Interaction and Virtual Environments

Developing Immersive Applications

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Learning Objectives:

- differentiate model-based vs image-based methods for creating virtual environments
- describe interaction mechanics in immersive environments
- explain how hardware enables different interaction mechanics
- understand the concept of embodiment and how it relates to immersion
- apply authenticity and interaction-design principles to immersive use cases

Creating Virtual Environments

Two fundamental approaches to constructing a VE:

Model-Based:

- Build 3D geometry (meshes, materials, lighting) from scratch or from assets
- Full 6-DOF exploration and interaction with objects
- Higher development effort, but supports dynamic, interactive scenes

Image-Based:

- Use captured images (360-degree photos, photospheres, light fields)
- Faster to produce from real-world scenes
- Limited to fixed viewpoints (3-DOF); less interactive

Choosing the Right Approach

Criterion	Model-Based	Image-Based
Exploration freedom	Full 6-DOF	Fixed viewpoints (3-DOF)
Object interaction	Rich (grab, manipulate)	Limited (point-and-click)
Visual realism	Depends on asset quality	Photorealistic capture
Production time	Longer (modelling needed)	Shorter (capture and stitch)
Hardware needed	3D modelling tools	360-degree camera
Best for	Training, games, simulations	Virtual tours, real-world showcase

Hybrid approaches combine captured environments with selective interactive model-based elements.

Image-Based: 360-Degree Video

360-degree capture enables rapid creation of photorealistic VEs from real-world scenes.

Key Characteristics:

- Captured using omnidirectional cameras
- Provides 3-DOF viewing (rotate, no translate)
- Ideal for virtual tours, documentaries, and education
- Can be enriched with interactive hotspots

Trade-off:
Fast production, photorealistic, but limited interactivity compared to model-based approaches.

Example 360-video lecture for SIT SE Module

Video: `https://youtu.be/2kKcFqSI-Ig`

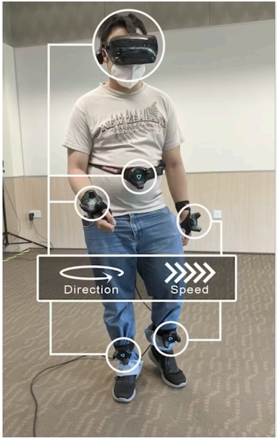
Interaction in Immersive Environments

Interaction is how users communicate intent and receive system feedback.

Key Interaction Modalities in XR:

- **Gaze-based**: user looks at targets to select
- **Controller-based**: buttons, triggers, thumbsticks
- **Hand tracking**: bare-hand gestures, pinch, grab
- **Raycasting**: virtual laser pointer for distant selection

Full-body interaction appears in specialized setups with additional trackers.



Authenticity in Interaction

Interactions classified by how closely they mirror real-world actions:

Natural Interaction

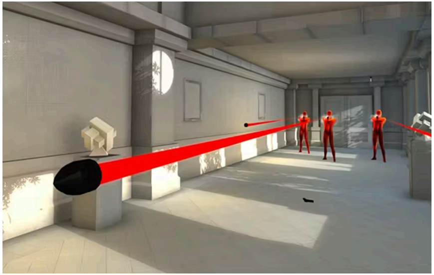
- 1:1 mapping of physical action to virtual effect
- E.g., physically walking, reaching out to grab

Augmented Natural Interaction

- Real physical action with enhanced virtual effect
- E.g., walk-in-place on a slidemill

Artificial (Magical) Interaction

- No real-world analogue; entirely virtual mechanic
- E.g., teleportation, time manipulation in SUPERHOT VR



Source: superhotgame.com

Implicit vs Explicit Interaction

Implicit (passive)

Triggered by the user's natural presence — no deliberate input required.

- Gaze direction activates UI elements
- Proximity triggers scene events
- Body movement drives animation

Explicit (active)

User deliberately initiates the interaction.

- Button press or grip to pick up
- Thumbstick or gesture to move
- Voice command to select

Design implication: Implicit interactions feel more natural and authentic; explicit interactions give users clarity and control.

	Implicit	Explicit
Input	Presence	Deliberate act
Feels	Natural	Controlled
Effort	Low	Higher
Authenticity	High	Variable

Embodiment in VR

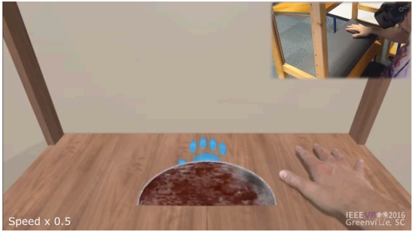
Embodiment is the sense of ownership and agency over a virtual body.

Factors that increase embodiment:

- **Visual appearance**: realistic hand/body representation
- **Visuomotor synchrony**: virtual body moves in sync with physical body
- **First-person perspective**: view from the avatar's position

Why it matters:

- Higher embodiment increases presence and emotional engagement
- Users avoid virtual hazards (e.g., routing hands around a virtual saw blade)
- Partial embodiment (hands only) can still be effective



Video: youtu.be/oE1XanOoRvw

Hardware Enabling Interaction

Different hardware capabilities enable different interaction modalities:

Hardware Feature	Interaction Enabled	Example
Hand tracking (skeletal)	Direct manipulation, pinch	Quest 3 hand tracking
Motion controllers	Button, trigger, thumbstick	Quest Touch controllers
Eye tracking	Gaze selection, foveated input	Quest Pro, Vive Pro Eye
Room-scale tracking	Physical locomotion	Lighthouse, Inside-out
Haptic gloves	Tactile feedback for grabs	SenseGlove, HaptX
Body trackers	Full-body input	Vive Trackers, KatVR

The choice of hardware constrains and enables the interaction design space.

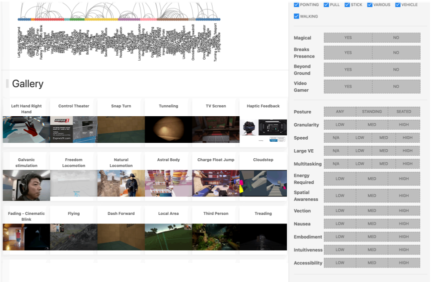
Locomotion in VR

How users move through virtual spaces is a fundamental design challenge.

Five Key Approaches:

- **(1) Teleportation**: point and jump to a target
- **(2) Joystick (continuous)**: smooth thumbstick gliding
- **(3) IMU-based WIP**: walk-in-place using body trackers
- **(4) Real walking**: physical room-scale movement
- **(5) 360 treadmills**: slidemill/omnidirectional WIP

Each approach balances comfort, presence, and hardware requirements differently.



Locomotion Vault: catalog of VR locomotion techniques

Source: `https://locomotionvault.github.io`

Locomotion: Pros and Cons

Approach	Pros	Cons
Teleportation	No motion sickness; simple to implement	Breaks spatial continuity and presence; jarring transitions
Joystick (continuous)	Intuitive for gamers; smooth traversal	High motion sickness risk from sensory mismatch
IMU-based WIP	Authentic walking motion; physically engaging	Requires extra hardware (body trackers); still WIP technology
Real walking	Most natural; best presence and comfort	Limited to room-scale physical space
360 treadmills	Room-scale walking in large virtual spaces	Expensive hardware; still WIP technology

The best locomotion method depends on the application's goals: realism (training), comfort (accessibility), or engagement (games).

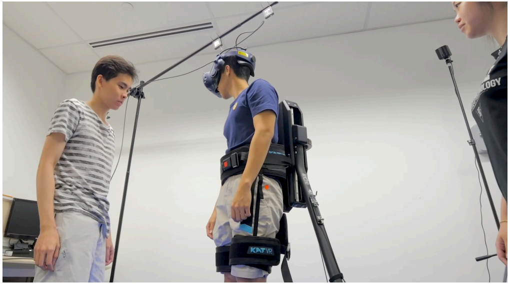
360 Treadmills: Bridging the Gap

Omnidirectional treadmills (slidemills) enable natural walking input mapped to large virtual spaces.

How they work:

- Low-friction concave surface
- User wears special shoes; harness keeps them centered
- Foot sliding motion mapped to virtual locomotion

Trade-off:
Combines presence of real walking with unlimited virtual distance, but requires dedicated hardware and space.



KatVR omnidirectional slidemill

Project: https://www.immersification.org/projects/2018/11/08/vrmt.html

Locomotion: Comfort Considerations

Cybersickness from locomotion is primarily caused by **sensory mismatch**: visual motion without corresponding vestibular (inner ear) input.

Design strategies to reduce discomfort:

- Use teleportation or snap turns instead of smooth rotation
- Add a vignette (tunnel vision effect) during continuous movement
- Provide a stable visual reference (e.g., a virtual nose or cockpit frame)
- Allow user control over movement speed and turning rate
- Let users choose their preferred locomotion method

The best locomotion method depends on the application's goals: realism (training), comfort (accessibility), or engagement (games).

Pattern 1: Behaviours

Fastest path for standard drag/grab interactions. Reusable, attach-to-mesh patterns.

```
// Attach drag behavior to any mesh
const dragBehavior = new SixDofDragBehavior();
dragBehavior.rotateWithMotionController = false;
mesh.addBehavior(dragBehavior);
// Also: PointerDragBehavior, FollowBehavior
```

When to use: You need standard grab, drag, or follow behaviour with minimal code.

Docs: BabylonJS Mesh Behaviors

Pattern 2: Actions (ActionManager)

Clean discrete event mapping. Trigger responses on pick, intersect, or keyboard input.

```
mesh.actionManager = new ActionManager(scene);
mesh.actionManager.registerAction(
new ExecuteCodeAction(
ActionManager.OnPickTrigger,
() => { console.log("Object clicked!"); }
)
);
```

When to use: You need a simple click, hover, or intersection handler on an object.

Docs: BabylonJS Actions

Pattern 3: Observables

Fully customizable continuous frame logic. Observer pattern for per-frame monitoring.

```
scene.onBeforeRenderObservable.add(() => {
const dist = Vector3.Distance(
player.position, target.position
);
if (dist < 2.0) { triggerProximityEvent(); }
});
```

When to use: You need custom continuous tracking, distance checks, or per-frame logic that no built-in pattern covers.

Docs: BabylonJS Observables

Implementing Teleportation in WebXR

BabylonJS provides a built-in teleportation feature for WebXR:

```
const teleportation = featureManager.enableFeature(
WebXRFeatureName.TELEPORTATION, "stable", {
xrInput: xr.input,
floorMeshes: [ground],
timeToTeleport: 2000,
useMainComponentOnly: true,
}, true, true
);
teleportation.parabolicRayEnabled = true;
```

Key parameter: `timeToTeleport` sets the hold duration (ms) before teleportation triggers.

GUI Design in Immersive Environments

GUI in VR/AR requires different approaches than traditional 2D interfaces:

Approaches:

- **World-anchored UI**: panels placed in 3D scene; feels natural and spatially grounded
- **Head-locked HUD**: UI follows viewpoint; always visible but can cause discomfort
- **Diegetic UI**: exists within the game world; most immersive (e.g., virtual clipboard, wrist display)

BabylonJS: `GUI3DManager` and `AdvancedDynamicTexture`

Video: `https://youtu.be/8gDKu2iyD2g`

Case Study: VR Bioreactor Training

When designing interactions for an immersive application, consider:

1. **User's goal?** Training fidelity, entertainment, exploration
2. **Hardware available?** Controllers, hand tracking, room-scale
3. **Natural-artificial spectrum?** Natural for training; magical for games
4. **Comfort budget?** Duration, experience level, motion tolerance
5. **Maintain plausibility?** Consistent responses, even if artificial

This VR bioreactor project applies authentic interaction for lab training.

VR Bioreactor training application

Video: `https://youtu.be/zMEs2bhJOMI`
Project: immersification.org/.../vrbioreactor

Summary

Today we covered:

- Model-based vs image-based approaches to creating virtual environments
- Interaction modalities: gaze, controller, hand tracking, full-body
- The natural-artificial interaction spectrum
- Embodiment and its role in immersion
- Authenticity and plausibility as design principles
- Locomotion techniques and comfort trade-offs
- BabylonJS interaction patterns: behaviours, actions, observables

Next: WEEK10 begins industry-led sessions with our Associate Faculty.

Further Reading

Interaction Theory:

- Marco Gillies: SUPERHOT and the Magic of Interaction
- Slater (2009): Place Illusion and Plausibility

Locomotion Resources:

- Locomotion Vault: catalog of VR locomotion techniques
- Centre for Immersification: VR locomotion methods

Embodiment Research:

- Siju Philip: Partial embodiment with hands in VR
- Disco-VR: Review of haptic gloves

See WEEK09 pre-class material for complete list