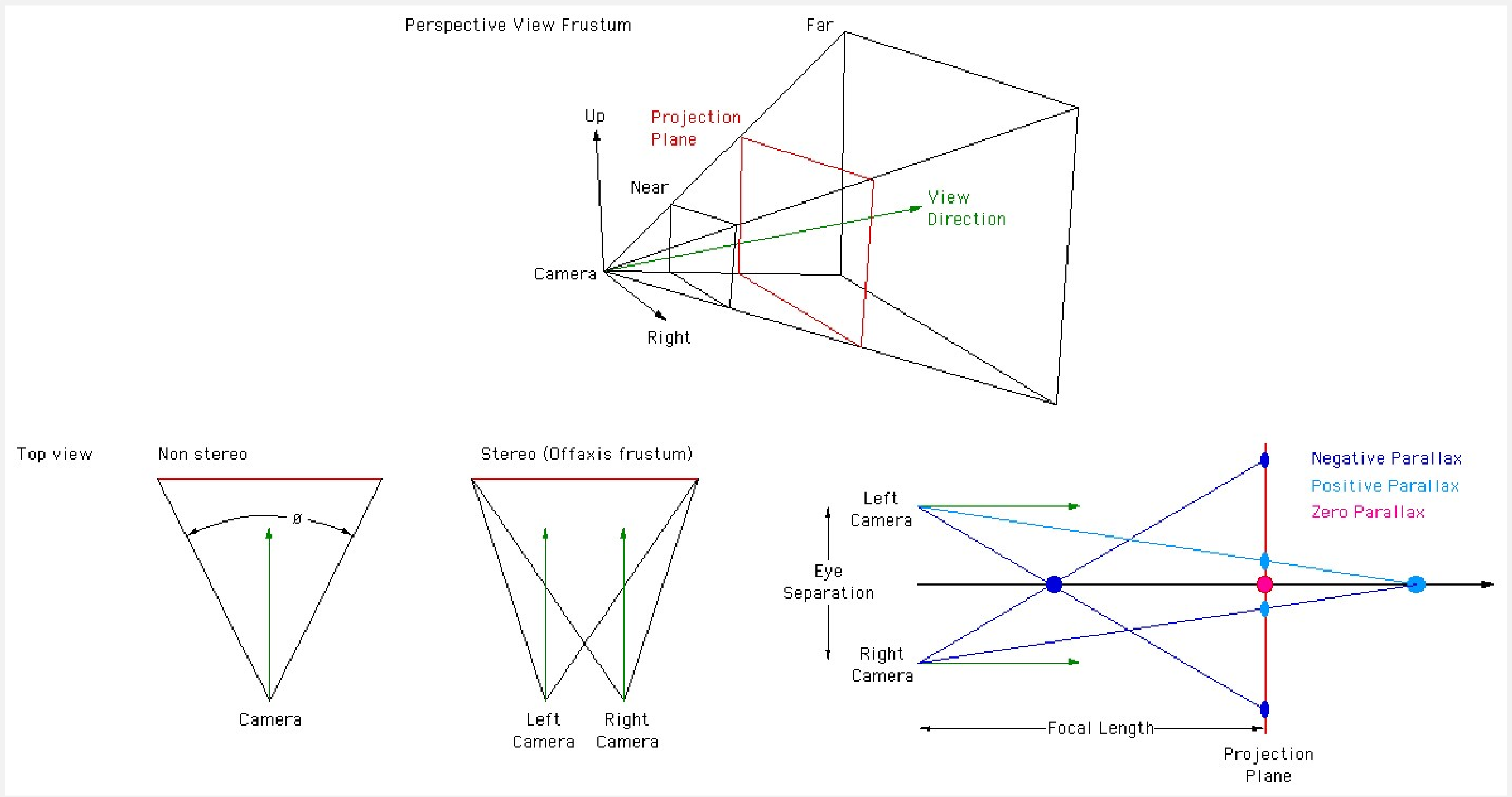
Stereo Pair: A pair of views of a 3D object designed to be viewed independently by the left and right eyes of the viewer. Any type of stereoscopic system involves visualizing a stereo pair to the viewer in some way.

IPD: The inter-pupillary distance (sometimes referred as pupillary distance, or PD) is the distance in millimeters between the centers of each pupil.

Stereo Rendering: The computer graphics process to visualize 3D content by rendering a stereo image pair in order to induce the viewer to achieve stereopsis.

Stereoscopic System: A system (hardware and software) that presents the viewer with an image of a 3D object such that it appears to have *"real"* depth (enabling the viewer to have depth perception of virtual content).

THEORY: VR STEREO CAMERA



THEORY: VR LOCOMOTION

Locomotion: The ability to move from place to another in the real world.

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.

Physical VR Locomotion: The avatar movement in VR is controlled by the user movement in the physical world. For example: the user head movement always corresponds to the VR camera movement.

Artificial VR Locomotion: The avatar movement in VR **does not** directly correspond to user movement in the physical world. For example: a VR avatar body movement controlled by using the VR controller thumbsticks.

Unobtrusive and natural locomotion is critical to achieve immersion and presence!

See: developer.oculus.com/resources/bp-core-types-of-locomotion

THEORY: MOTION PERCEPTION

Vection: The sensation of movement in space produced purely by visual stimulation.

For example: the illusion of self-motion experienced when watching a moving train through the windows of a stationary train.

Vestibular System: Apparatus in the human inner ear that detects the position and movement of our head in space, allowing for the coordination of eye movements, posture, and equilibrium.

Visual-Vestibular Mismatch (VVM): Sensory conflict between visual and vestibular signals.

BASICS: COMFORT

Physiological Comfort: Body senses do not feel conflict in sensory stimulation.

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.

BASICS: VR SICKNESS

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: (aka Simulator Sickness) It is the discomfort caused by sensory conflicts experienced by a VR user, and generated by a VR experience.

Common symptoms are: nausea, cold sweat, headache, sleepiness, etc.

Ergonomics: 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.

BASICS: VR SICKNESS (2)

These factors can cause VR sickness:

- **Acceleration** (minimize any acceleration).
- **Control** (ensure that the user has a good degree of control in VR).
- **Session Duration** (allow breaks during VR sessions or design short sessions).
- **Visual Flow** (avoid strong visual flows).
- **Binocular Disparity** (remember that not everyone is capable of fusing stereo pairs).
- **FOV** (decreasing the FOV could reduce comfort).
- **Latency** (minimize it because *"lags"* cause discomfort in VR).

Remember that VR developers/users become resilient to VR sickness!

BASICS: VR AVATAR

VR Avatar: A VR avatar is a virtual representation of the user in the VR environment, and it facilitates both locomotion and interactions.

A VR avatar can range from a basic 3D shape (e.g., a capsule-like body) to an animated 3D model (e.g., a player character).

See: en.wikipedia.org/wiki/Avatar_(computing)

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

See: research.facebook.com/publications/pixel-codec-avatars/

See: www.youtube.com/watch?v=TKlxw0vh9X0

BASICS: HMD AND CAVE

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 (inertia measurement units).

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.

CAVE: A Cave Automatic Virtual Environment (CAVE) is a VR system including a room-sized cube in which 3-6 walls are back-projected in order to create an immersive virtual environment, designed specifically for a multi-user experience.

BASICS: HAPTICS

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.

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.

APPLICATION: VR APPLICATION FIELDS

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.

APPLICATION: 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).

APPLICATION: 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).

APPLICATION: 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.

PART 1B: VR SYSTEM DESIGN

This section briefly introduces 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.

Then, a summary of principles and guidelines to design a VR system will be presented.

SOFTWARE: VR (GAME) ENGINES

A VR (game) engine provides software developers with a framework for creating a VR app.

Note: Current VR engines are game engines supporting VR devices, with some VR engines supporting also AR-MR app development; at this time there is no engine designed specifically for VR.

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++.

HARDWARE: STEREOSCOPIC SYSTEMS

Traditional stereoscopic systems employ an apparatus that keeps the left and right eye images directed solely at the appropriate eye. For example:

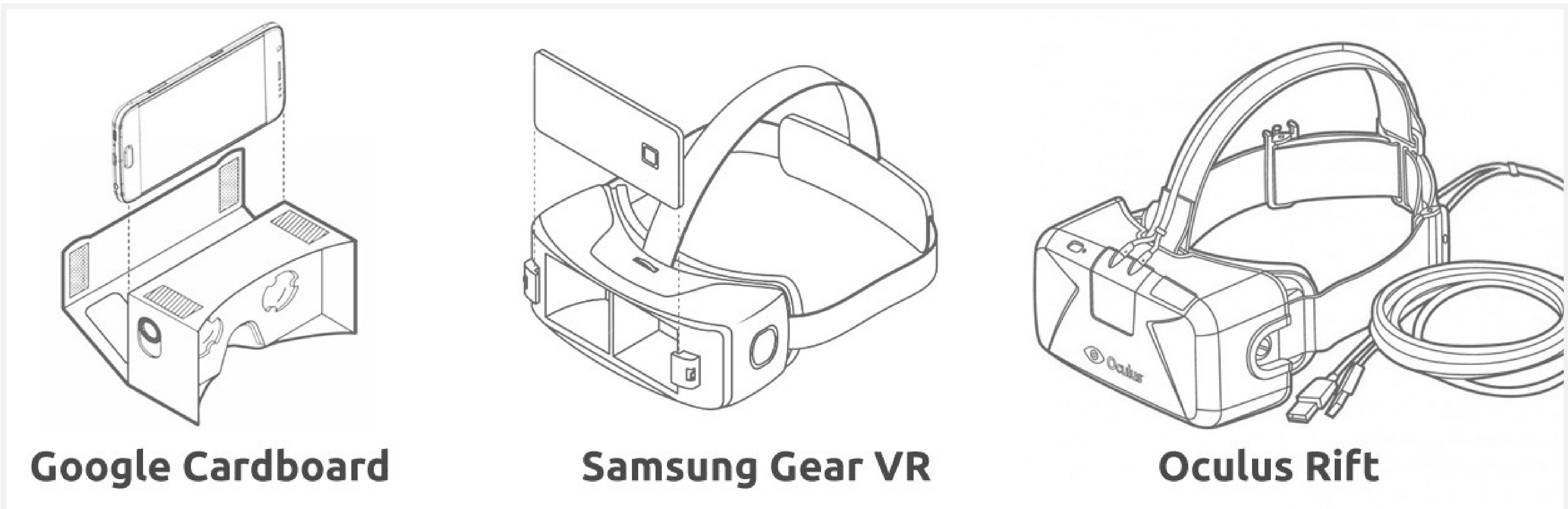
- Head-mounted displays (HMDs).
- CAVEs.
- Active shutter glasses.
- Anaglyph glasses.

The *"holy grail"* of stereographics are autostereoscopic systems that do not require special glasses or lighting conditions. For example:

- Parallax barriers.
- Lenticular lenses.
- Holographies.

HARDWARE: HMD

These are just examples of the anatomy of 3 different modern VR HMDs.

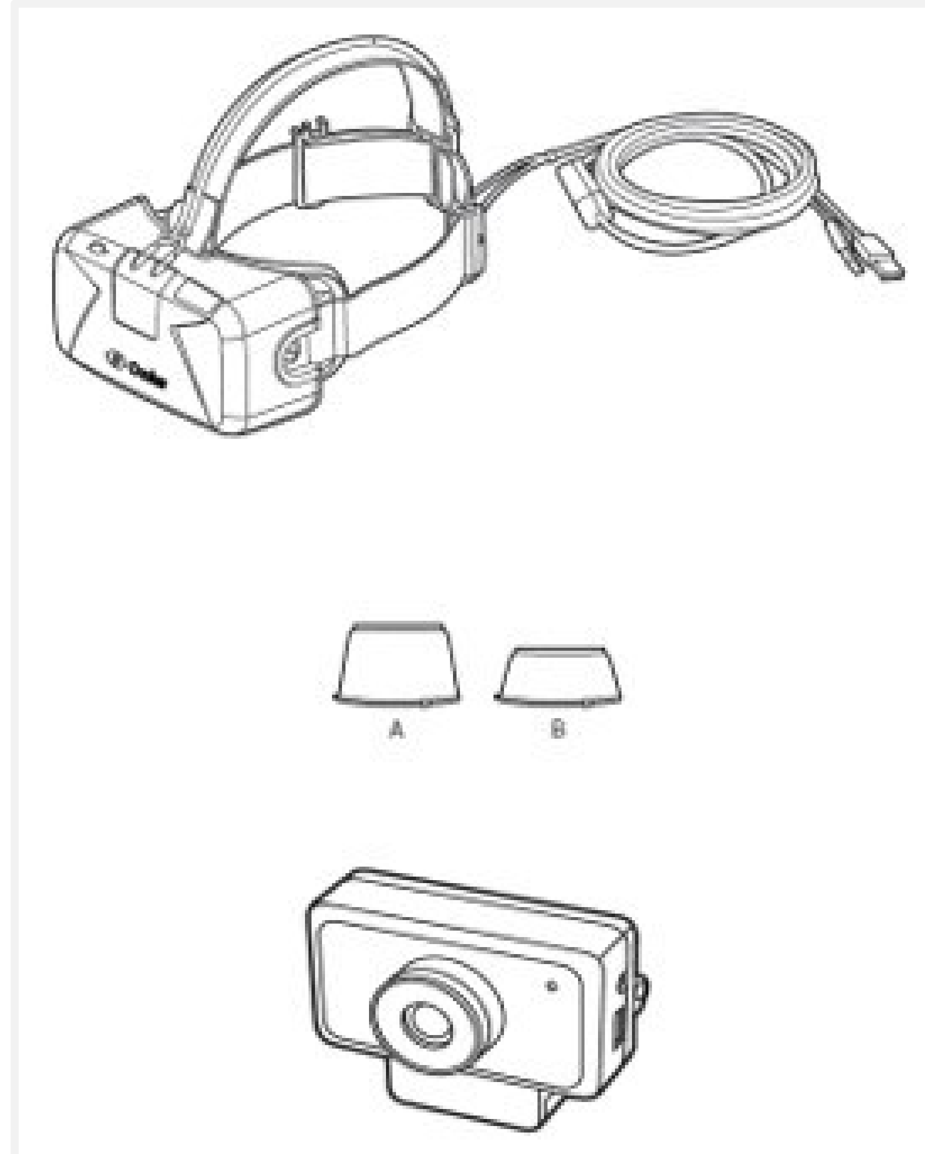


Note: Knowing an HMD hardware is not critical to create VR systems, but it could facilitates the design, testing, and debugging.

HARDWARE: HMD (2)

These are some of the main components of a modern VR HMD:

- The helmet usually includes an **IMU and/or IR tracking cameras** for the pose tracking.
- The internal display usually includes a **pair of Fresnel lenses** on top to allow the user eyes to focus (even at such short distance).
- Sometimes the **pose tracking system** is external (outside-in tracking), but nowadays modern VR HMDs integrate an internal pose tracking system (inside-out tracking).

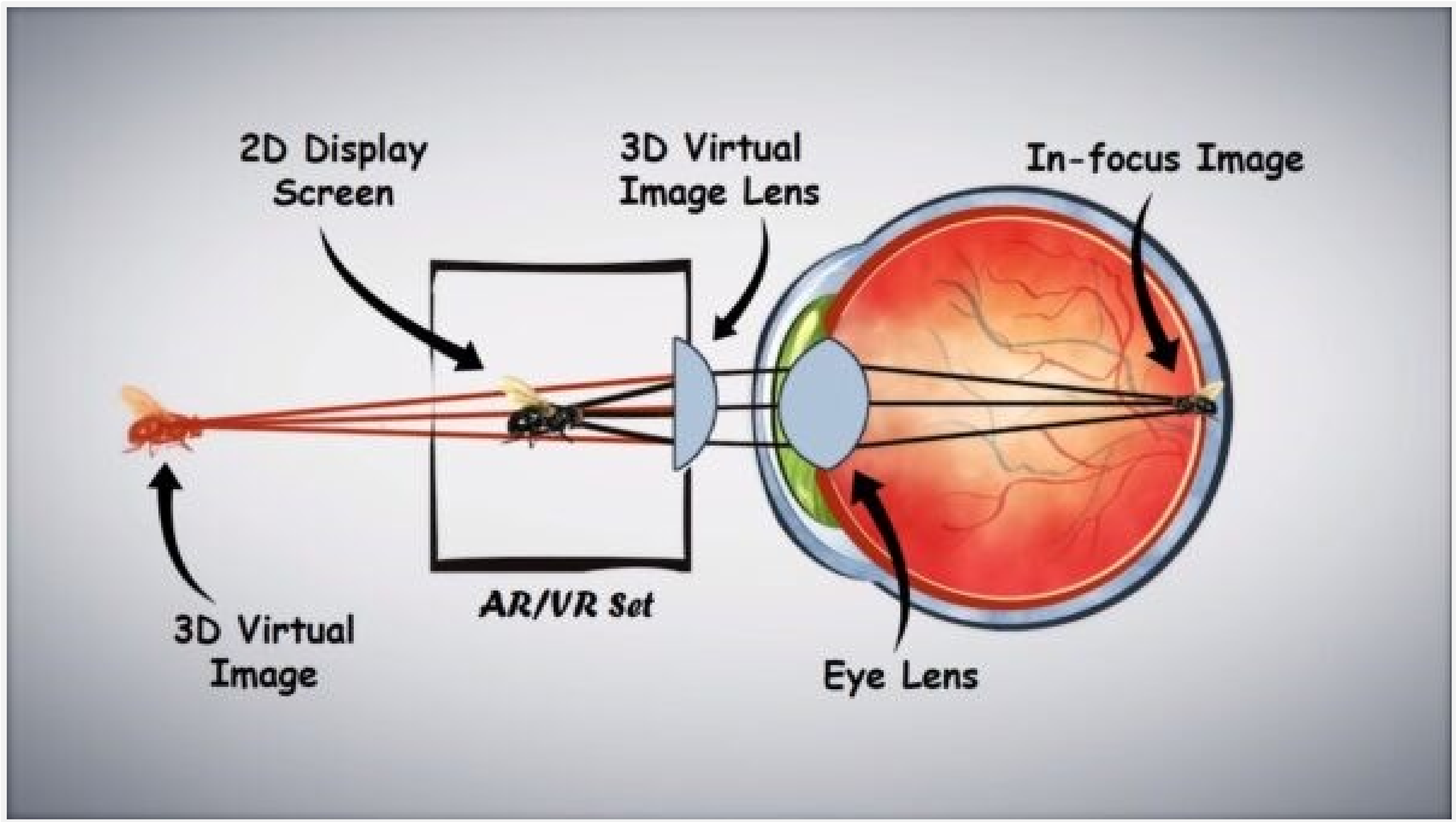


HARDWARE: HMD (3)

Stereo pair visualized on the internal display of a modern VR HMD in split-screen modality.

HARDWARE: HMD (4)

Diagram illustrating the role of the internal Fresnel lenses in a modern VR HMD.



HARDWARE: 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.

HARDWARE: CAVE

CAVE: A Cave Automatic Virtual Environment (CAVE) is a VR system including a room-sized cube in which 3-6 walls are back-projected in order to create an immersive virtual environment, designed specifically for a multi-user experience.

Typically, CAVE users wear shoe covers and stereoscopic glasses (e.g., shutter glasses), and use VR controllers (e.g., a VR wand).

See: en.wikipedia.org/wiki/Cave_automatic_virtual_environment

HARDWARE: CAVE TECHNICAL SPECS

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

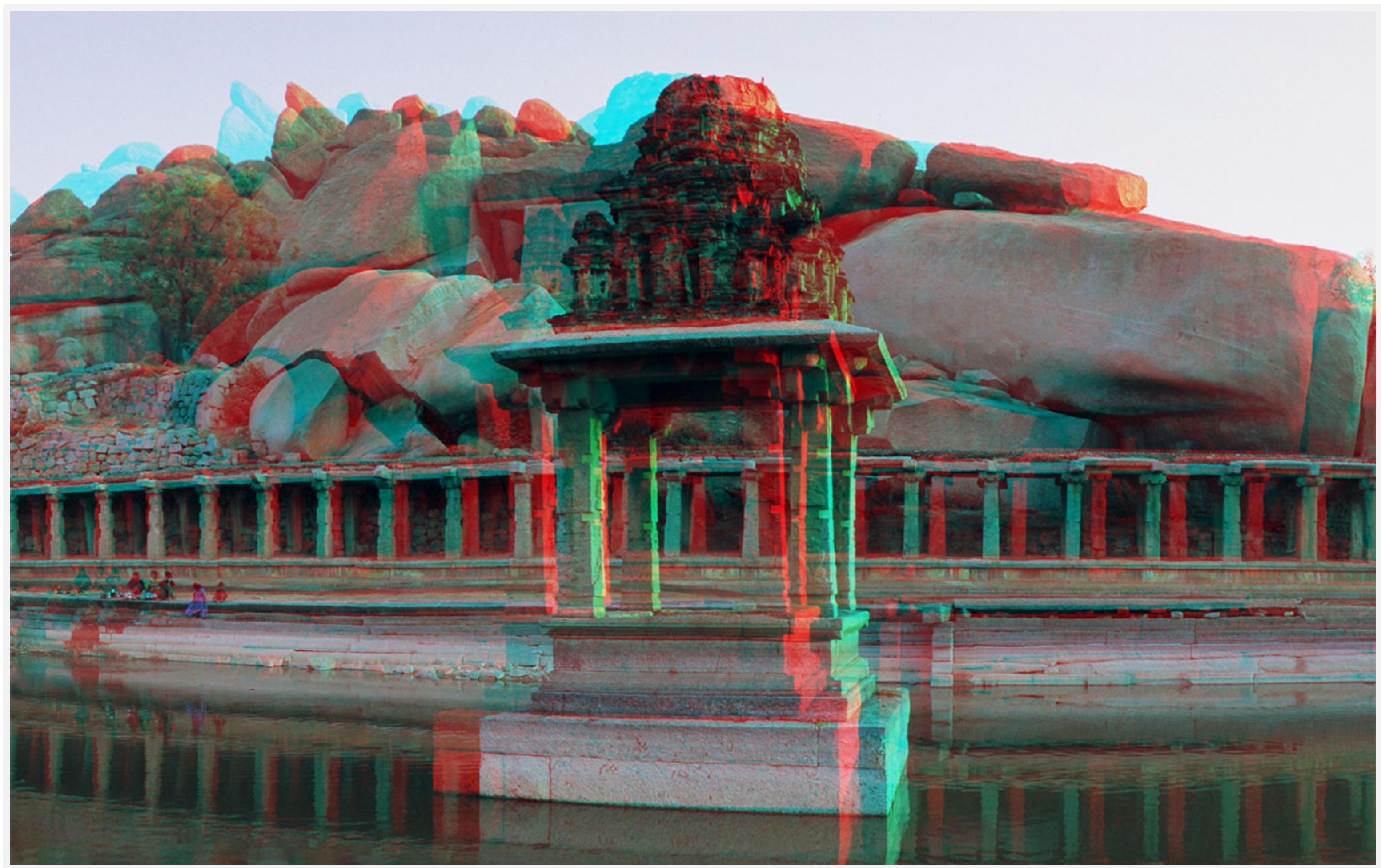
- **Cost:** starting at 50000 $.
- **Dimensions:** starting at 3×3×3 m.
- **Displays:** 4–5 projection screens, used with stereoscopic glasses (shutter glasses).
- **Users:** up to 5 users simultaneously.
- **Interactions:** using VR controllers (wands, data gloves, joysticks, etc.).

HARDWARE: ANAGLYPH GLASSES

Anaglyphs rely on the encoding of a stereo pair into a single image exploiting color filters, and then using special glasses (**anaglyph glasses**) including the proper color filters to block/enable (decoding) the proper left/right image to the relative eye.

HARDWARE: ANAGLYPH GLASSES (2)

An example of a red-cyan anaglyph.

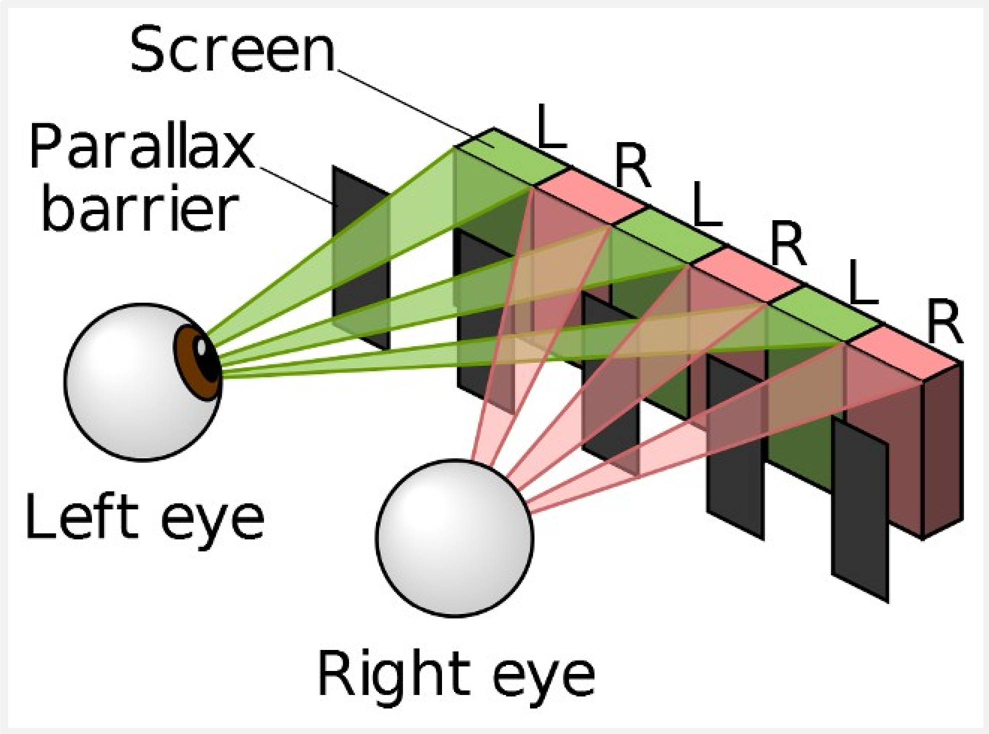


HARDWARE: ACTIVE SHUTTER GLASSES

A stereoscopic system based on **active shutter glasses** consists in the visualization of stereo pair alternating the visualization of the left and right images at high frequency, and relying on special glasses capable of blocking/enabling the proper image to the correct eye in synch with the visualization frequency.

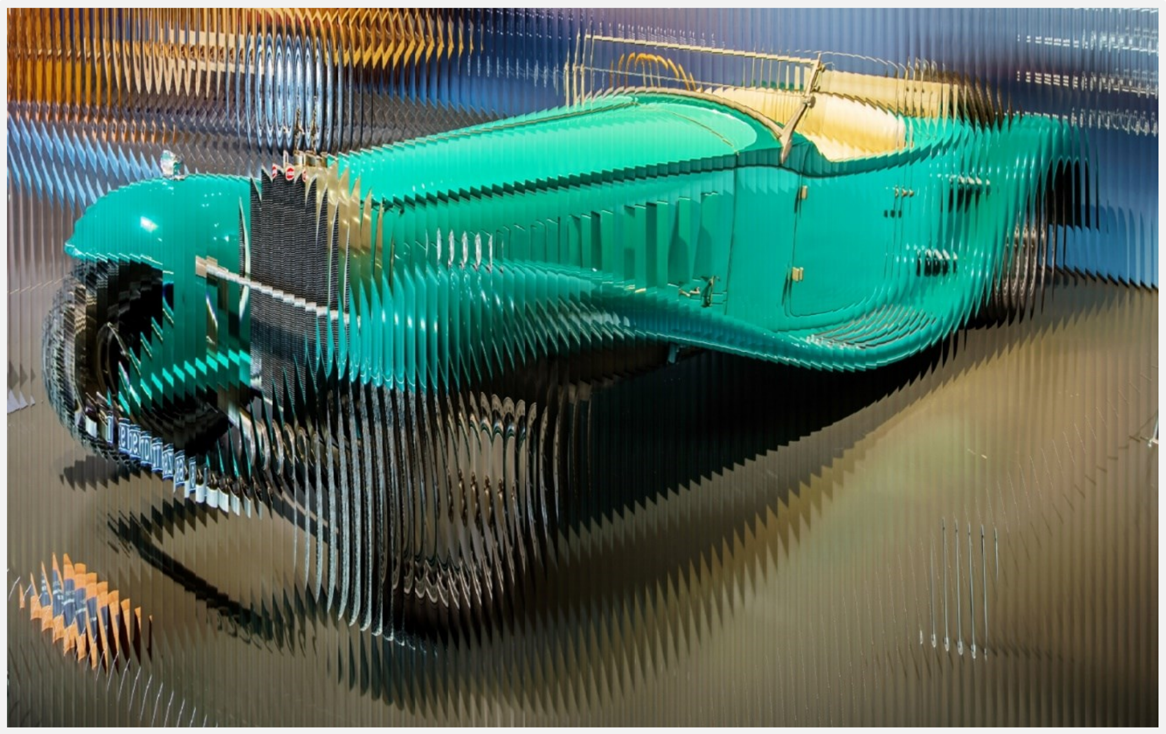
HARDWARE: PARALLAX BARRIER

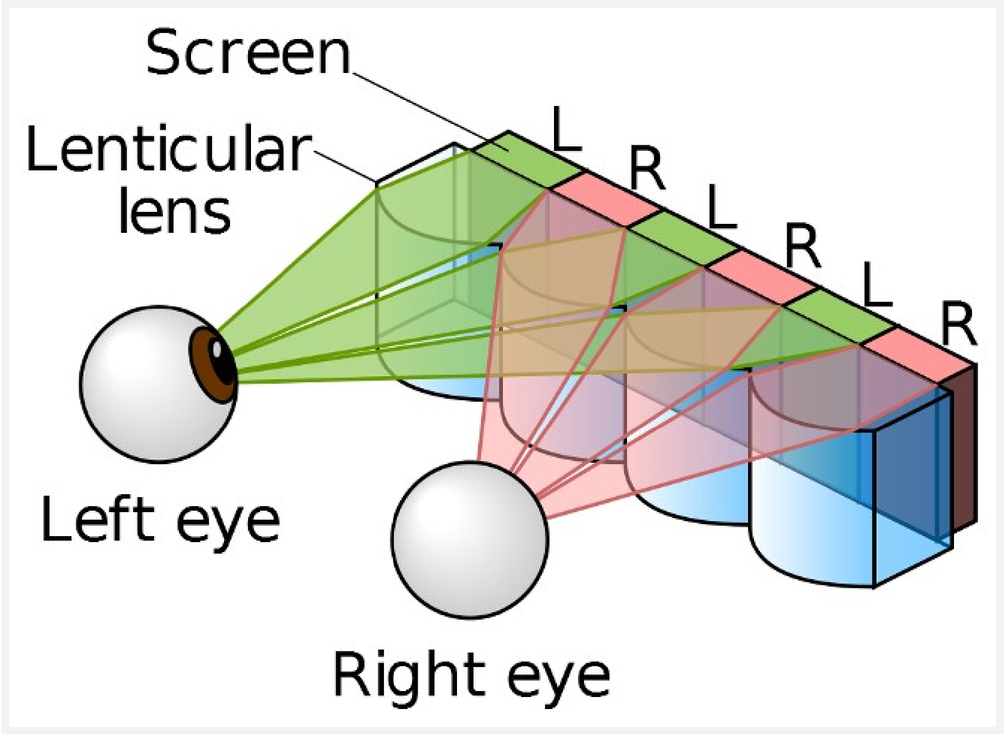
A **parallax barrier** is an autostereoscopic system allowing the visualization of stereo pairs without the need of additional optical devices. The image visualized integrates the stereo pairs interlacing the left and right images, that are delivered them to the proper eye using a semi-transparent barrier exploiting horizontal parallax.



HARDWARE: LENTICULAR LENS

Lenticular lenses are an autostereoscopic system allowing the visualization of stereo pairs without the need of additional optical devices. The image visualized integrates the stereo pairs interlacing the left and right images, that are delivered to the proper eye using a semi-transparent lens sheet to steer the view properly.





HARDWARE: 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.

HARDWARE: VR TRACKING

Pose Tracking: In VR a pose tracking system detects the precise pose (3D position and orientation) of HMDs, VR controllers, and other objects or body parts.

Pose tracking is often referred to as 6-DOF tracking, for the six degrees of freedom in which the pose is often tracked.

Note: Pose tracking is sometimes referred to as positional tracking, but it is an error!
Pose tracking tracks both 3D position and 3D orientation of a target.
Positional tracking only tracks the 3D position of the target (and no 3D orientation).

Outside-In Tracking: Tracking cameras are placed in static locations to track the position of markers on the target (HMD, VR controllers, etc.).

Inside-out tracking: Tracking cameras are placed on the target (HMD) and look outward to determine its location considering the surrounding environment.

See: en.wikipedia.org/wiki/Pose_tracking

HARDWARE: VR TRACKING SPECS

In most VR tracking systems the main targets are the HMD and the VR controllers.

Depending on the target, different tracking performance requirements may be needed.

For example: the HMD tracker must run at > 20 Hz with a latency < 50 ms.

DESIGN: VR BEST PRACTICES

This is a summary of the *"best practices"* to design and implement VR systems:

- Do not neglect monocular depth cues (e.g., illumination, details, etc.).
- The most comfortable depth range in VR is 0.75-3.50 m.
- Ensure that text elements in VR are easy to read and avoid small unnecessary elements in areas where the user focuses.
- The most comfortable VR experiences do not integrate any *"self motion"* for the user, excluding head/body movement to look around.
- If *"self motion"* is necessary in VR, slow user movements are the most comfortable.
- Ensure that any form of acceleration (of the user or other elements) is as hort and unfrequent as possible.

DESIGN: VR BEST PRACTICES (2)

This is a summary of the *"best practices"* to design and implement VR systems (continued):

- User head movements and virtual camera movements should always match!
- Do not integrate *"head bobbing"* in the VR avatar movements.
- To achieve comfortable VR experiences, minimize backward and lateral movements.
- Careful with situations inducing strong vection (visual feeling of motion), for example climbing stairs, accelerating, etc.
- Minimize (if possible) both *"lag"* and latency.
- If latency is unavoidable, a variable *"lag"* is worse than a constant *"lag"*.

Follow these guidelines to maximize comfort and usability of a VR experience, minimizing: visual fatigue, disorientation, nausea, etc.

DESIGN: UI FOR VR

The design and implementation of UIs for VR includes:

- **Menus:** for specific views, in-game menus, integrated in 3D, etc.
- **Heads-Up Displays (HUDs):** minimaps, timers, etc.
- **Controls:** keyboard-mouse, point-and-click, joypad, etc.
- **Interaction Feedback:** visual (highlighting), audio (clicks), tactile (vibration), etc.

Designing UI for VR means determining which information/interactions should be available to the user, and how these will be implemented (usually maximizing comfort and usability).

DESIGN: UI FOR VR (2)

A non-diegetic UI in a traditional videogame (first-person action shooter).

DESIGN: UI FOR VR (3)

These are some guidelines to design and implement UI for VR:

- Integrating UIs in the virtual environment (diegetic UIs) is the best design.
- Visualize reticles/crosshairs on the target (not at a fixed distance).
- Hide virtual instruments when not in use.
- Be careful with inconsistencies of virtual avatars.
- No standard input device is ideal in VR, the best option is a gamepad.
- Use familiar input devices (remember that the user does not see the controllers in VR).
- Be careful with the intense use of gestures and gaze (it can easily cause fatigue).
- Locomotion is still unexplored in VR (it can create issues never seen before).

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See: unity.com

REFERENCES

- Unity website: unity.com
- Unity online manual: docs.unity3d.com/manual
- Unity scripting reference: docs.unity3d.com/scriptreference
- Unity Asset Store: assetstore.unity.com

- *"Virtual Reality"* by Steven M. LaValle: lavalle.pl/vr

- *"Best Practices for Immersive VR"*: developer.oculus.com/resources/bp-overview

APPENDICES

- VR Videos
- Gesture Recognition

BASICS: VR VIDEOS

180-Degree Video: A VR video format (aka VR180) that limits the user FOV to 180 degrees (frontal). This format allows for increased control over what users see in their FOV.

360-Degree Video: A VR video format (aka VR360) that includes a full 360-degree, spherical view of the user surroundings (front and back).

Note: VR video recordings require an **omnidirectional camera** or a collection of cameras.

See: en.wikipedia.org/wiki/360-degree_video

BASICS: GESTURE RECOGNITION

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

See: en.wikipedia.org/wiki/Gesture_recognition