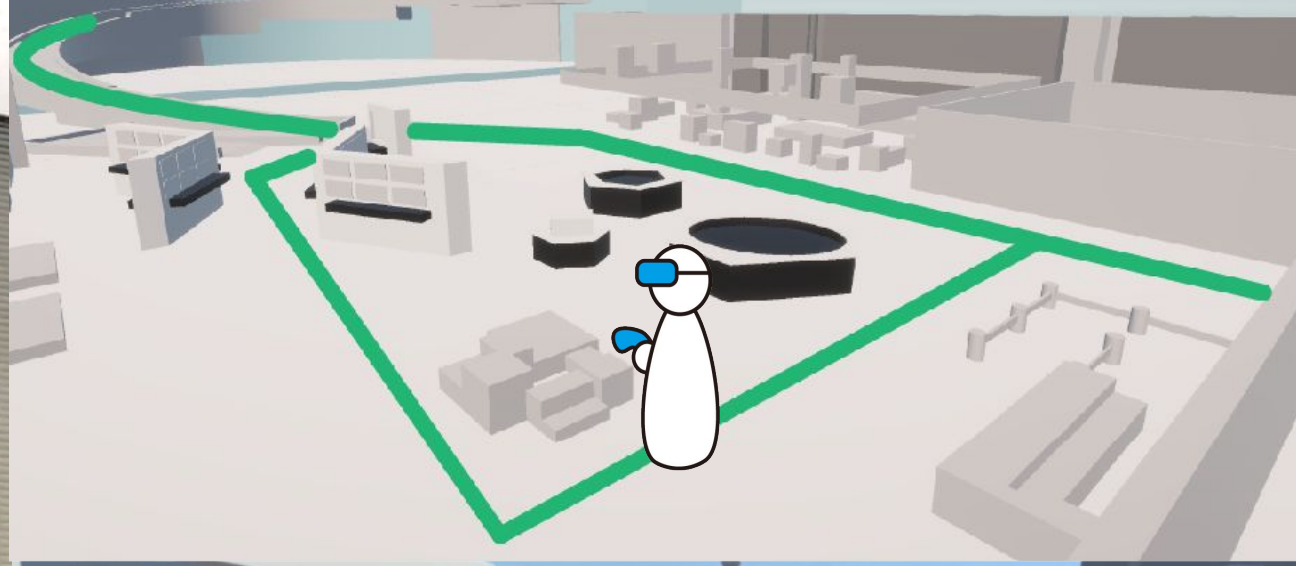
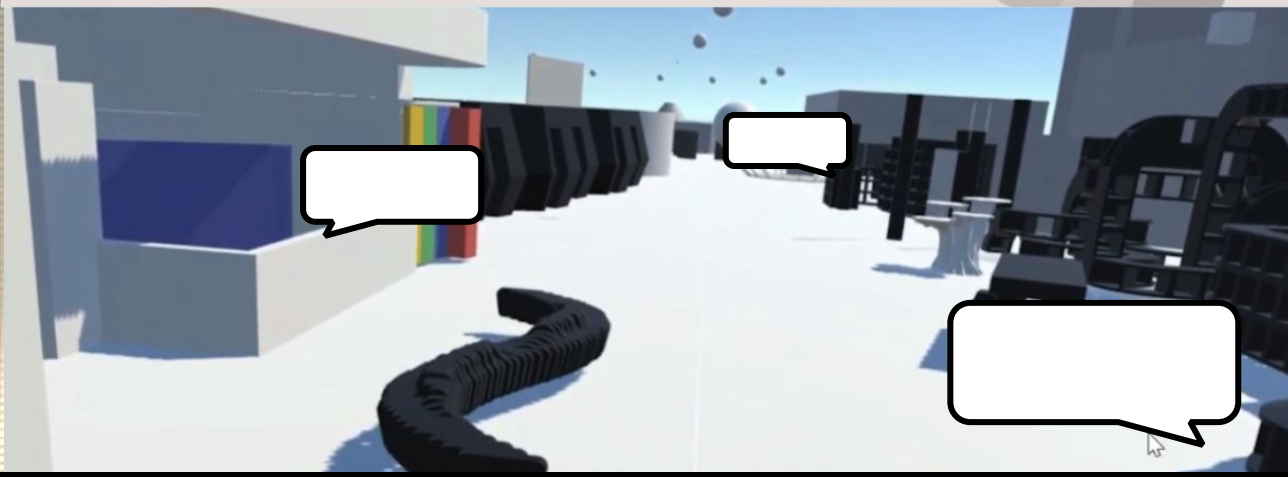






Virtual Exploration for Blind People to Perceive Geometric and Spatial Features

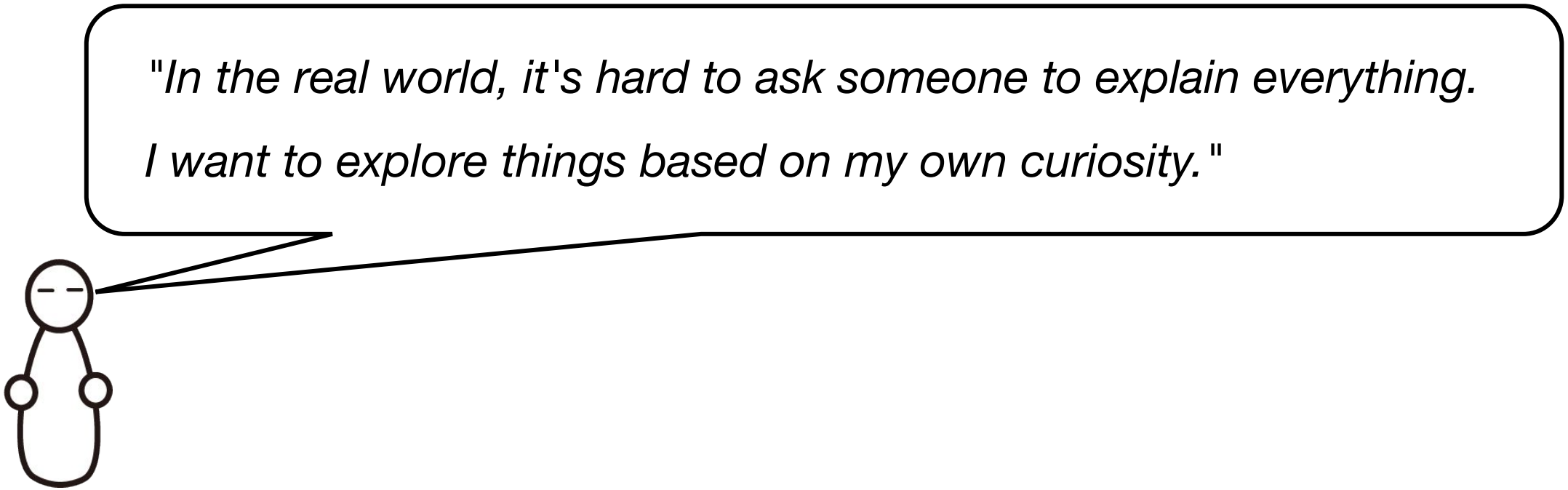
Masaya Kubota[1], Masaki Kuribayashi*,[1], Renato Alexandre Ribeiro*,[2], Shigeo Morishima[1]

*Authors contributed equally, 1.Waseda University, 2. Miraikan - The National Museum of Emerging Science and Innovation

Miraikan Accessibility Lab.

Blind People Have a Strong Desire to Explore Unfamiliar Places[1]

Comprehensive **exploration without sight remains challenging.**

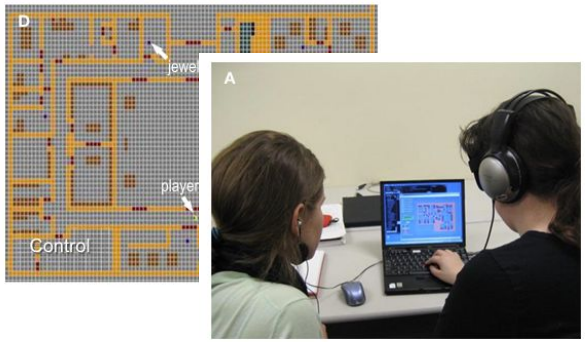


[1] Müller et al. "Traveling More Independently: A Study on the Diverse Needs and Challenges of People with Visual or Mobility Impairments in Unfamiliar Indoor Environments"

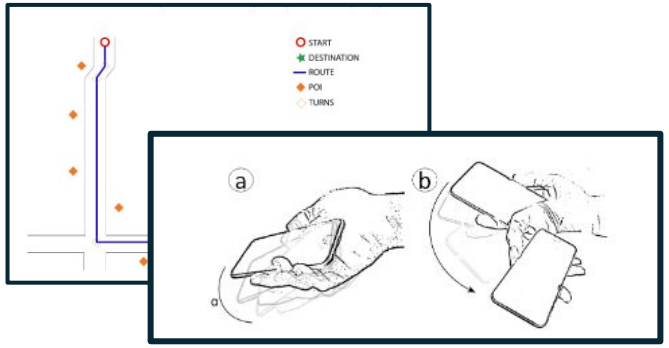
Virtual Pre-Exploation Before a Real Visit

Prior work use VR for safe, repeatable pre-exploration and mobility training.

Audio-Based Video Game[2] (Connors et al., 2014)



Smartphone-Based Navigation[3] (Guerreiro et al., 2017)



Headset-Based VR with a White Cane[4] (Thevin et al., 2020)



[2] Connors et al. "Virtual Environments for the Transfer of Navigation Skills in the Blind: a Comparison of Directed Instruction Vs. Video Game Based Learning Approaches "
[3] Guerreiro et al. "Virtual Navigation for Blind People: Building Sequential Representations of the Real-World"
[4] Thevin et al. "X-Road: Virtual Reality Glasses for Orientation and Mobility Training of People with Visual Impairments"

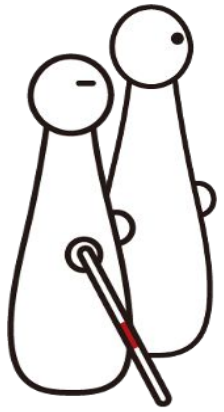
Why Focus on Route Geometry and Spatial Features?

They seek **routes, shape of spaces, and object arrangement**[5].

We focus on the two aspects for understanding complex virtual environments.

Geometric Route Structure

Does this hallway go straight?



Spatial Features

What's along this hallway?

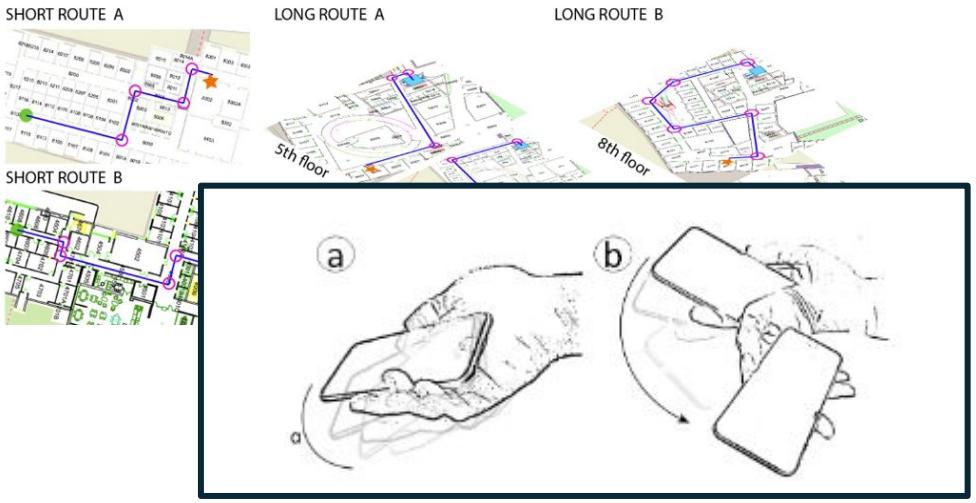
[5] Jain et al. "I Want to Figure Things Out": Supporting Exploration in Navigation for People with Visual Impairments

Prior Work 1: Geometric Route Perception in VR

Supports virtual route learning through spatial audio and guided locomotion[2,5].

However, they **focus on simplified layouts** with a small number of turns.

Smartphone-based Virtual Navigation[3]



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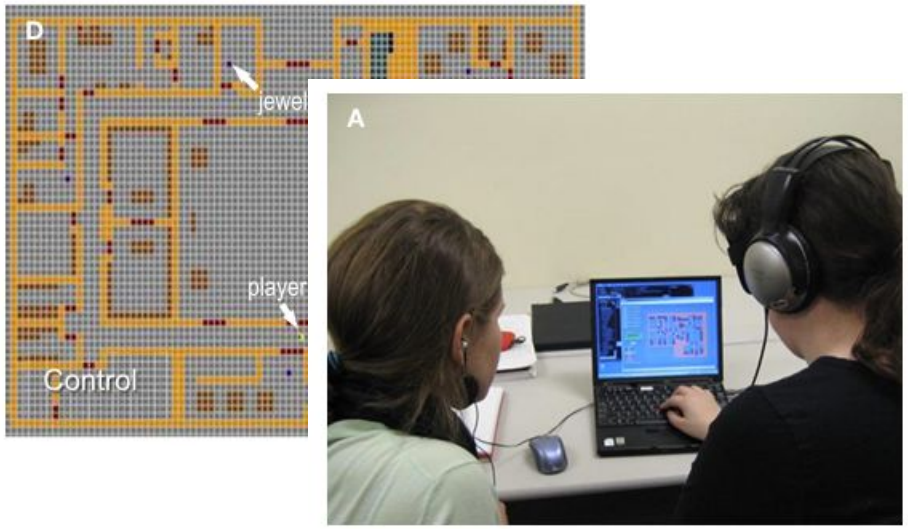
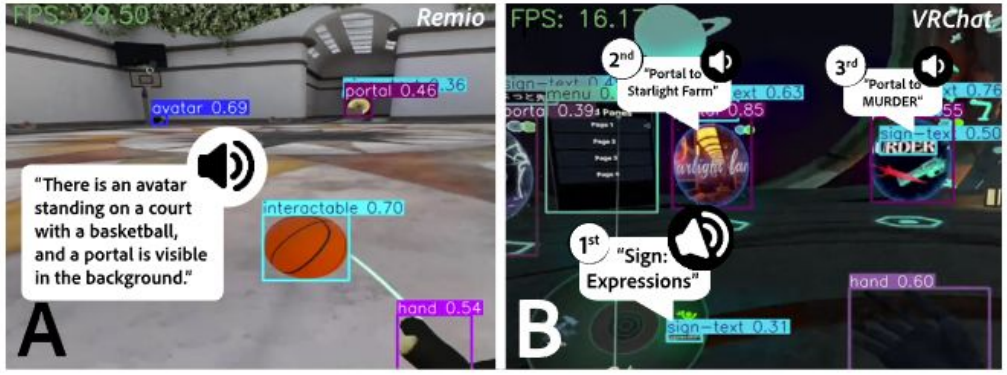


Prior Work 2: Spatial Feature Perception for Exploration

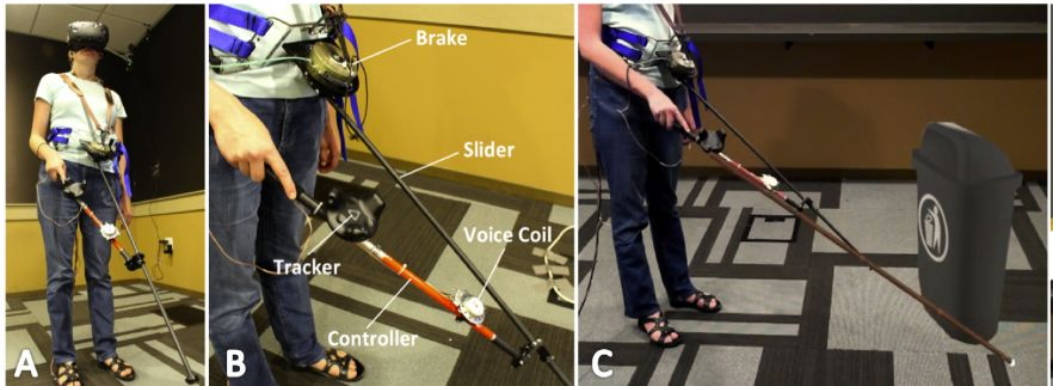
Explore multimodal techniques to convey nearby objects and scene contexts.

These systems help blind users **find out what is around them** in VR.

AI Description[6]



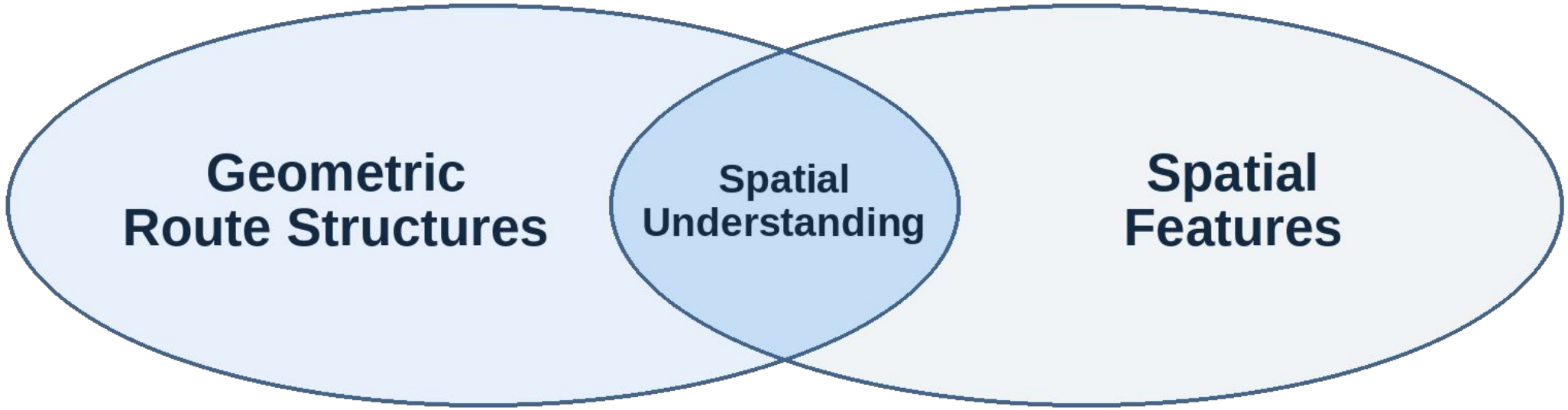
Virtual Cane System[7]



[6] Killough et al. "VRSight: An AI-Driven Scene Description System to Improve Virtual Reality Accessibility for Blind People"
[7] Zhao et al. "Enabling People with Visual Impairments to Navigate Virtual Reality with a Haptic and Auditory Cane Simulation"

Research Questions

It remains unknown how blind users perceive spatial features and combine multiple interaction methods in complex environments.



Our Research Vision

What if blind users could explore a large, complex place like this in VR, with many objects to discover and routes with multiple turns?



Research Questions

RQ1:
To what extent can blind users perceive **geometric route structures** in complex virtual environments?

RQ2:
To what extent can blind users perceive **spatial features** in complex virtual environments using multiple interaction methods?

RQ3:
How do blind users **use and combine interaction methods** during exploration of complex virtual environments?

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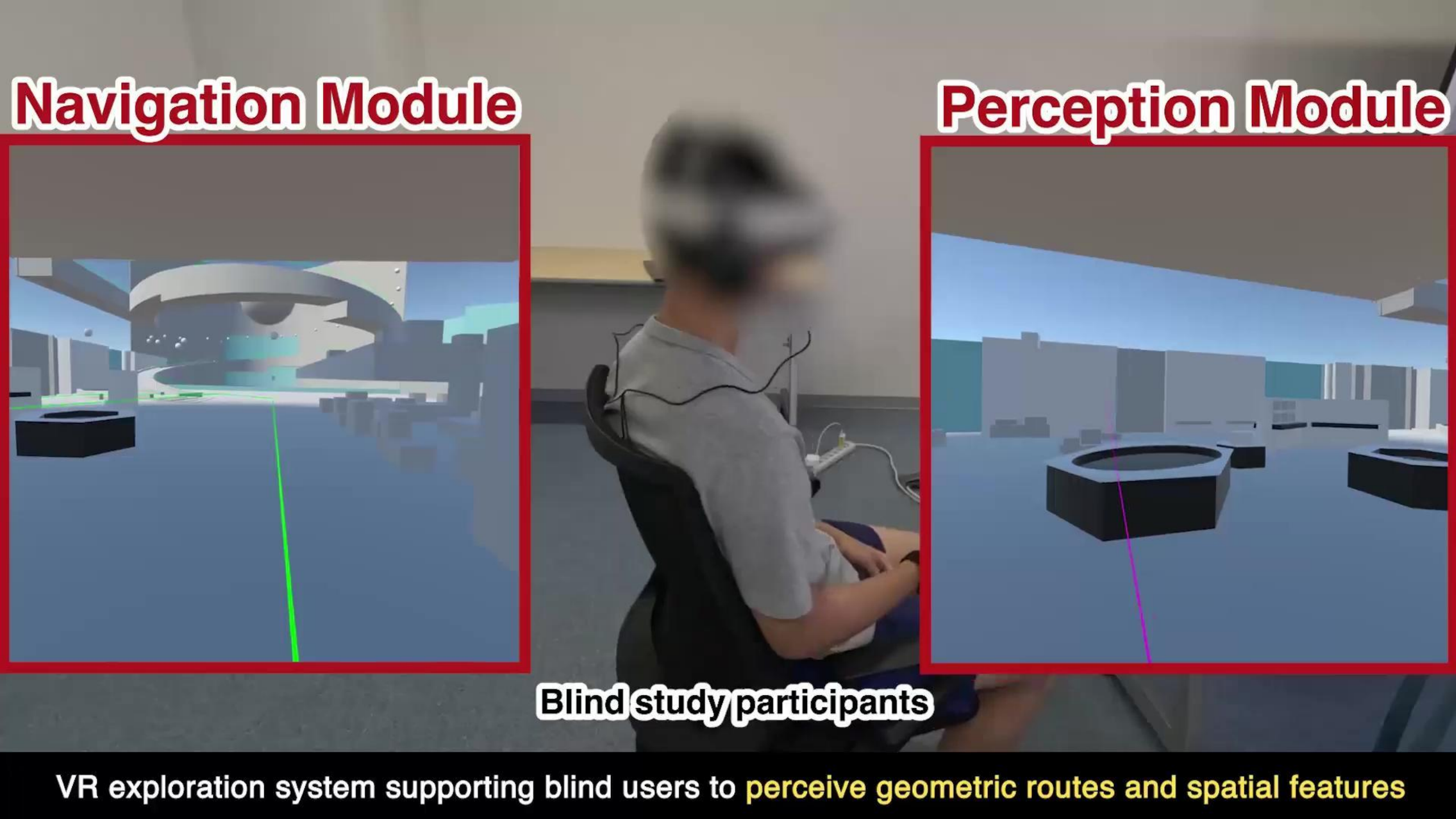


VR exploration system supporting blind users to perceive geometric routes and spatial features

Why HMD-Based VR for Blind Exploration?

HMD-based VR can Use and Convey

- Head orientation
- Controller-based interaction
- Spatial audio
- Haptic feedback





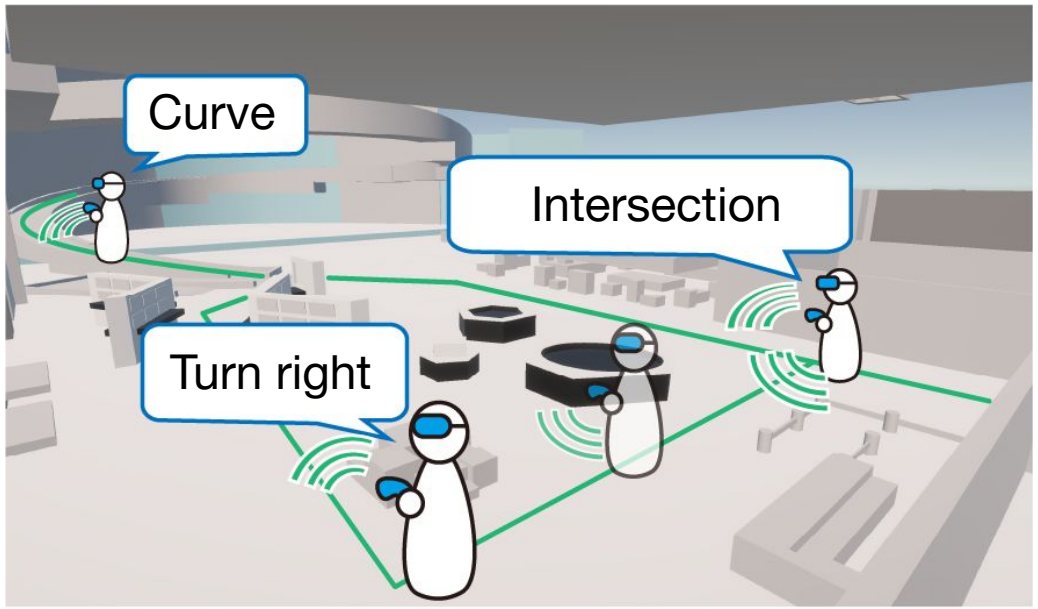
Users can

- Orient themselves for non-visual spatial understanding
- Use embodied interaction (e.g., pointing) for understanding spatial & geometric feature

System Overview

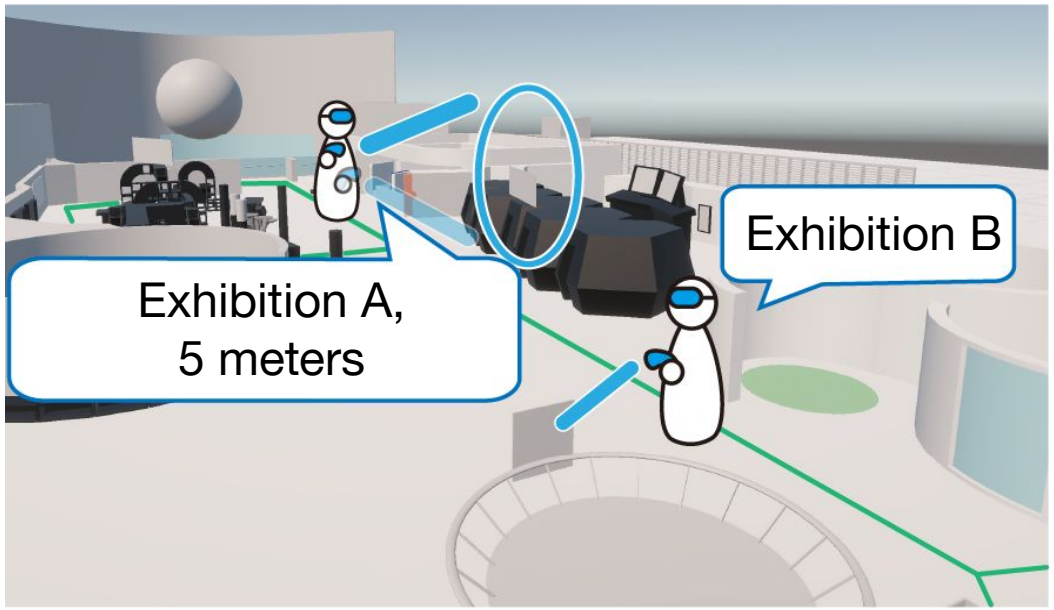
Navigation Module

Guide navigable directions
via spatial audio and haptics



Perception Module

Provide surrounding object and
scene information via 4 modes



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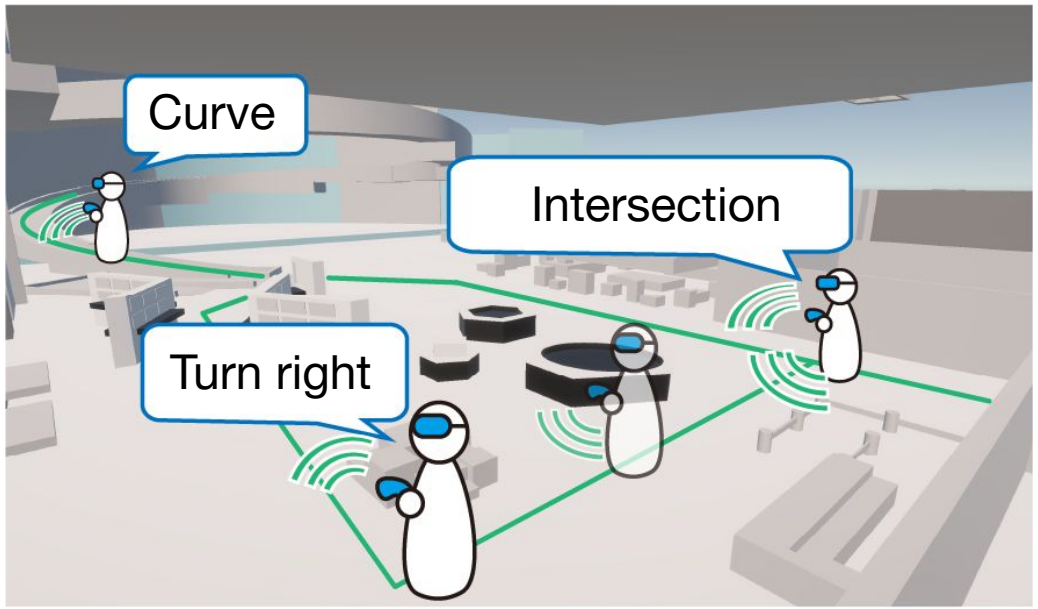


Perception Module

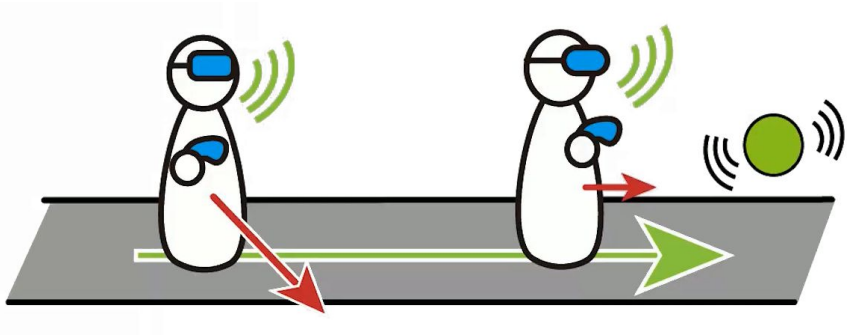
Provide surrounding object and
scene information via 4 modes

Navigation Module: Multimodal Path Guidance

Guides blind users along pre-mapped routes by coordinating spatial audio and directional haptic feedback

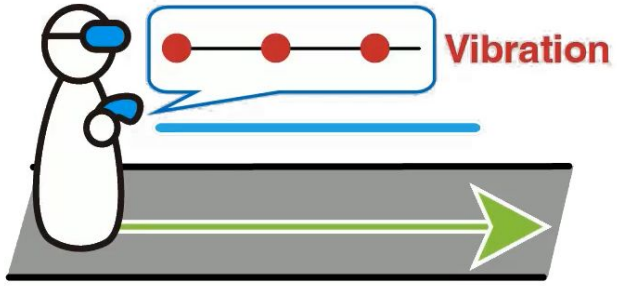
Spatial Audio

Indicates both direction and distance.

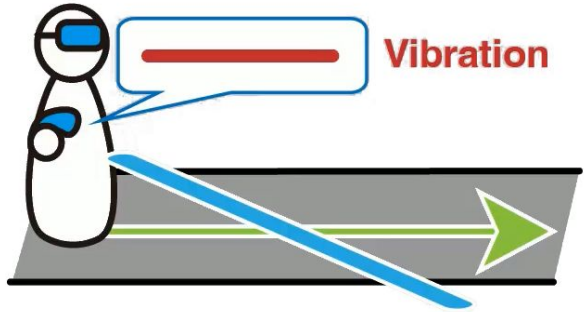


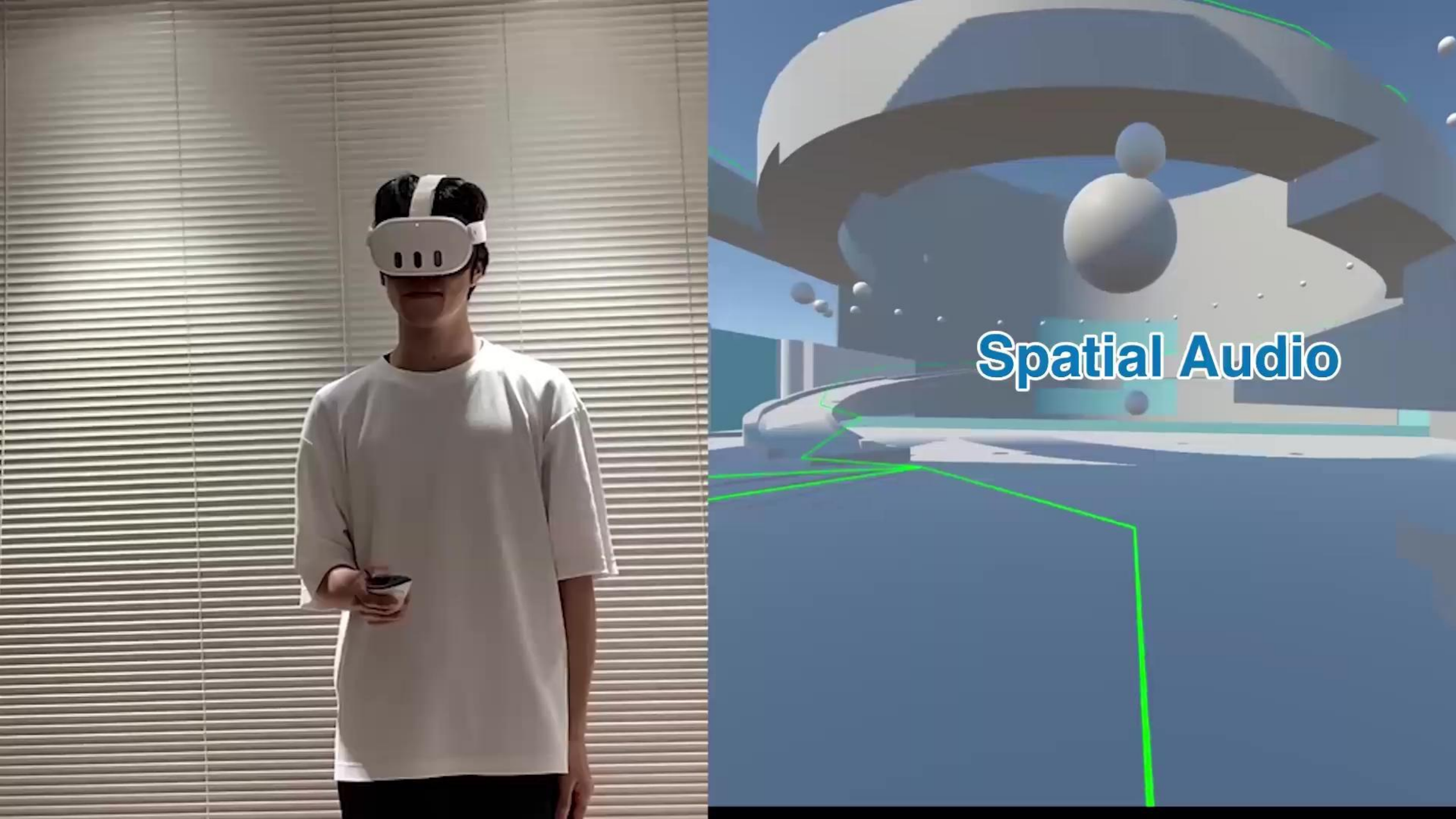
Haptic Feedback

navigable direction → brief pulse vibration



non-navigable direction → continuous vibration



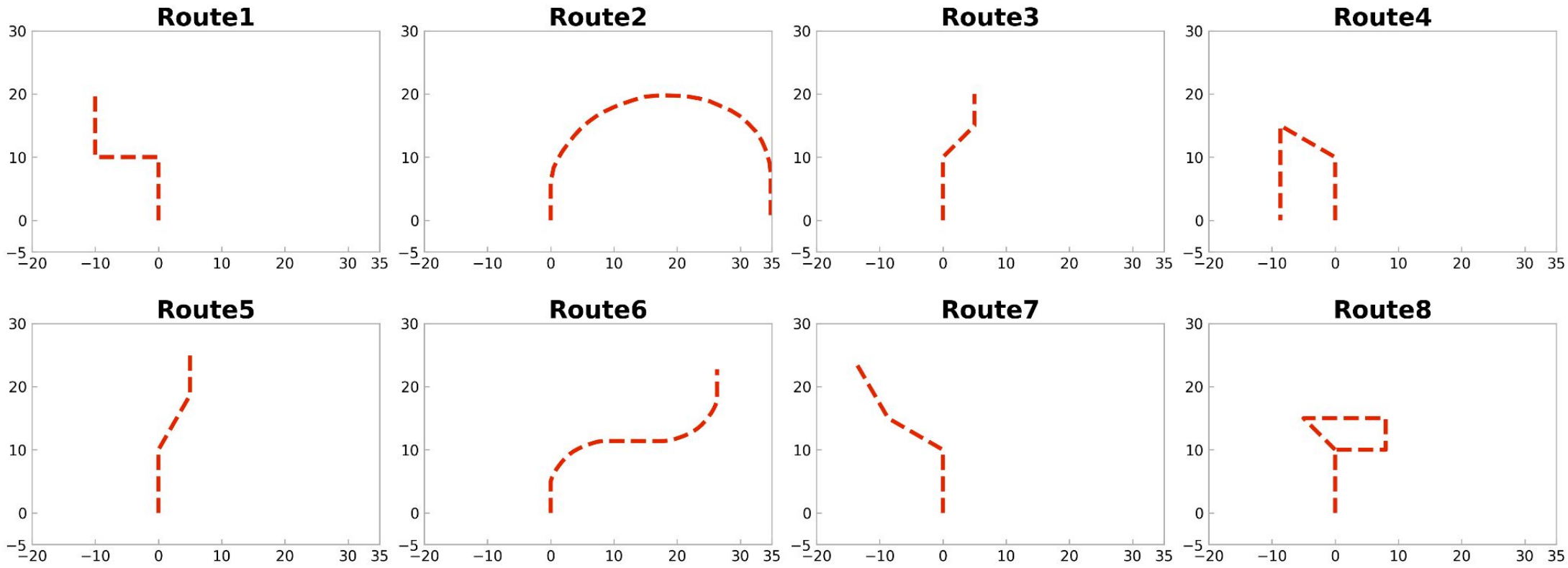

Spatial Audio


User Study with 6 Blind Participants

User Study of Navigation Module (N = 6)

RQ1: To what extent can blind users perceive geometric route structures?

Environment: 8 Ground-Truth Routes (Including straight lines, turns, and curves)



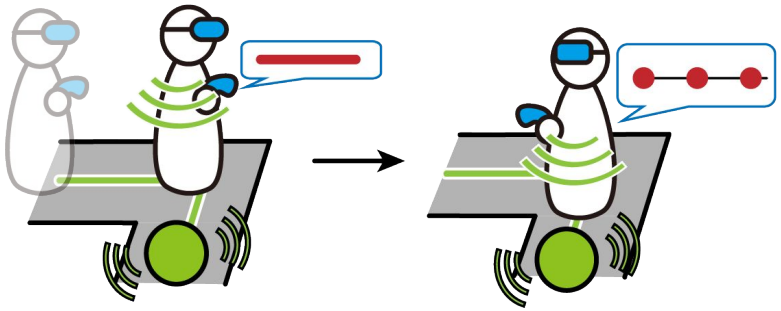
User Study of Navigation Module (N = 6)

RQ1: To what extent can blind users perceive geometric route structures?

Task: Repeat Guided Navigation and Reconstruction

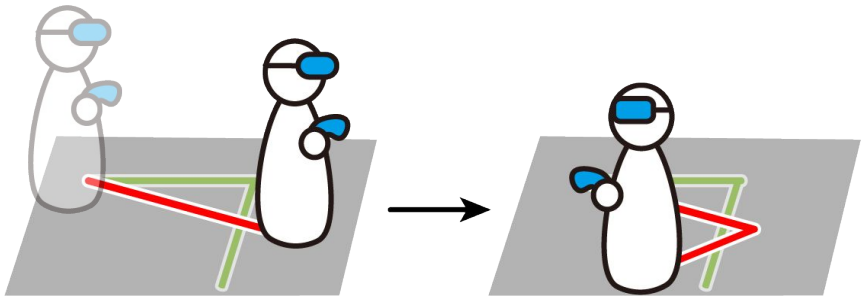
Guided Navigation

Follow a pre-mapped route with System's multimodal feedback

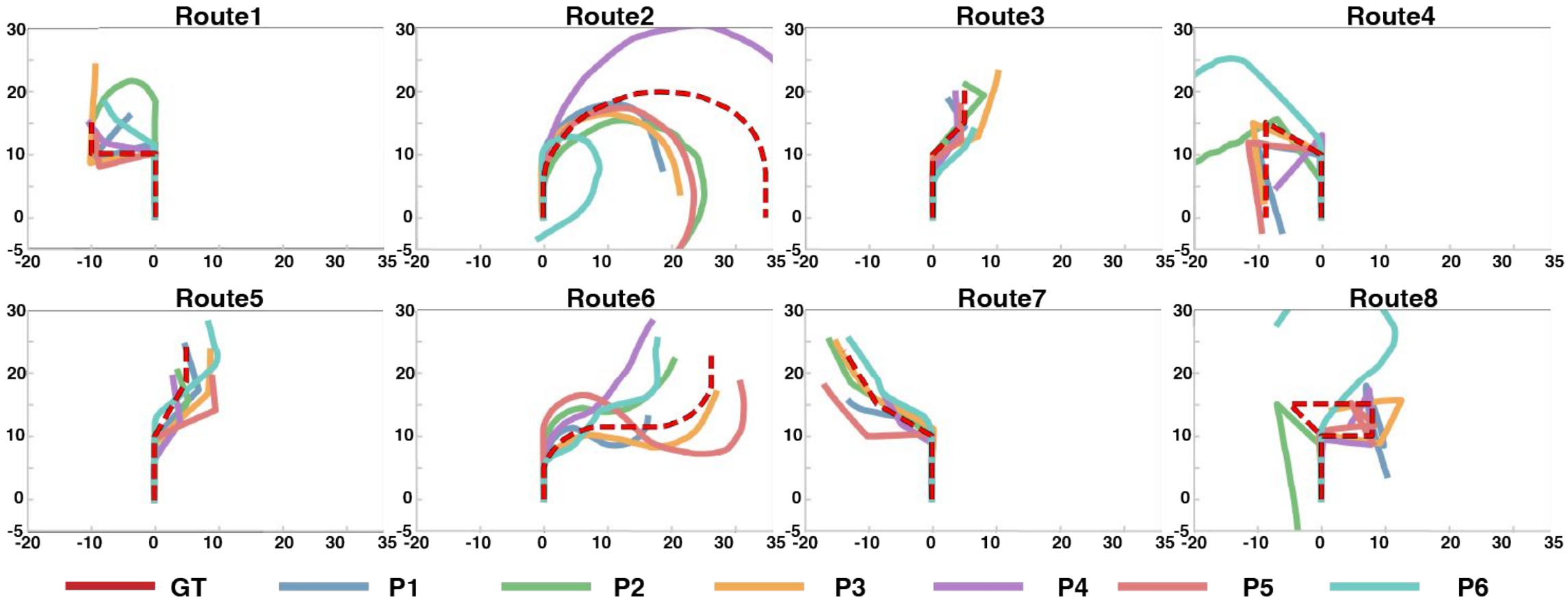


Reconstruction

Reproduce the route from memory in an open virtual space without system guidance



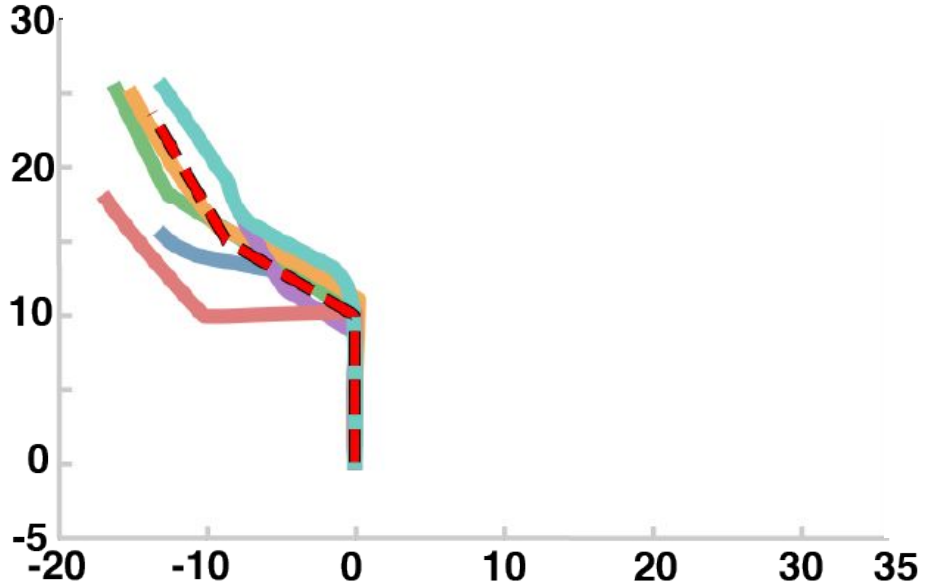
Trajectory Reconstruction Results Across 8 Routes

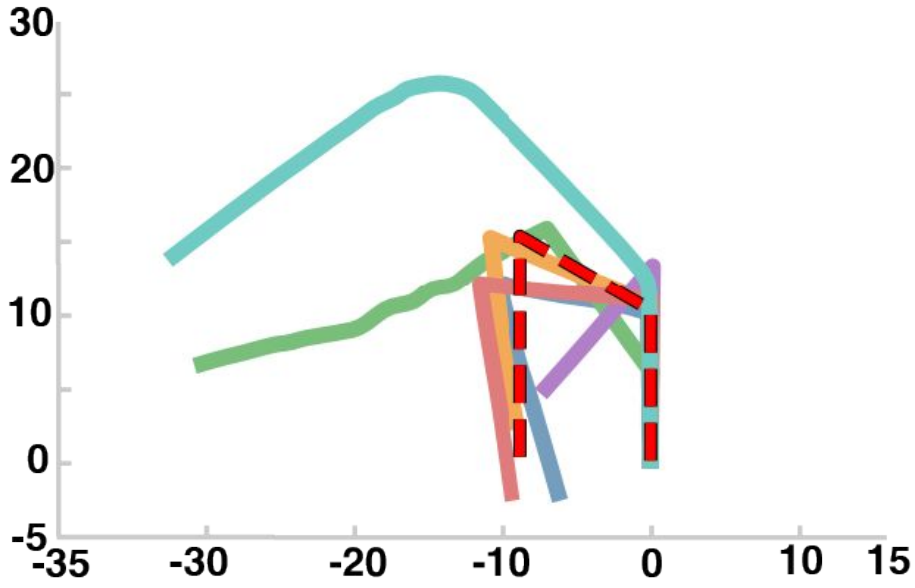


Route Perception: Accuracy Drops for Obtuse Turns

Participants correctly identified

90° turns: 64.3% / turns below 90°: 47.6% / turns above 90°: 8.3%





Design decision for Study 2:

Based on these findings, we limited turns on the pre-mapped routes in Study 2 to 90° or less.

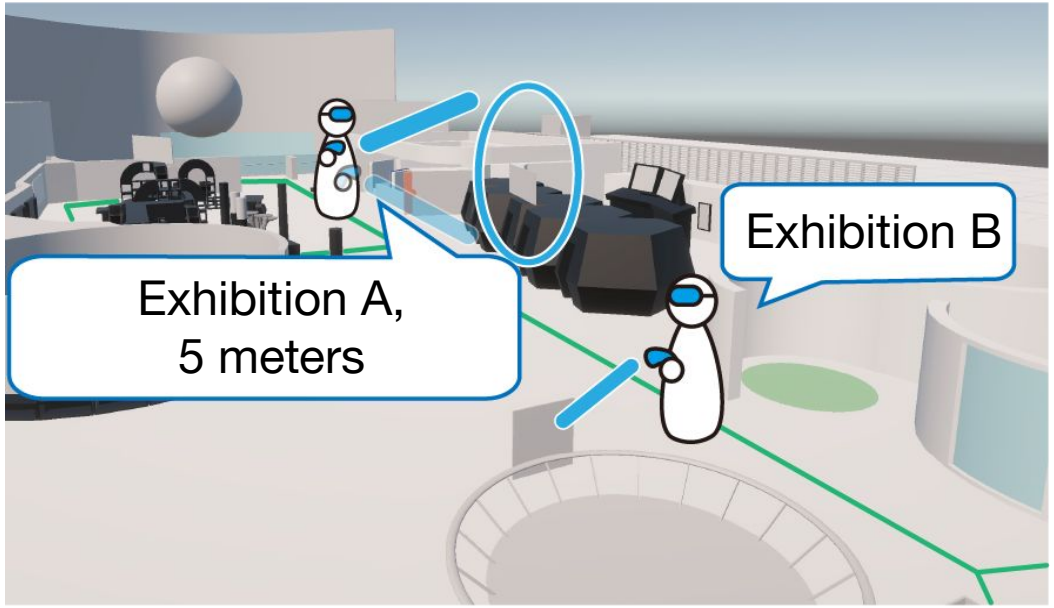
System Overview

Navigation Module

Guide navigable directions
via spatial audio and haptics

Perception Module

Provide surrounding object and
scene information via 4 modes

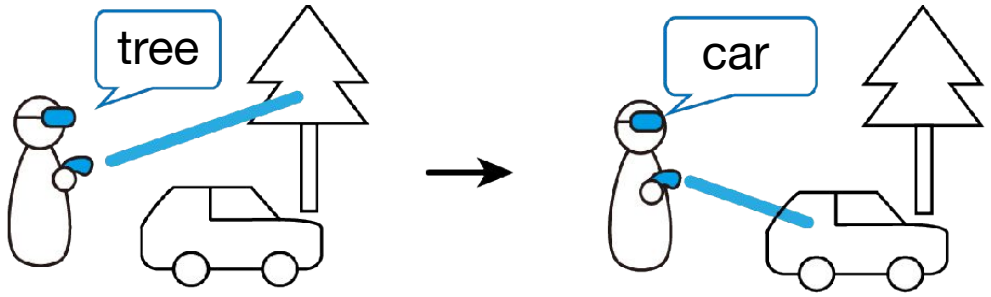


Four Interaction Modes of Perception Module

Users can freely select and switch modes to perceive surroundings

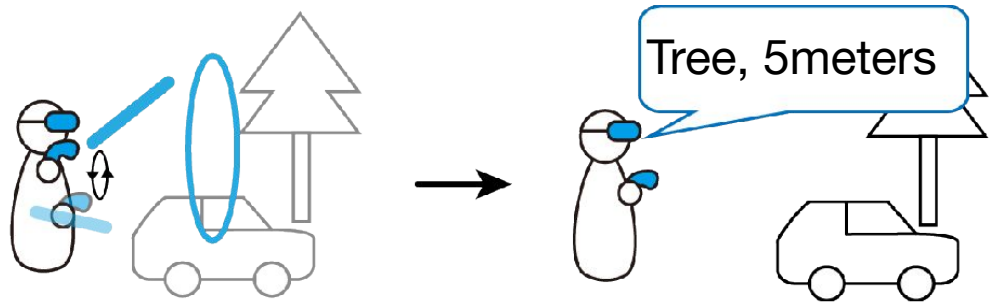
Point Mode

Individual object via raycasting & distance haptics



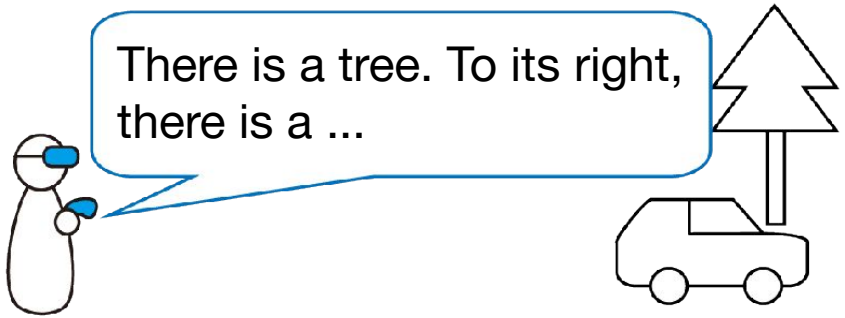
Circle Mode

Nearby objects within a user-drawn circle



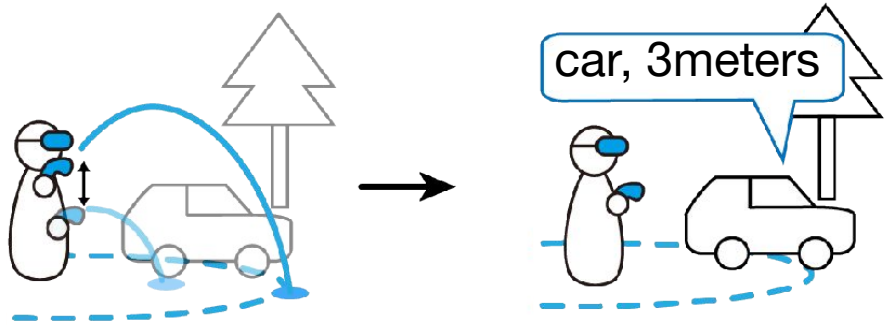
AI Caption Mode

Scene-level description within the field of view



Shock Wave Mode

Area-based objects within an adjustable radius



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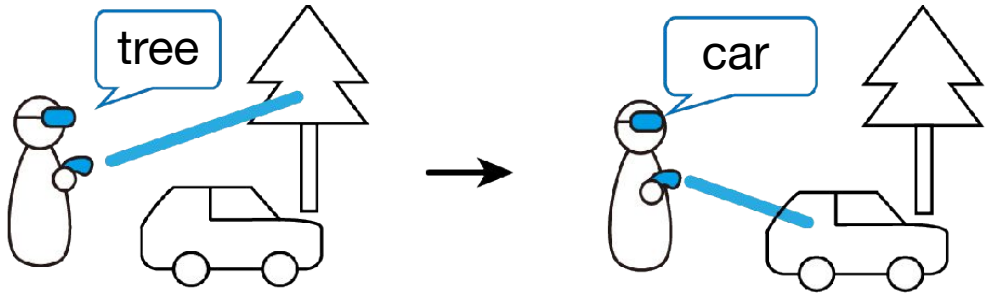

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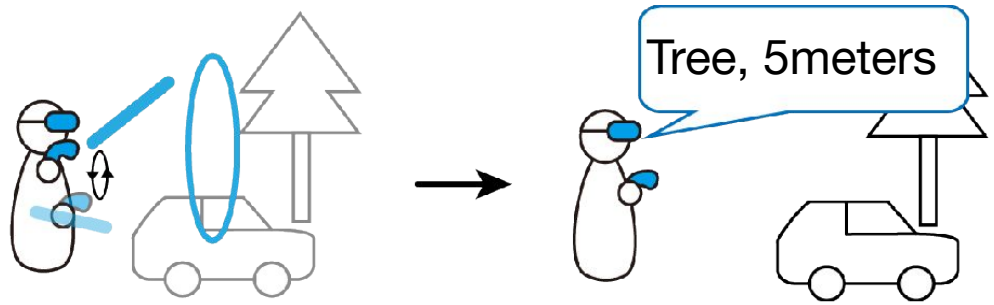

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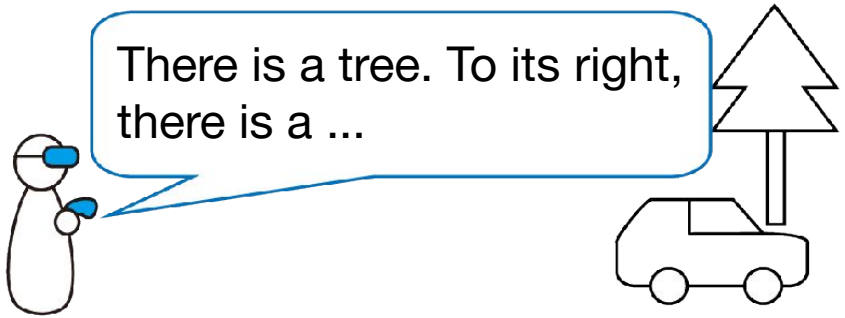

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Area-based objects within an adjustable radius

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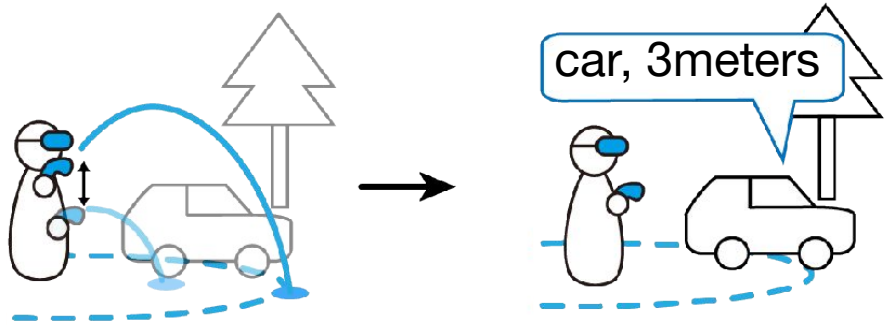


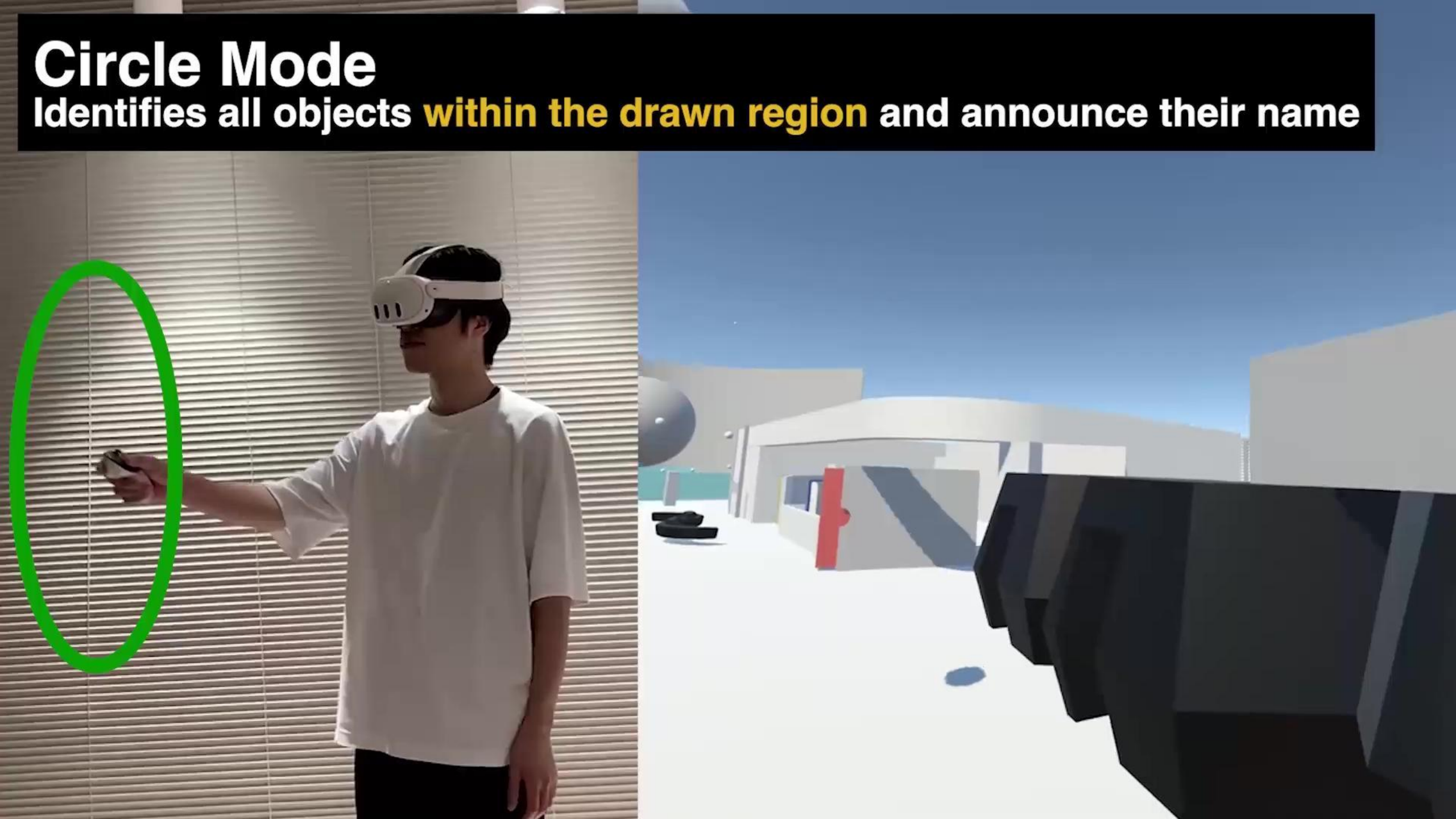
Point Mode

Announces the object name in the direction pointed by the controller



Circle Mode

Identifies all objects within the drawn region and announce their name



User Study with
7 Blind Participants







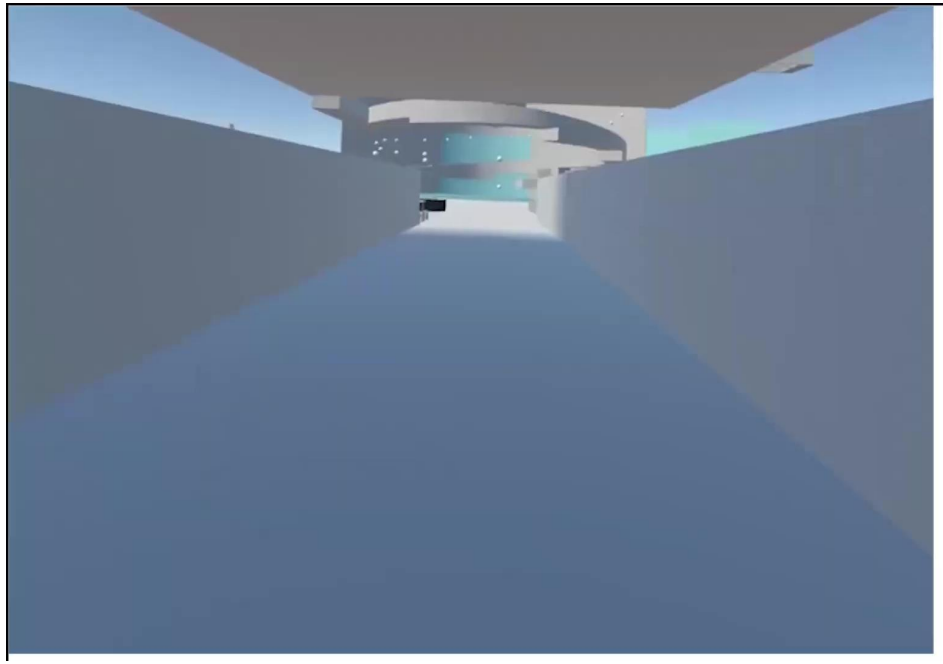


User Study of Perception Module (N=7)

RQ2: To what extent can blind users perceive spatial features?
RQ3: How do blind users use and combine interaction methods?

Environment: 3D model of a **real Science Museum**
Task: 30-min **free virtual exploration** followed by 15-min physical visit

Virtual Exploration



Real-World Validation



Result 1: Landmark Perception & Real-World Validation

Highlights **the need for memory retention support** to facilitate real-world transfer

Virtual Exploration

Discovered landmarks: **60.20%±24.35%** (out of 14)

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Highlights **the need for memory retention support** to facilitate real-world transfer

Virtual Exploration

Discovered landmarks: **60.20%±24.35%** (out of 14)

Real-World Validation

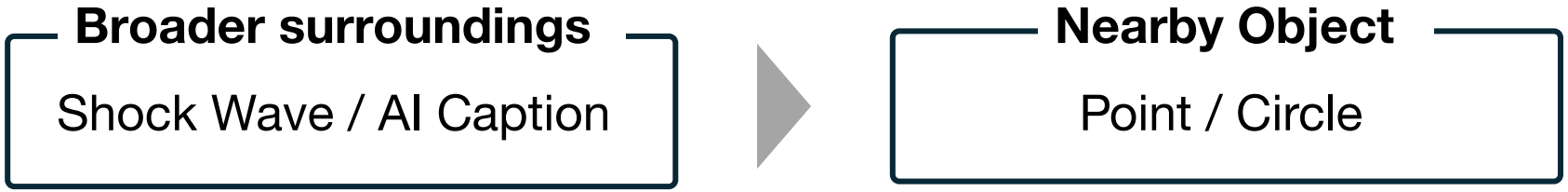
Recalled landmarks: **49.78%±19.76%**
(out of the landmarks conveyed during the virtual exploration)



Result 2: How Participants Combined Interaction Modes

All seven participants described using multiple modes during exploration.

From overview to detail (5 of 7 participants)



Switching when more information was needed (2 of 7 participants)

P09 switched from Circle to AI Caption when Circle gave too little context.

[8] Balasubramanian et al. "Enable Blind Users' Experience in 3D Virtual Environments: The Scene Weaver Prototype. "

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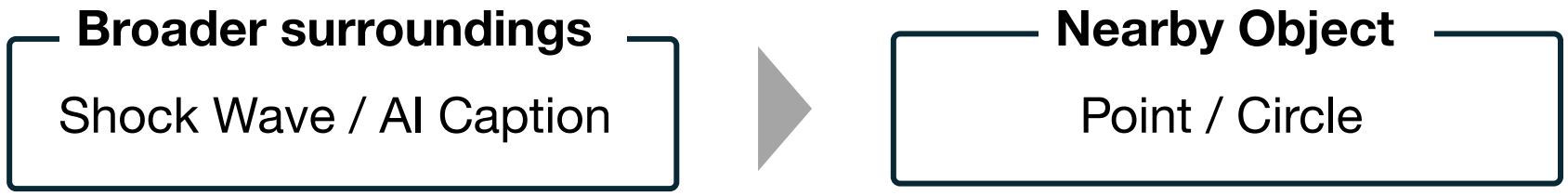

Switching when more information was needed (2 of 7 participants)

P09 switched from Circle to AI Caption when Circle gave too little context.

Participants combined modes to explore at different scales and fill gaps in what they learned.

[8] Balasubramanian et al. "Enable Blind Users' Experience in 3D Virtual Environments: The Scene Weaver Prototype. "

Discussion: From Local Features to the Larger Environment

Participants understood local features more readily than how features fit together.

	Study 1: Route Geometry	**Study 2: Spatial features**
Local Understanding	Recognized right-angle turns and curves	Learned about nearby objects and landmarks
Larger-scale understanding	Had difficulty **reconstructing complex routes**	Had difficulty **understanding** how exhibits were **arranged relative to one another**

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Design Implication:

Help users connect landmarks to the routes they traveled and the areas they have already explored.

Future Work: Evaluate Joint Learning of Routes and Landmarks

Our Research

Route structures and spatial features were evaluated separately.
Simultaneous learning and the relationships between them remain uninvestigated.

Future Work

Design evaluation methodologies to assess how blind users jointly understand routes and landmarks in virtual environments (e.g., tactile block reconstruction[2])

Virtual Exploration for Blind People to Perceive Geometric and Spatial Features

In Study 1, blind participants followed pre-mapped routes in VR and recognized individual turns and curves, but found complex routes harder to reconstruct.

In Study 2, blind participants explored a virtual museum, combining interaction modes to get an overview and examine nearby objects and landmarks.

These findings suggest that VR systems should help users build a broader understanding of a place by linking landmarks to routes they've taken and areas they've explored.