VIRTUAL REALITY: THEORY AND PRACTICE

LESSON 4: VR LOCOMOTION

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TABLE OF CONTENTS

PART 1: INTRO TO 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.

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

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

THEORY: PHYSICAL VS ARTIFICIAL

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.

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!

PART 2: VR LOCOMOTION INTERFACES

Motion tracking interfaces are critical in creating immersive VR locomotion experiences:

- **Omnidirectional Treadmills:** Devices allowing users to walk/run in multiple directions simultaneously. These treadmills are particularly effective for users prone to motion sickness, and can enhance the feeling of presence.
- **Inside-Out Tracking:** The most common form of motion tracking for VR, these systems involve sensors placed inside the VR headset that precisely track its movements in space by *"looking"* at the surrounding environment.
- **VR Chairs:** A seated solution for VR locomotion, usually integrating sensors to track the user/chair movements with 6DOF motion tracking technology and IMUs.
- **Wearable Locomotion Devices:** Wearable VR locomotion and motion tracking devices sense movements using IMUs.

See: walkovr.com/vr-locomotion-solutions

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 Touch Controllers), usually 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 CONTROLLERS (2)

VR Controllers

A pair of hand-held joysticks, usually integrating both 6-DOF tracking and basic tactile feedback.

Oculus Touch Controllers

These controllers consist in a pair of handheld units, each featuring: 1 analog stick, 3 buttons, and 2 triggers.

Some versions also include: a dedicated thumbrest, and a system for detecting finger gestures.

The controller ring contains infrared LEDs to allow 6-DOF tracking.

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).

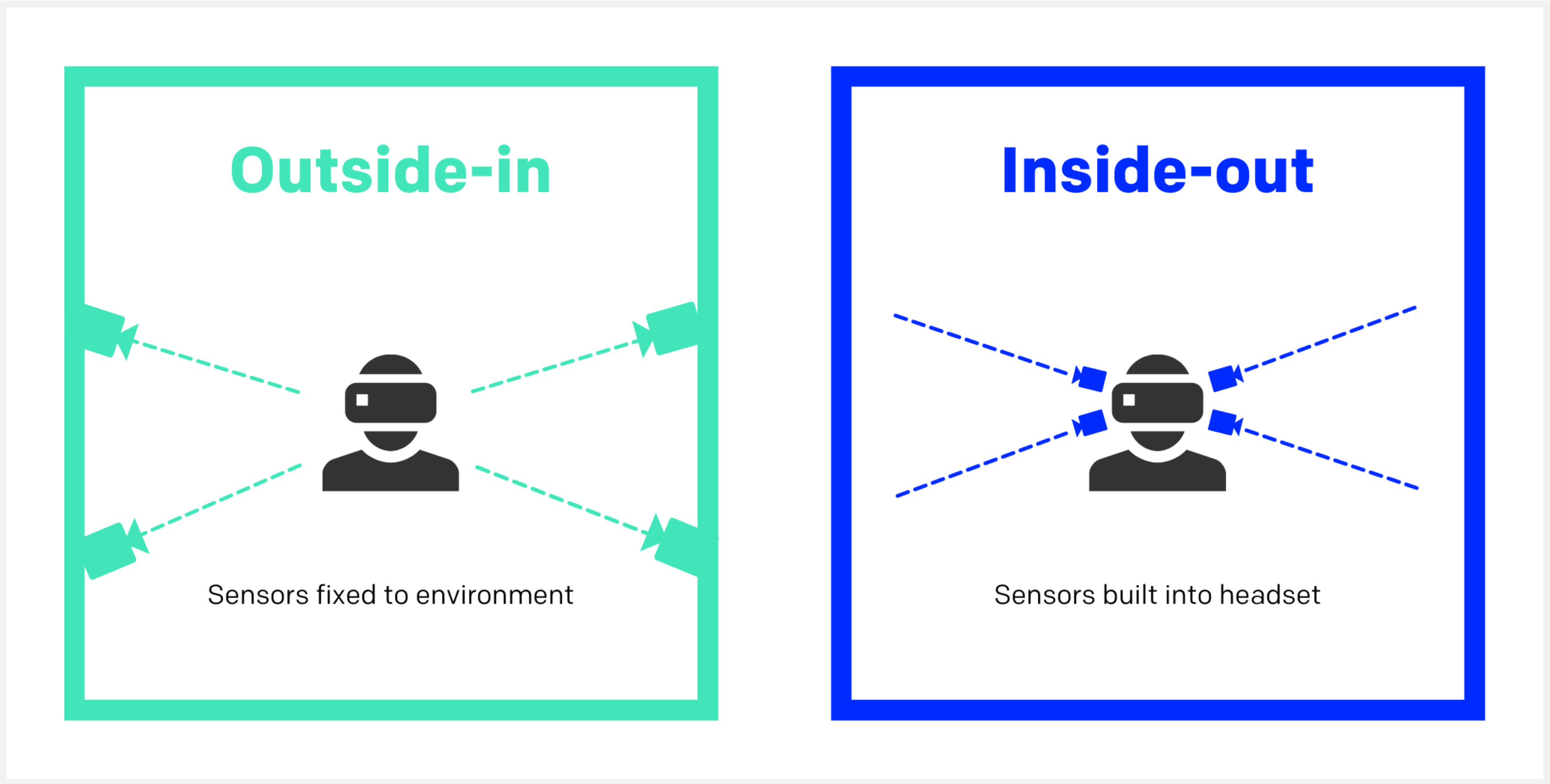
Outside-In Tracking: Tracking cameras are placed in static locations to track the position of markers on the target (HMD, VR controllers, etc.).

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 (2)

Comparison between outside-in and inside-out tracking methods for VR.



See: *"Inside a VR Headset: Outside-In Tracking"* on YouTube.

See: *"Inside a VR Headset: Inside-Out Tracking"* on YouTube.

HARDWARE: OMNIDIRECTIONAL TREADMILL

An omnidirectional treadmill (ODT) is a mechanical device, similar to a standard treadmill, that allows a person to perform locomotive motion in any direction, allowing for 360 degrees of movement (forward/backward, left/right, and any other combination of ground movements). Integrating an ODT in a VR system provides these advantages:

- Natural navigational movement of the ODT system while still providing contextual cueing which simulate physical traversal through the VR environment.
- Reverting immersive navigation tasks from hand-based (mouse, joystick) to mentally hard-wired whole body (leg) -based.
- Enhancing immersion by providing a whole-body experience that begins at the soles of the feet and ends at the top of the head.
- Facilitating whole-body haptic interaction.

See: en.wikipedia.org/wiki/Omnidirectional_treadmill

HARDWARE: OMNIDIRECTIONAL TREADMILL (2)

HARDWARE: VR CHAIR

A VR chair is a seat designed specifically for motion tracking and locomotion in virtual reality, and it can incorporate various features for comfort, immersion, and interaction:

- **Motion Tracking:** VR chairs often include sensors or motors that track the user's movements (head orientation, body position, foot movements, etc.).
- **Locomotion Enhancement:** VR chairs allow users to move within the virtual world while remaining seated (without physically walking).
- **Comfort and Ergonomics:** VR chairs prioritize comfort during extended VR sessions. They may have padded seats, adjustable headrests, and lumbar support.
- **Integration with VR Headsets:** VR chairs can synchronize with VR headsets. For example, when the user turns their head, the chair may rotate accordingly.
- **Foot Controls:** VR chairs can incorporate foot pedals allowing the user to simulate walking or other movements.

HARDWARE: VR CHAIR (2)

HARDWARE: WEARABLE LOCOMOTION DEVICES

Wearable devices for VR locomotion are innovative solutions designed to enhance locomotion and interaction in virtual reality experiences.

These are some of the advantages of wearable locomotion devices in VR:

- **Convenience:** Wearable devices are compact and portable, making them ideal for home-scale VR users.
- **Cost-Effective:** Compared to omnidirectional treadmills or VR chairs, wearables locomotion devices are affordable and accessible.
- **Minimal Setup:** No need for large equipment assembly; just put on the wearables and dive into VR experiences.

DESIGN: WEARABLE LOCOMOTION DEVICES (2)

A set of wearable devices for VR locomotion.

PART 3: VR LOCOMOTION DESIGN

This section briefly explores the main concepts in design VR locomotion:

- **VR Locomotion Types:** Describes physical and artificial VR locomotion.
- **Artificial VR Locomotion Types:** Describes methods of locomotion that do not depend on the user physically moving in their workspace (world pulling, scripted movement, avatar movement, etc.).
- **Controlling Artificial Locomotion:** Overview of controls to drive artificial VR locomotion (thumbstick-driven, teleport-based, seated controls, etc.).
- **VR Locomotion Design Challenges:** Guide for challenging VR scenarios (climbing, crawling, jumping, peeking over ledges, etc.).
- **Comfort and Usability Issues:** Overview of the way our sensory systems respond to VR, techniques for improving comfort, and other usability issues.
- **Best Practices:** Specific locomotion techniques to improve comfort and usability.

DESIGN: VR LOCOMOTION TYPES

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.

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

DESIGN: ARTIFICIAL VR LOCOMOTION TYPES

Artificial locomotion in VR has multiple forms. Each form occurs either when there is user input or when the virtual environment acts on the user avatar:

- Avatar movements.
- Scripted movements.
- Steering movements.
- Environmental movements.
- Teleportation.
- World pulling.

See: developer.oculus.com/resources/artificial-locomotion

DESIGN: AVATAR MOVEMENTS

Avatar Movements: This artificial VR locomotion method consists in moving the avatar by using some combination of controller inputs (thumbstick, button, headset, motion controllers, or gameplay states, etc.).

This technique is used by most first-person videogames, and it is the most common VR locomotion method today.

See: developer.oculus.com/resources/artificial-locomotion

DESIGN: SCRIPTED MOVEMENTS

Scripted Movements: An artificial VR locomotion method to move the VR camera along a predefined path of motion. Sometimes, but not always, the orientation of the camera is part of this movement.

Scripted movements include: roller coasters, theme park rides, trains, and cinematic camera moves.

See: developer.oculus.com/resources/artificial-locomotion

DESIGN: STEERING MOVEMENTS

Steering Movements: An artificial VR locomotion technique to enable the user to control artificial motion that continues to move without continuous input (for example driving a car).

Typically, this kind of movement has inertia and momentum.

Unlike avatar movement, steering movement prevents immediate starts, stops, or changes in direction.

Examples include flight simulators and driving games.

See: developer.oculus.com/resources/artificial-locomotion

DESIGN: ENVIRONMENTAL MOVEMENTS

Environmental Movements: An artificial VR locomotion method consisting of movement as a byproduct of VR environment affecting the avatar.

Examples include:

- Falling off a ledge.
- Moving platforms or elevators.
- Explosion or other forces that move the player.
- Being pushed by a car.
- Being pushed by an NPC.
- Sinking into water.
- Etc.

See: developer.oculus.com/resources/artificial-locomotion

DESIGN: TELEPORTATION

Teleport: An event leading to a sudden change in the avatar pose (position and orientation).

Teleportation: An artificial VR locomotion technique using teleports (teleport pads, point-and-click teleporting) to move the avatar in the VR environment.

Unlike other types of movement, teleportation is not always a form of continuous movement. This can be helpful for people sensitive to the side effects of vection, since teleportation can prevent vection entirely.

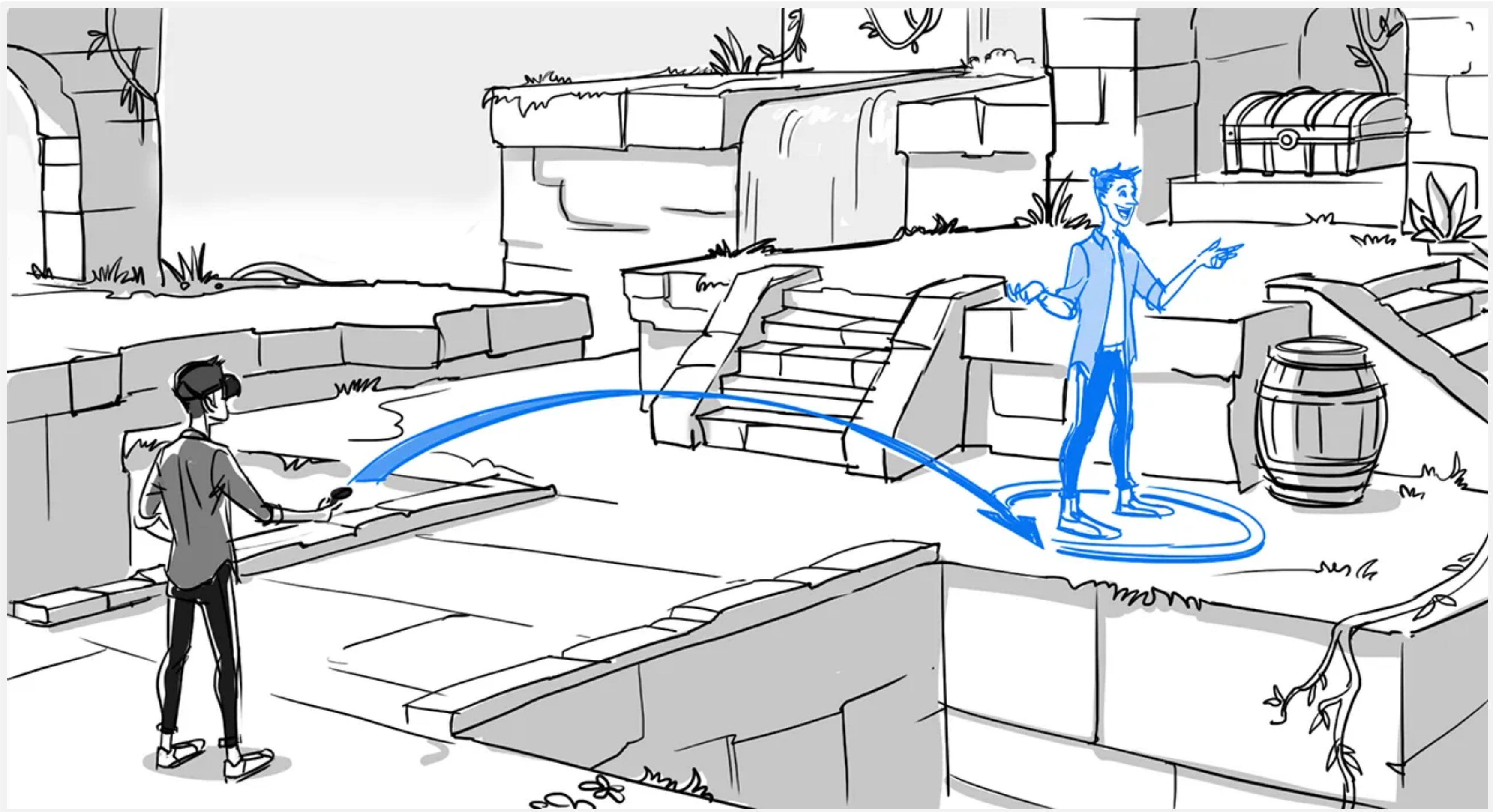
You can integrate teleportation into your design as:

- **Player-controlled teleports** (point-and-click, teleport pads).
- Action-based teleports (to dynamic locations, see *"Damaged Core"*).
- Game-logic-based teleports (narrative events).

See: developer.oculus.com/resources/artificial-locomotion

DESIGN: TELEPORTATION (2)

A point-and-click teleportation, with a different orientation at destination (disorientation).



See: developer.oculus.com/resources/locomotion-comfort-usability

DESIGN: WORLD PULLING

World Pulling: An artificial VR locomotion technique consisting on the user being stationary until they grab some anchor point in the VR world and pull or push it. This action shifts the perspective as the VR world moves to follow the push or pull motion.

Examples include: rock climbing, ladders, wall scaling, and zero-gravity movement (see: *"Lone Echo"*, *"The Climb"*, *"POPULATION: ONE"*, etc.).

See: developer.oculus.com/resources/artificial-locomotion

DESIGN: ARTIFICIAL VR LOCOMOTION CONTROLS

A VR user can use artificial VR locomotion by using some interfaces/inputs.
This section presents techniques to enable a VR user to control their artificial VR locomotion:

- Thumbstick-driven locomotion.
    - With direction mapping.
    - With turning controls.
- Teleport controls.
    - Thumbstick-triggered.
    - Button-triggered.
- Motion-tracked locomotion.
    - With simulated activities.
    - With pose-driven controls.
- **Seated mode considerations.**

See: developer.oculus.com/resources/artificial-locomotion-controls

DESIGN: THUMBSTICK-DRIVEN LOCOMOTION

Thumbstick-Driven VR Locomotion: Using the VR controller thumbsticks to control the artificial VR locomotion. This is usually more complicated than just moving the avatar in the direction of the stick. There are no standards to do this, however commonly-used design patterns include: direction mapping and turning controls.

Direction Mapping: Determining the direction the user moves based on how the thumbstick directions are mapped to directions in the virtual space. Directions in VR can be defined in multiple ways (controller/headset orientation), so usually this is a user setting. Some common types of direction mapping that you should support if possible include:

- Head-relative.
- Initial head-relative.
- Controller-relative.
- Initial controller-relative.

See: developer.oculus.com/resources/artificial-locomotion-controls

DESIGN: THUMBSTICK-DRIVEN LOCOMOTION (2)

Turning Controls: Controlling the VR camera/avatar rotation using the VR controller thumbstick. Three of the most common artificial turning control schemes are:

- Quick turns.
- Snap turns.
- Smooth turns.

Supporting artificial turning based on thumbstick input makes the **VR app more accessible** (users seating in non-spinning chairs, wheelchair users, tethered VR headsets, etc.).

To maximize usability and prevent motion sickness, the user should be able to easily anticipate how the camera will move in response to headset movements and controller inputs.

See: developer.oculus.com/resources/artificial-locomotion-controls

DESIGN: TELEPORT CONTROLS

The process of performing a teleport is a sequence of events that generally includes:

- Activating the teleport (optional).
- Aiming at the teleport destination (optional).
- Controlling the landing orientation (optional).
- Triggering the actual teleport (optional).

Usually teleports are triggered/activated by a button-click, but the design can be more complex including features ranging from destination selection to automatic triggering etc. The 2 most common methods to activate/trigger a teleport are:

- **Thumbstick-triggered teleports** are initiated moving the thumbstick. A beam allows the user to point at the destination. Teleport happens when thumbstick is released.
- **Button-triggered teleports** use a controller button to initiate. The thumbstick can be used for other purposes (control landing orientation, etc.).

See: developer.oculus.com/resources/artificial-locomotion-controls

DESIGN: MOTION-TRACKED LOCOMOTION

Use motion controllers to enable VR locomotion functionality without using VR controllers.

These motion-tracked locomotion techniques often consider posture, hand poses, and other physical movements as inputs for controlling movement.

These are just few examples:

- **Simulated activities** map the user physical movements to a real-world or imaginary activity, increasing immersion. For example: swimming-like movements, running-in-place, etc.
- **Pose-driven controls** use learned poses and abstract gestures to perform a movement. For example: point with one hand and initiate the movement with a gesture on the other hand, etc.

See: developer.oculus.com/resources/artificial-locomotion-controls

DESIGN: SEATED MODE CONSIDERATIONS

Supporting seated mode, when it is not part of the original design, means to simulate a standing VR experience while the VR user is seated. This makes the VR app more accessible and helps reduce fatigue in extended VR sessions (with the VR user standing).

Seated mode should include the following features:

- A **prompt** early in the VR experience to choose between seated and standing modes.
- A **VR avatar height** and camera height that default to a customizable player height.
- Support for **artificial turning** because VR users do not always use spinnable chairs.
- Controls to **toggle poses** (crouching, etc.) not possible in seated mode.

See: developer.oculus.com/resources/artificial-locomotion-controls

DESIGN: VR LOCOMOTION DESIGN CHALLENGES

Designing for **physical VR locomotion** can lead to VR environments with limited designs.

Supporting **artificial VR locomotion** solves this issue, but some environmental features (ladders, gaps, ledges, etc.) require special logic and planning.

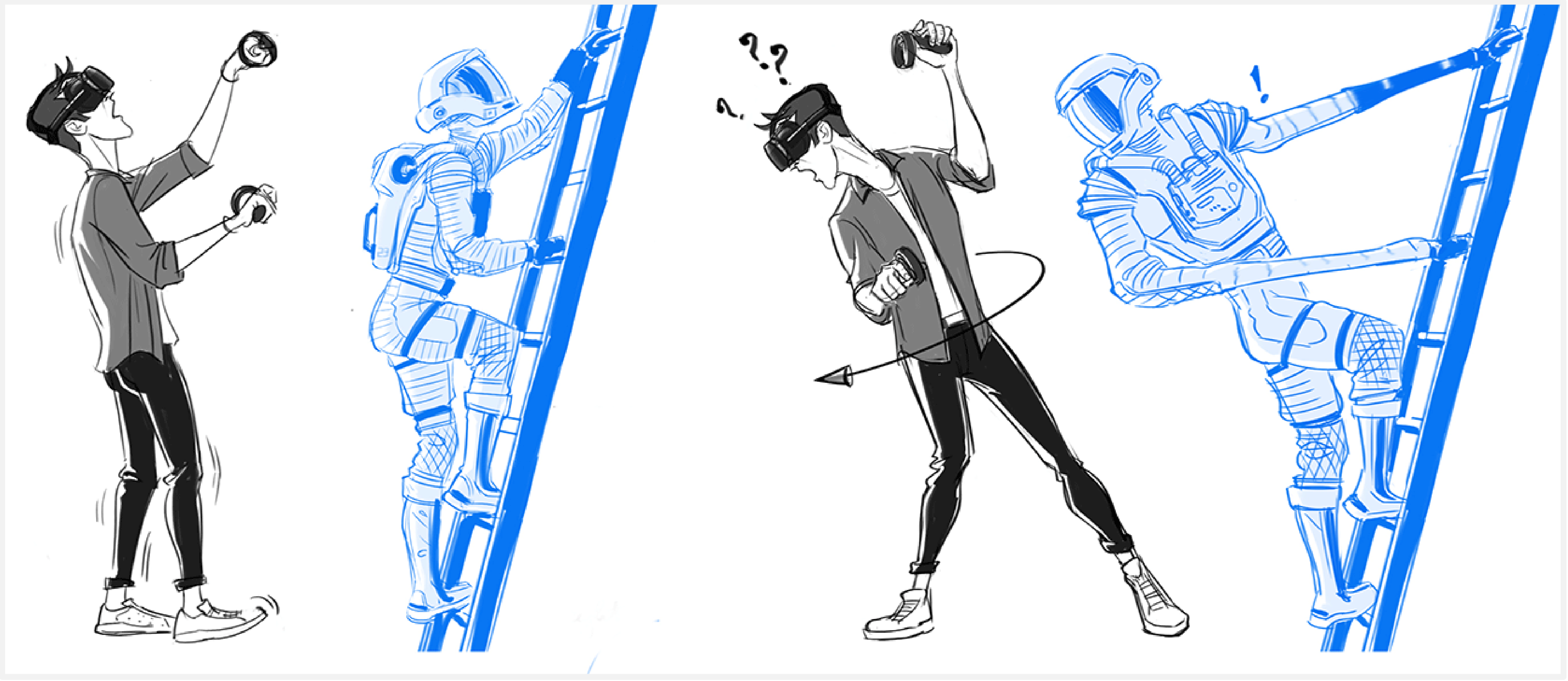
Design the VR environment so that it works with the VR locomotion system.

Every locomotion system has limitations, test the VR environment using every possible locomotion scenario the user could encounter (slopes, doorway dimensions, step heights, path obstructions, tunnels, ceilings of various heights, ledges, ladders, etc.).

See: developer.oculus.com/resources/locomotion-design-challenges

DESIGN: CLIMBING CHALLENGE

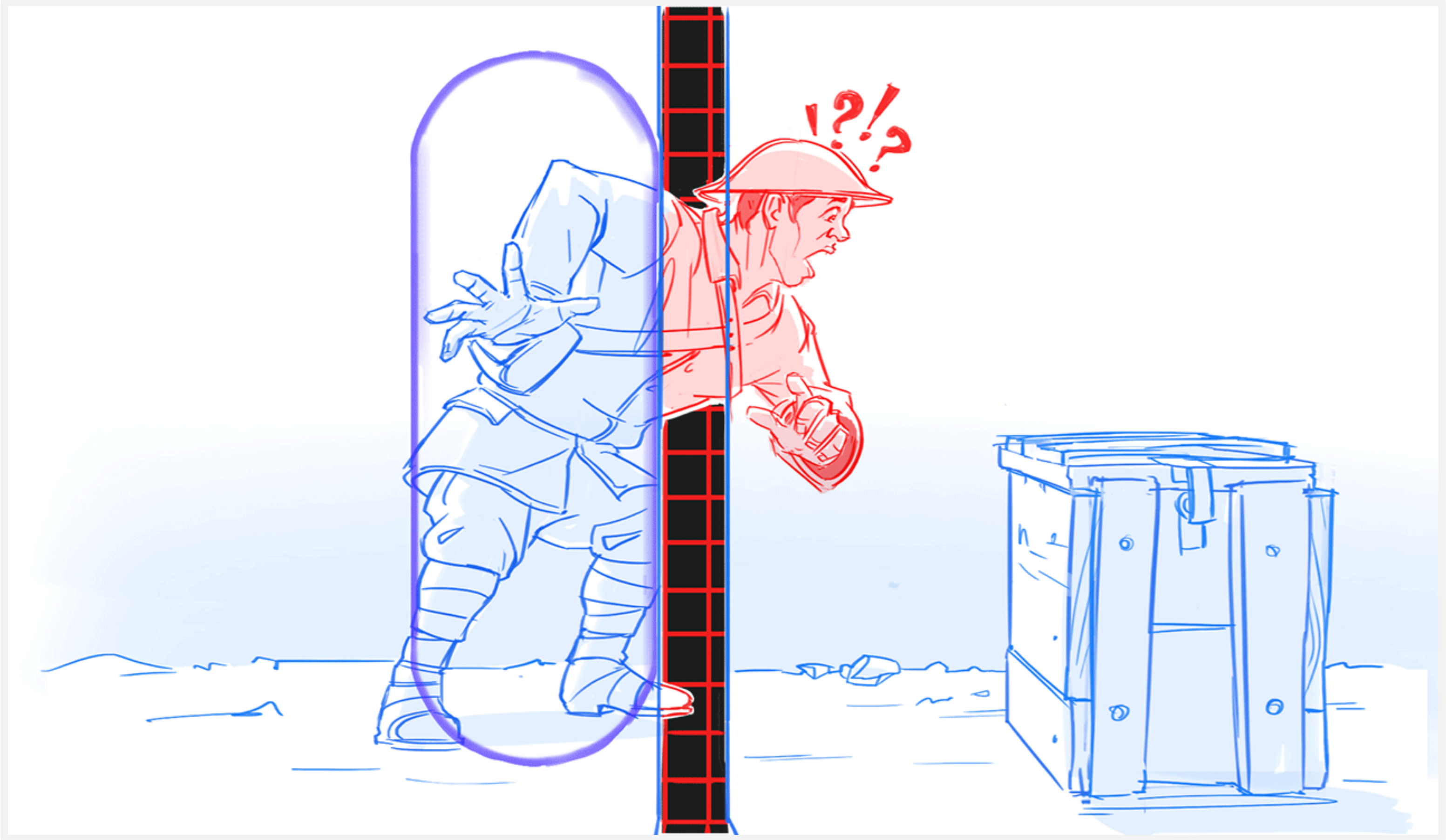
The VR avatar arms are still attached to the ladder (but are stretched) because the user has moved away during a climbing action, while keeping the grip buttons pressed.



See: developer.oculus.com/resources/locomotion-design-challenges

DESIGN: CAMERA COLLISIONS CHALLENGE

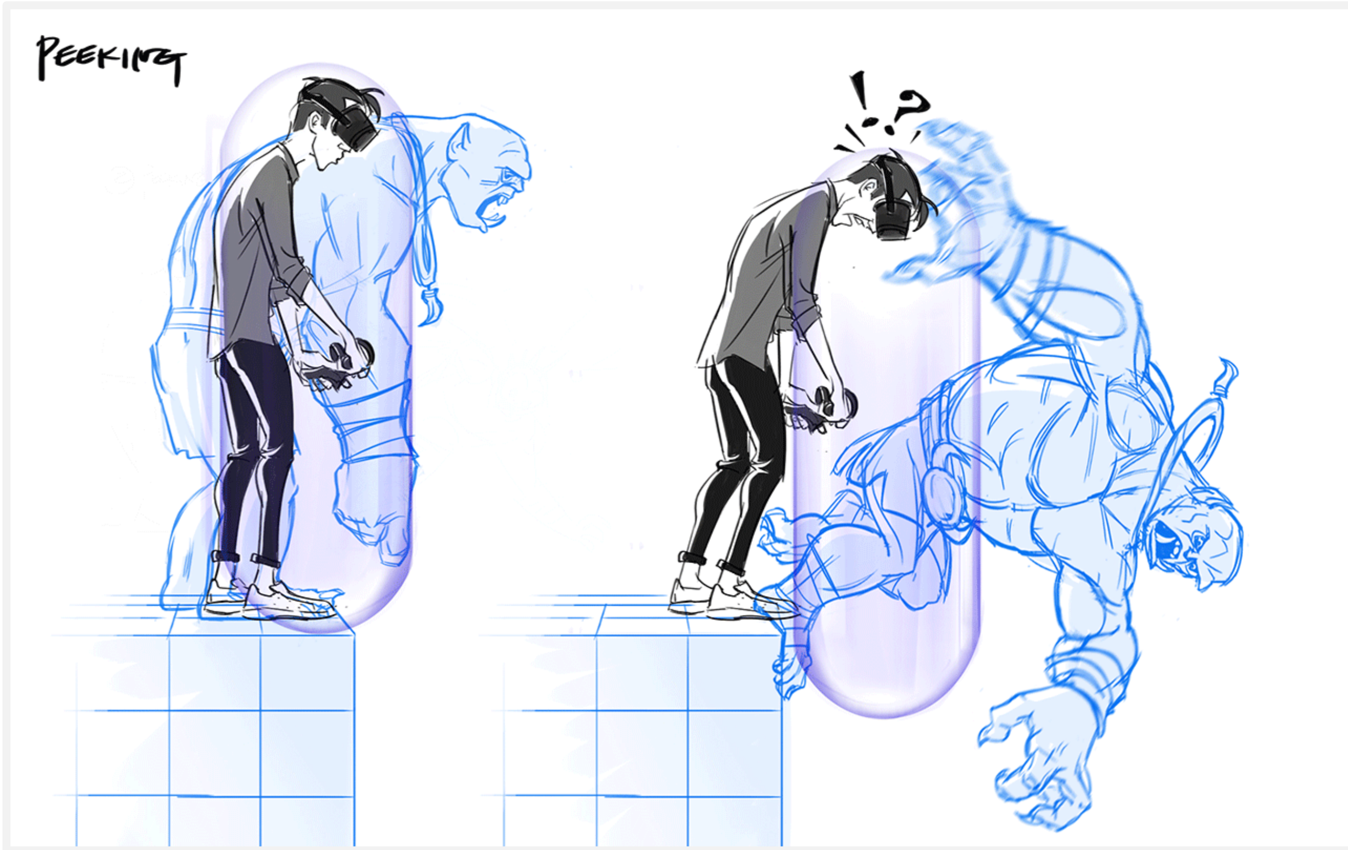
A VR locomotion system that does **not** prevent the camera from colliding with objects in the environment (walls, doors, etc.) allows the user to view inaccessible areas.



See: developer.oculus.com/resources/locomotion-design-challenges

DESIGN: PEEKING OVER CHALLENGE

The VR avatar movement usually follows the physical position of the VR headset; so, if the VR headset moves over the edge of a cliff, then the VR avatar might fall off the cliff by accident.



See: developer.oculus.com/resources/locomotion-design-challenges

DESIGN: HEIGHT ADJUSTMENT CHALLENGE

Depending on the VR environment, the VR avatar may need to shrink (vertically) in order to enable access to areas with low ceilings or to better approximate the VR user posture.

See: developer.oculus.com/resources/locomotion-design-challenges

DESIGN: TELEPORT DISORIENTATION CHALLENGE

Teleports have side effects: are difficult for an observer to follow (causing disorientation), and problematic for NPCs trying to reach the player (causing NPC code to fail).

See: developer.oculus.com/resources/locomotion-design-challenges

PART 4: VR SW DEVELOPMENT IN UNITY

"Unity is so much more than the world's best real-time development platform – it's also a robust ecosystem designed to enable your success. Join our dynamic community of creators so you can tap into what you need to achieve your vision."

UNITY TECHNOLOGIES

Applicazion Fields: videogames, architecture, automotive, movies, XR, etc.

"Create once, deploy across 25+ leading platforms and technologies to reach the largest possible audience."

UNITY TECHNOLOGIES

See: unity.com

REFERENCES

- These slides are available online at: github.com/turinig/vrphd
- Unity website: unity.com
- *“VR Locomotion Design Guide”* developer.oculus.com/resources/bp-locomotion
- *“Which One Is The Best?: VR Locomotion Solutions”*
- *"VR Locomotion Control Techniques"*