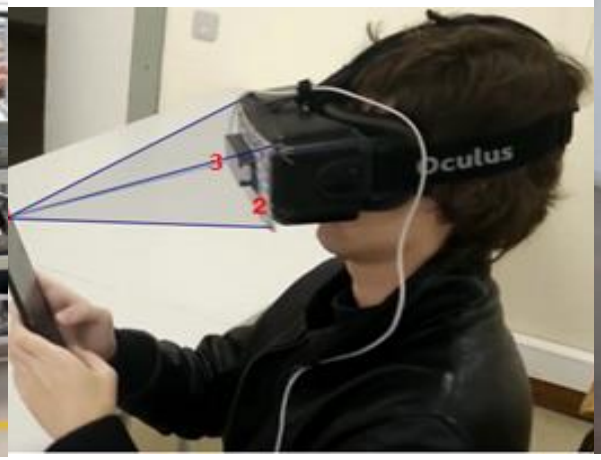
Universidade de Aveiro
Departamento de Electrónica,
Telecomunicações e Informática

Interaction in Virtual and Augmented Reality – 3DUIs



Realidade Virtual e Aumentada 2025

Beatriz Sousa Santos

Challenges to wide adoption of VR

Design and technology:

- 3D user interfaces (3DUIs)
- Convenience and control (easy to use and affordable)

"The biggest barrier to wide adoption of immersive technologies is the lack of good user experience design"

3 Reasons Why VR and AR Are Slow to Take Off

“ Interaction is the communication that occurs between a user and the VR (AR/MR) application … mediated through the use of input and output devices...” (Jerald, 2016)

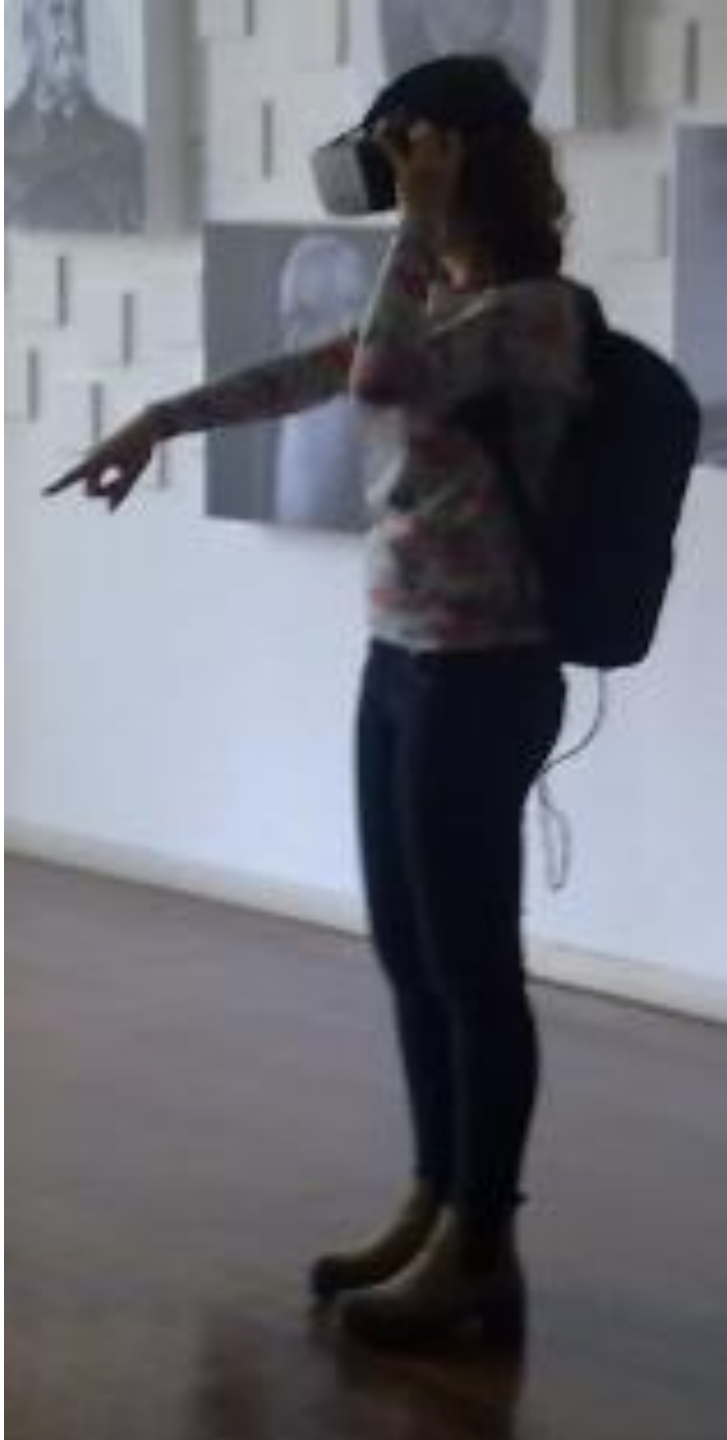
- Goals of **interaction design** in VR and AR (XR in general) applications:
  - **Usability and UX** (performance, ease of use, ease of learning, satisfaction, user comfort and safety)
  - **Usefulness** (users focus on tasks, interaction helps users meet goals)

as in any interactive system (3D or not)…

but comfort and safety are greater concerns in VR!

What is a 3D User Interface?

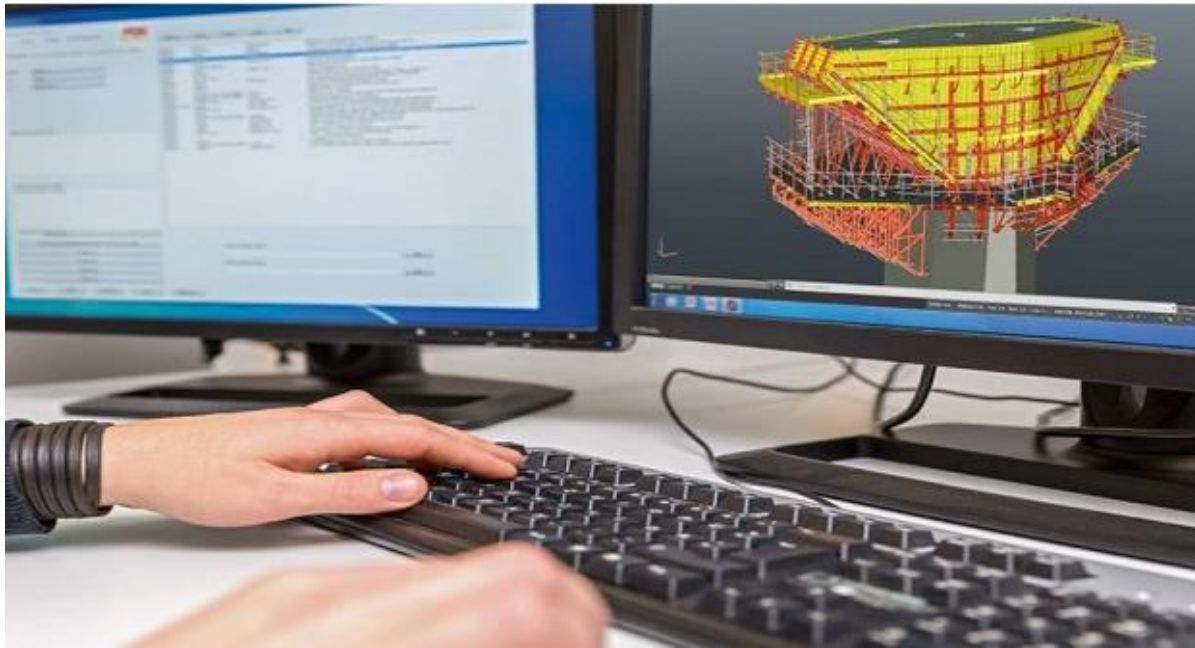
- Not easy to define …



Is this a 3D User Interface?

- A typical example:

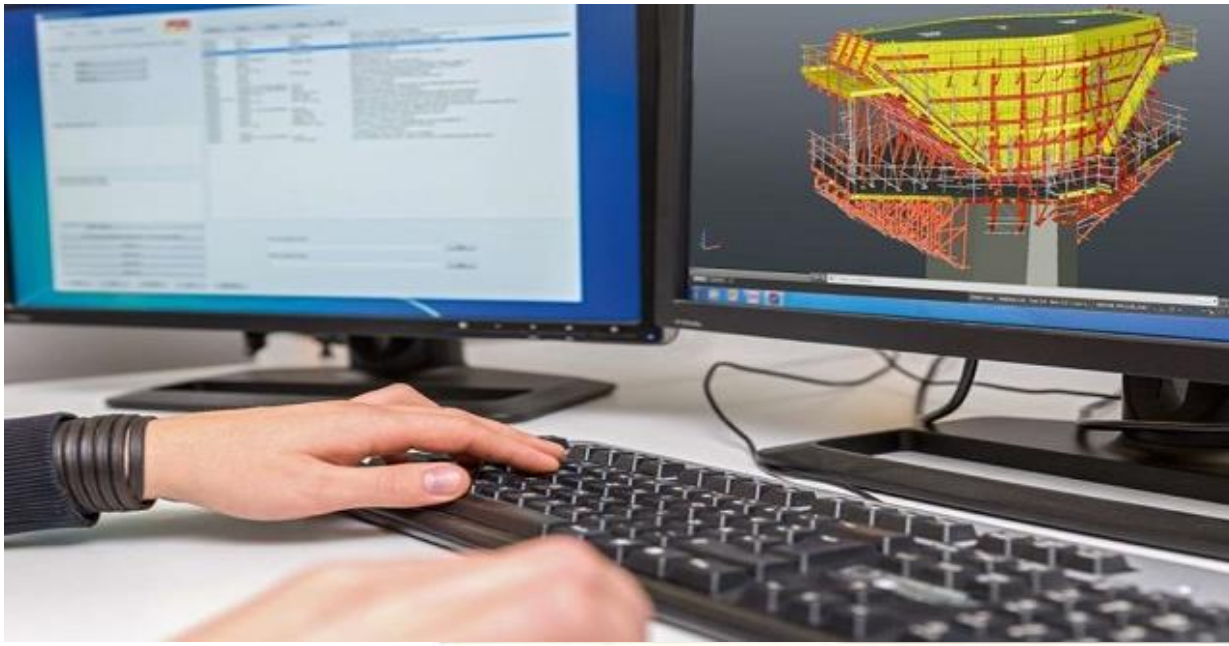
  Computer Aided Design (CAD) scenario



What is NOT a 3D User Interface

- If a system displays a virtual 3D space, but the user interacts **indirectly** with this space—e.g.,
  - by manipulating 2D widgets,
  - entering coordinates,
  - or choosing items from a menu

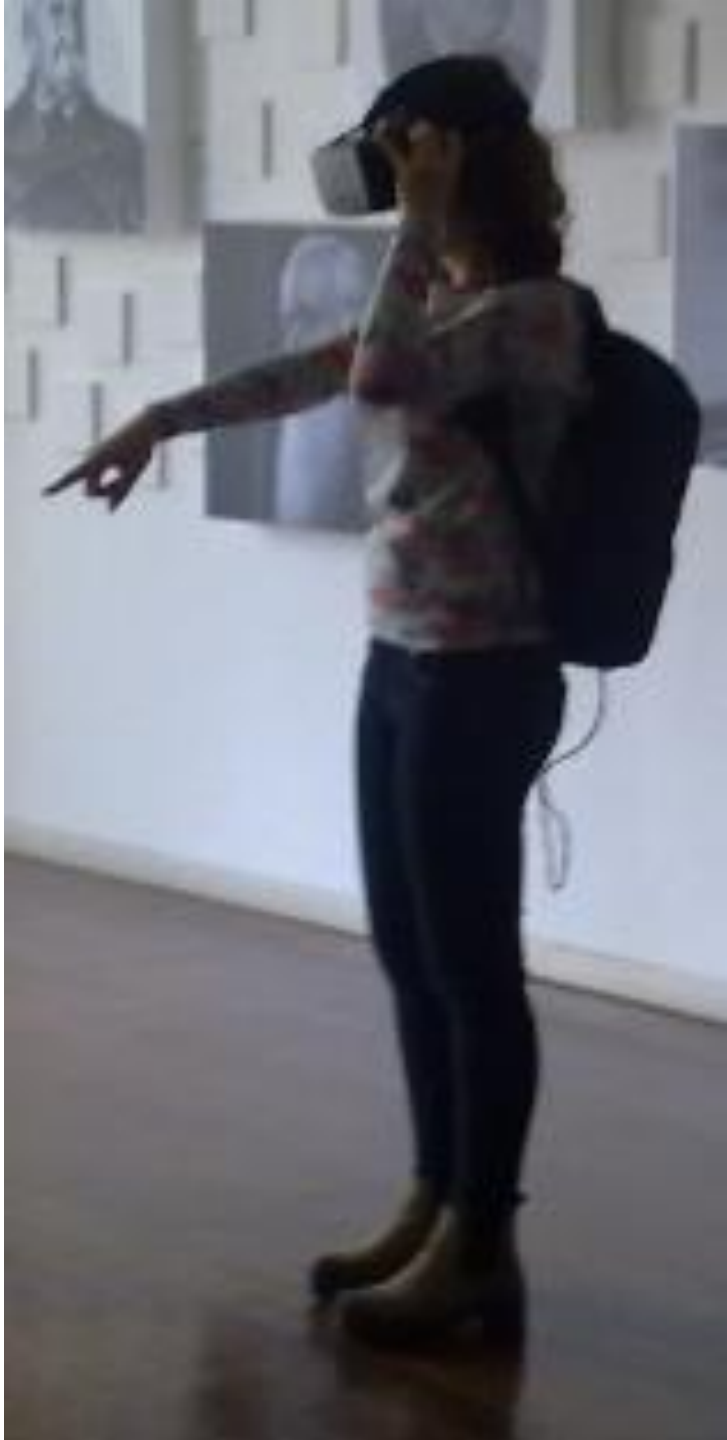
- **It is not a 3D UI !**



What is a 3D User Interface?

- Not easy to define…
- a UI that involves 3D interaction
- the user's tasks are performed **directly in a 3D spatial context**
- based on 3D spatial input …

(Laviola et al., 2017),



- What makes 3D interaction difficult?
  - Spatial input
  - Lack of constraints
  - Lack of standards
  - Lack of tools
  - Lack of precision
  - Fatigue
  - Layout more complex
  - Perception, …

- 3D User Interfaces (UIs) let users interact with virtual environments, objects, or information using direct 3D input in the physical and/or virtual world

- Isn't the 3D interface obvious?

  Naturalism *vs*. **Magic**

  – **Naturalism**: make the Virtual Environment work "exactly" like real world

  – **Magic**: give user new abilities
  - Perceptual
  - Physical
  …

Naturalism *vs* Magic – a debate

- High levels of naturalism can enhance performance and the overall UX

- **Traditional interaction** styles can provide good performance,
  but result in lower presence and engagement

- **Hyper-natural, magic** design approaches may improve performance and usability

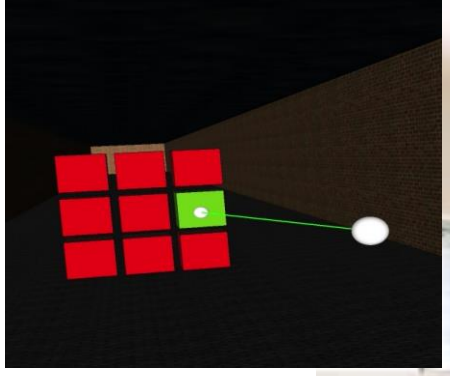
- **All have to be carefully designed!**

Bowman, D. A., McMahan, R. P., & Ragan, E. D., "Questioning naturalism in 3D user interfaces". *Communications of the ACM*, *55*(9), 78–88, 2012. http://doi.org/10.1145/2330667.2330687

Universal interaction tasks for VEs

- Navigation
  - Travel – motor component
  - Wayfinding – cognitive component
- Selection
- Manipulation
- System control
- Symbolic input

(Laviola *et al*., 2017)

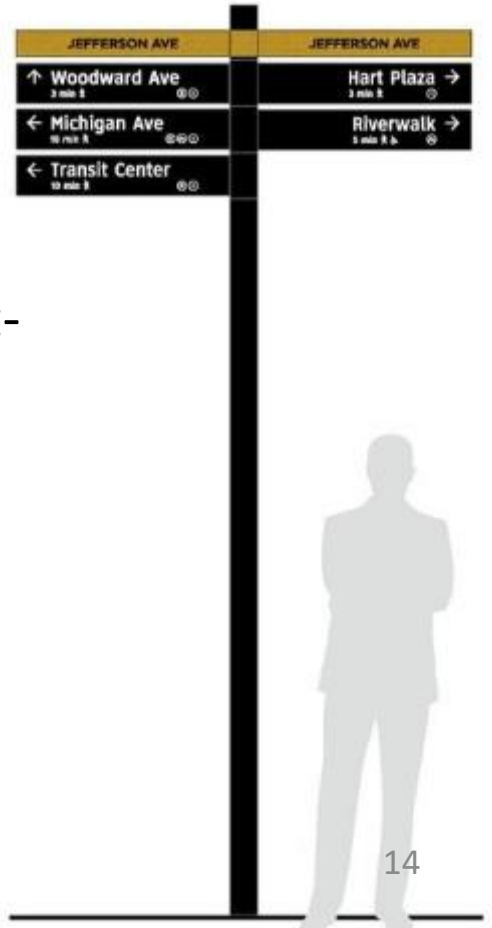


Navigation – travel and wayfinding

- Travel refers to the **user's movement** within the virtual environment,
- Wayfinding involves the cognitive process of **determining and following a route** to a destination.
- Travel focuses on the physical movement
- Wayfinding is about **planning and navigation**.
- Both are crucial for creating immersive and engaging VR experiences

Navigation

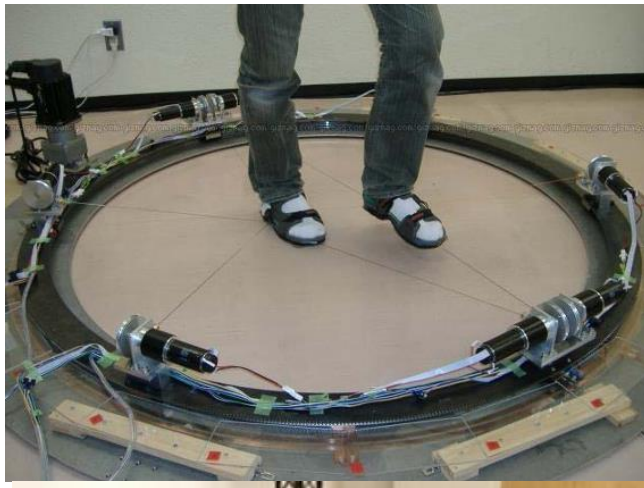
- Ensures users can easily explore and engage with a virtual world
- May involve providing users with a virtual map and step-by-step guidance to reach their destination



- Virtual world should provide sufficient environment-based wayfinding cues:
  - visual/auditory cues,
  - interactive elements,
  - landmarks and signage,
  - virtual agents,
  - path guides, maps…

Travel

- Travel may be done in different ways:
  - walking,
  - running,
  - teleporting,
  - steering …
- Consider both natural and magic travel techniques
- Provide multiple travel techniques to support different travel tasks in the same application
- The most common travel tasks should require a minimum amount of effort from the user

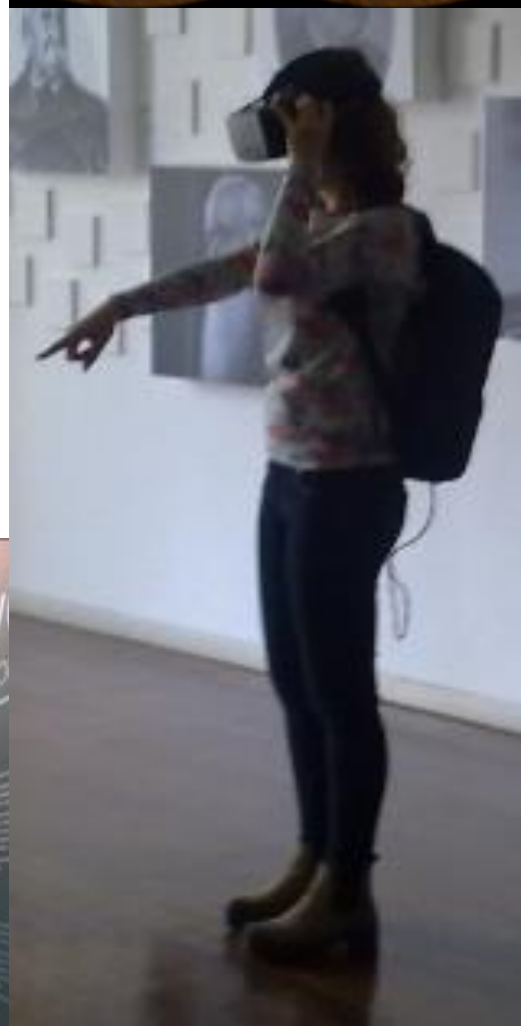


Travel | La Viola 2020

Examples with our work:
The Imaginary Museum
an interactive exhibit

- The user was immersed in a virtual replica of a room
- Could explore virtual contents (text, videos, 3D models)
- And set their own virtual exhibits

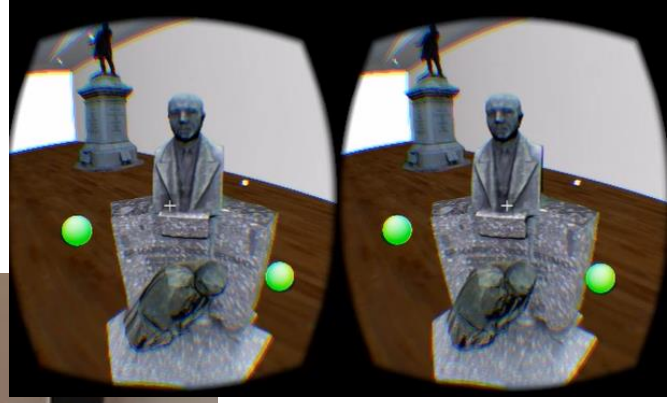
- **Tasks**: navigation + selection + manipulation
- **Interaction methods**: walking + gestures

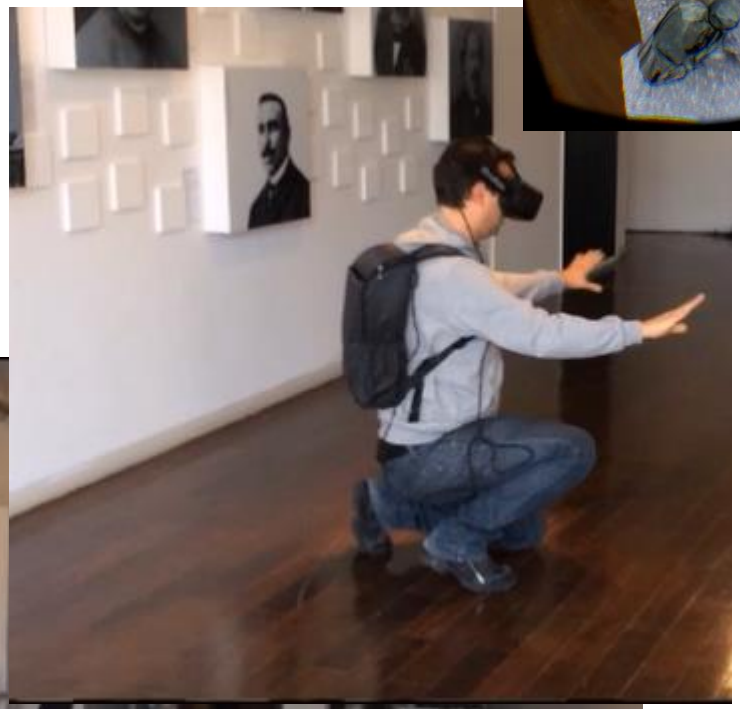


Imaginary museum

Imaginary Museum tasks and Interaction

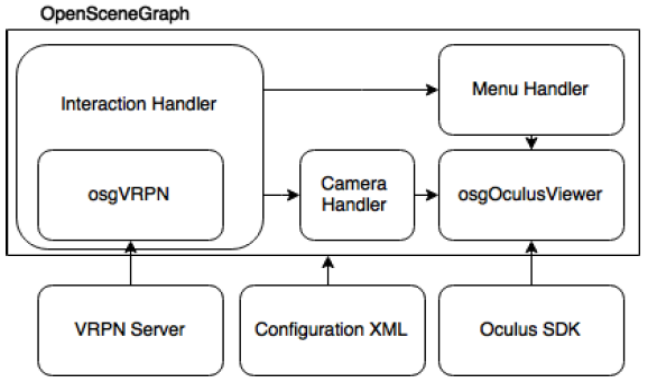
- Placing 3D virtual objects in a virtual exhibit using spatial gestures





- While walking in the real/virtual worlds (1 : 1 mapping)

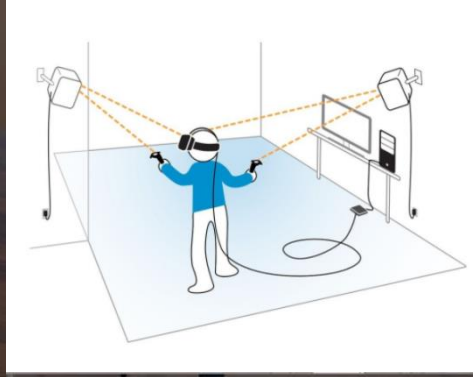
Example: Imaginary Museum setup

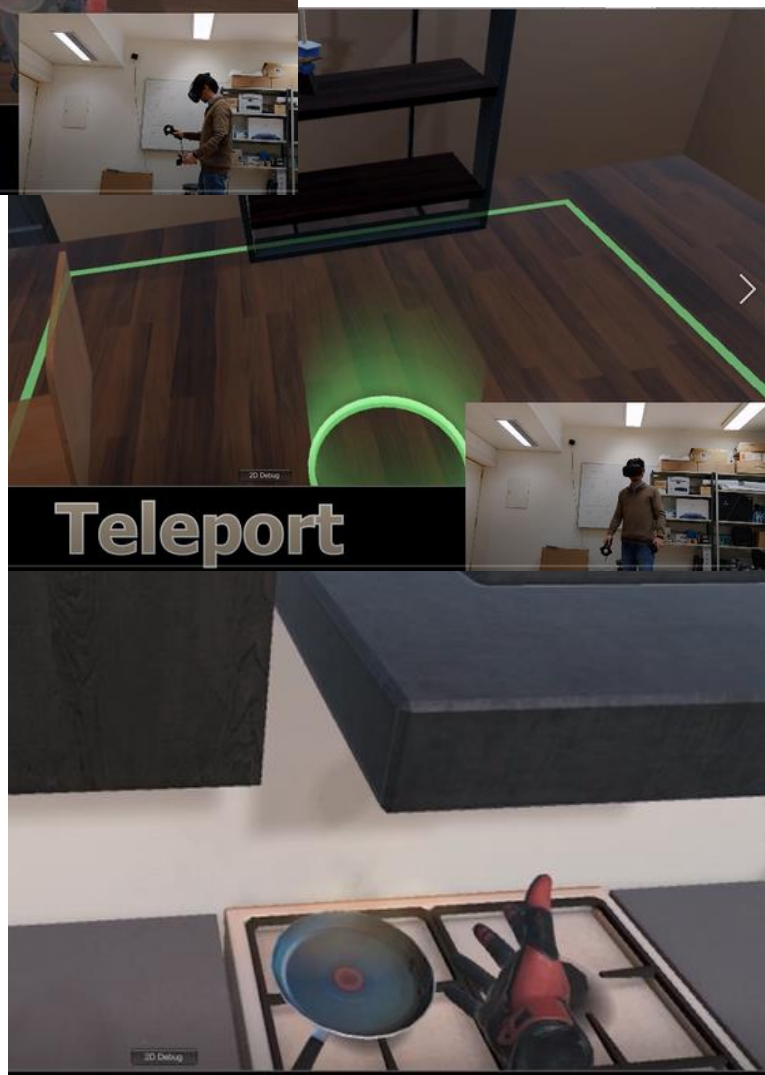


The user walks in a real room and navigates in the virtual room (similar to the real one)

Paulo Dias, João Pinto, Sérgio Eliseu, Beatriz Sousa Santos, “Gesture interactions for Virtual Immersive Environments: navigation, selection and manipulation”, N. Streitz and P. Markopoulos (Eds.), *Distributed, Ambient, and Pervasive Interactions DAPI 2016*, *Lecture Notes in Computer Science* ,LNCS 9740, pp. 211-221

Another example:
Virtual escape room





Same tasks

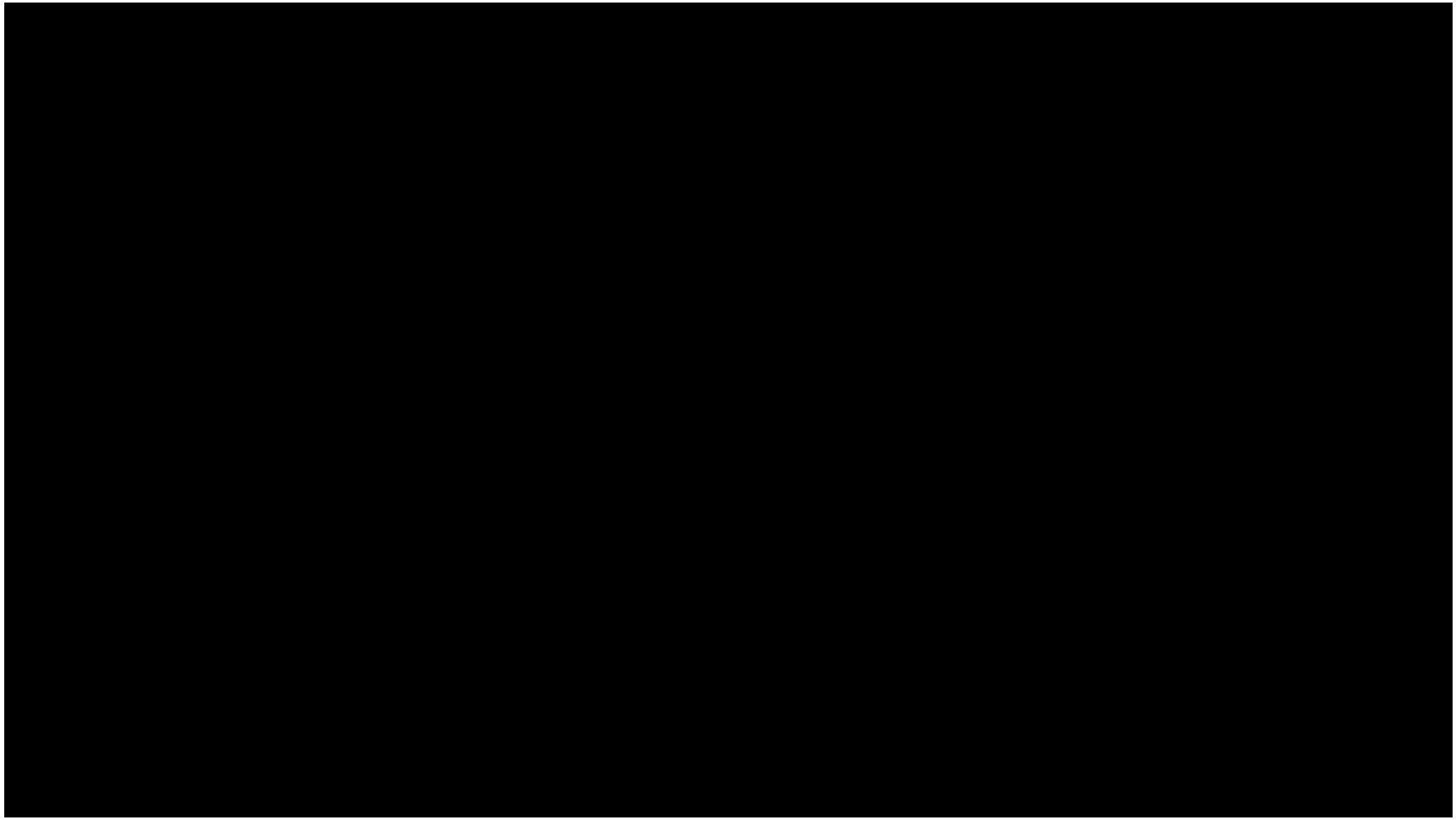
different interaction techniques

Navigation – Walking + Teleport

Manipulation

input devices:
(HTC Vive)
controllers

Another example:
Virtual escape room



Yet another example:

Same tasks; different interaction techniques

Navigation

Selection

input devices:
controllers
(Razer Hydra)

Selection and Manipulation

- Human hand allows to manipulate physical objects quickly and precisely, without much thinking about it

- Creating new 3D UI manipulation techniques is a strong **research area**

- 3D manipulation techniques **map user input** captured by input devices, into the desired action **in the virtual world**

Selection and Manipulation parameters

selection
distance and direction to target; initial orientation; target size; density of object around the target, number of targets to be selected; target occlusion

positioning
distance and direction to initial position, distance and direction to target position, translation distance, required precision of positioning

rotation
distance to target, initial orientation, final orientation, amount of rotation, required precision of rotation

scaling
distance to target; initial scale; final scale; amount of scale; required precision of scale

Manipulation Techniques and Input Devices
the device impacts design

- the input device has a major impact on the possibilities for manipulation
- control dimensions (i.e., DOFs) and integration of control
- force vs position control, e.g., joystick vs mouse
- device placement and form factor,
  e.g., power grip vs precision grip

(La Viola, 2017)

Manipulation techniques for Grasping – Simple Grasping

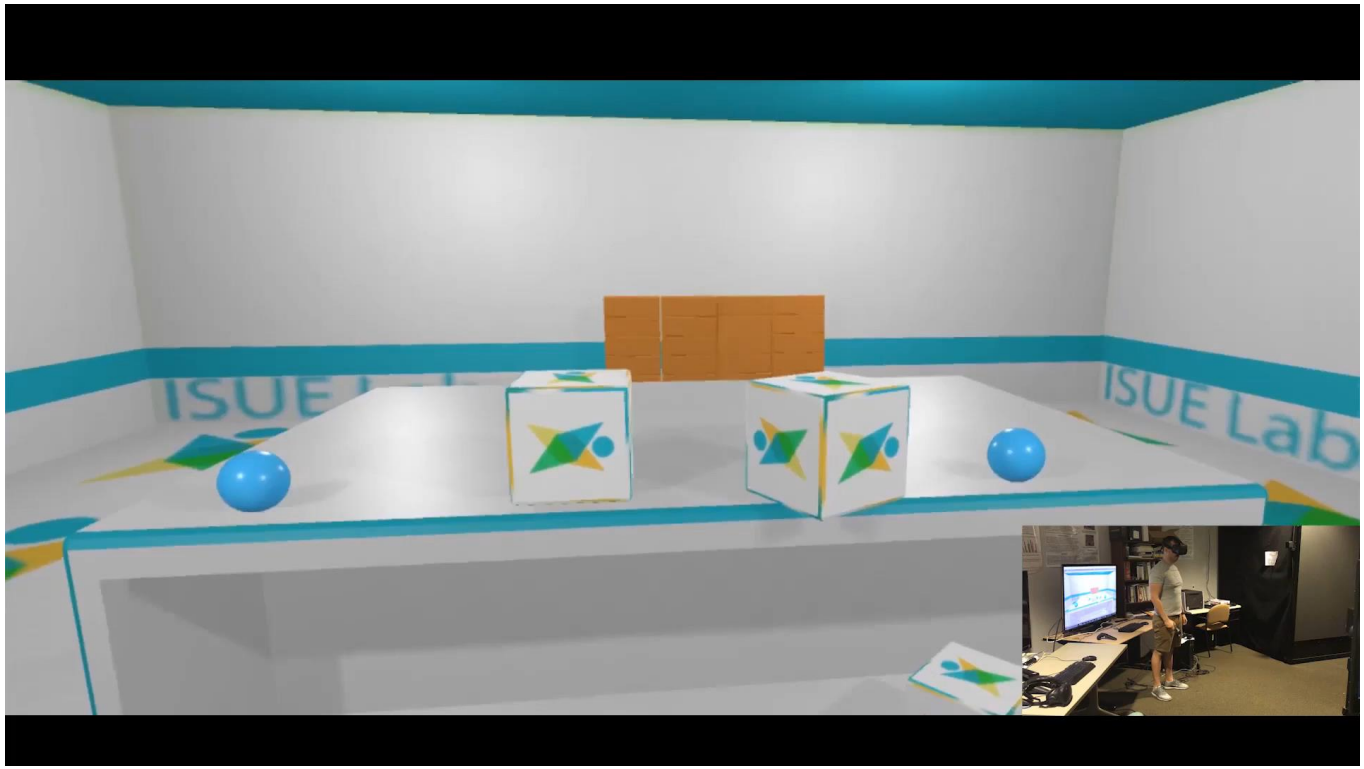
- direct mapping of the user's hand motion to a virtual hand

- very intuitive

- only objects within the area of user reach can be selected and manipulated

Grasping Metaphor - Simple Grasping

Manipulation techniques for Grasping – GoGo



[Grasping Metaphor - GoGo Interaction]

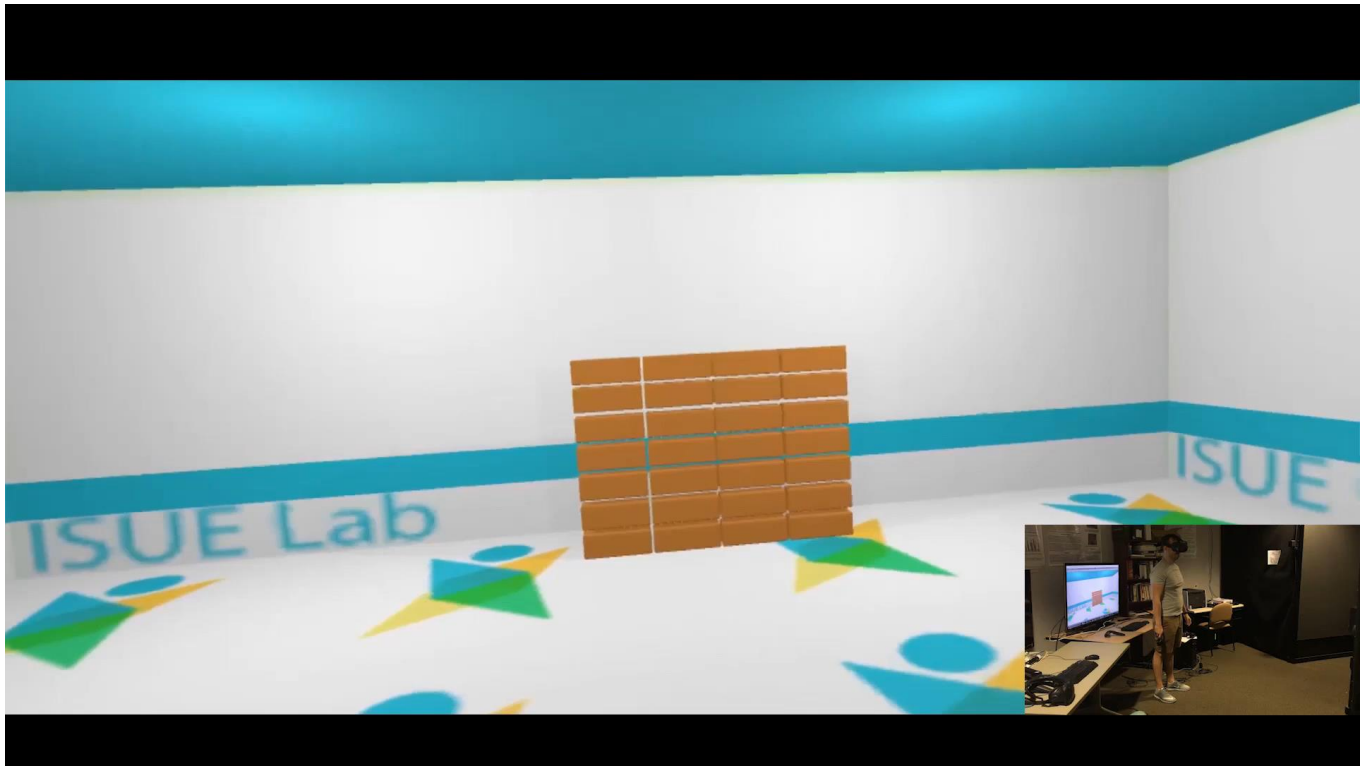
- improve simple grasping

- unobstrusive technique to “extend” the length of the virtual arm

- at close range, it uses one-to-one mapping

- beyond a specific distance, mapping is non linear

Selection techniques for Pointing – Ray Casting



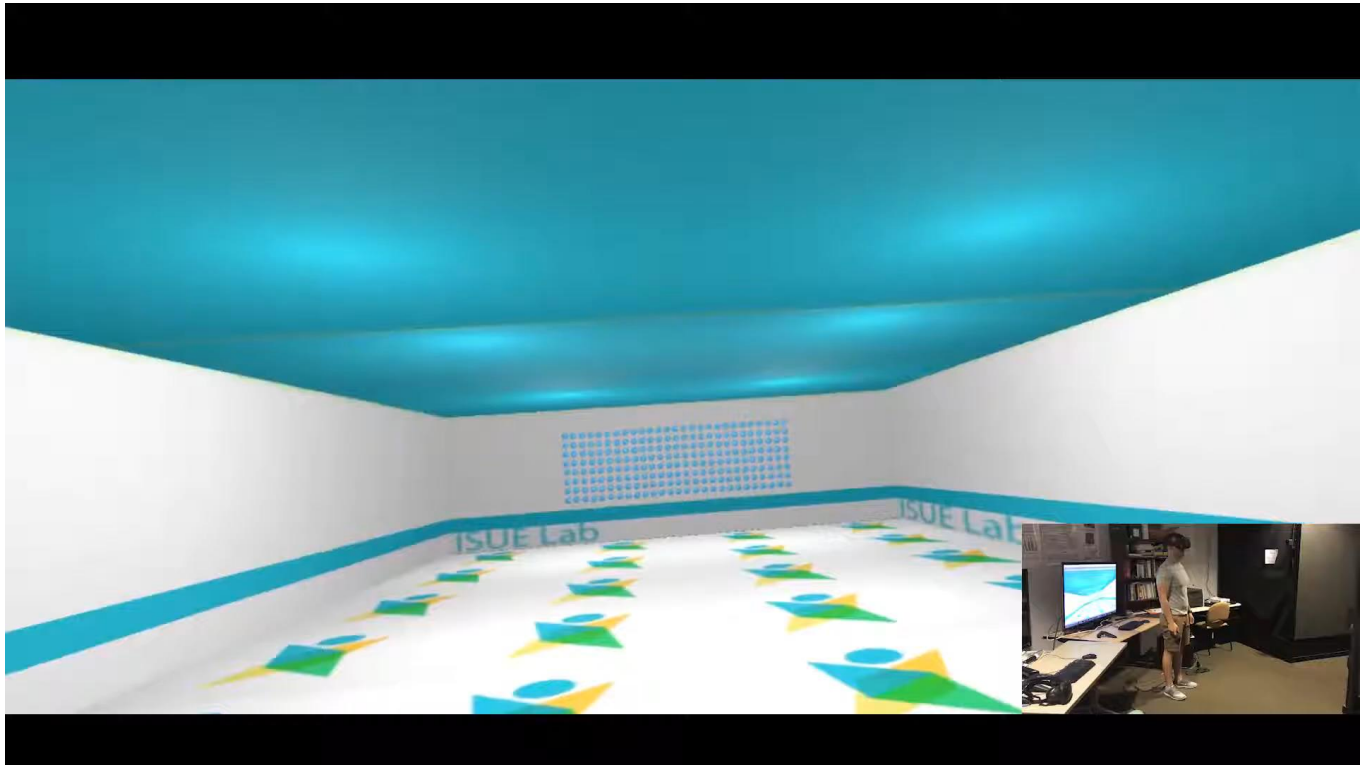
[Pointing Metaphor - RayCasting]

- user points at object with a virtual ray defining the direction of pointing

- not very good for selection of small or faraway objects

- the farther the object the greater the jitter/error

Selection techniques - Pointing – Flashlight



- avoids precision and accuracy required for ray casting method

- direction is as in ray casting

- ray replaced by conic selection volume (such as a flashlight)

Pointing Metaphor - Flashlight

- System control – involves changing the mode or de state of the VE
  - Often done through commands (gesture/voice) or menus
- Symbolic input
  - Entering or editing text, numbers, or other symbols
- These tasks have not been as much researched as the previous ones
- Another task may be important: 3D modeling

- There are many techniques to perform a task

- And several taxonomies of techniques

- **Why are taxonomies relevant**?

  - organize knowledge by using a controlled vocabulary;

  - make it easier to find related information

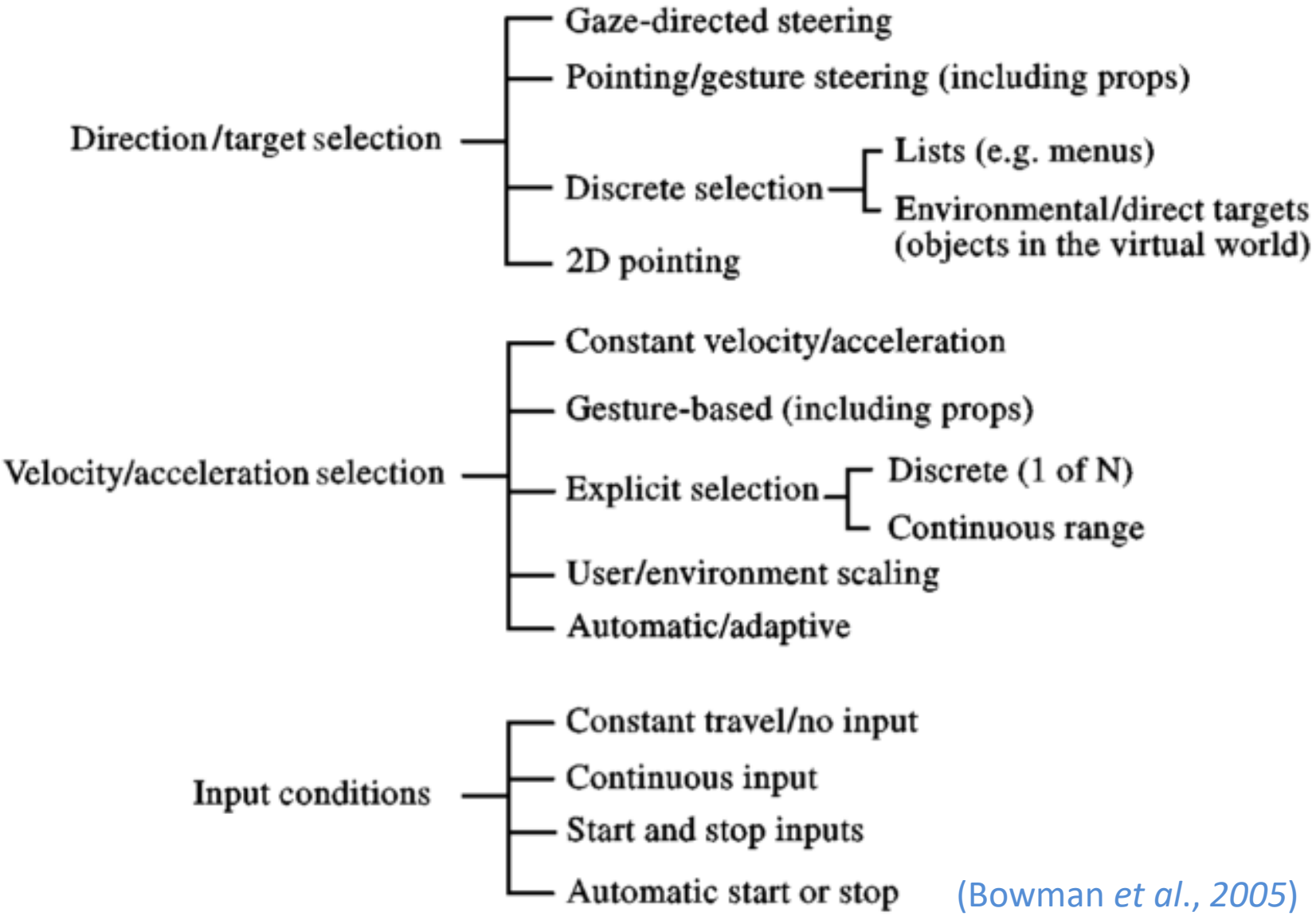
Example: Travel tasks

- 3D travel tasks according the user goal:
  - Exploration
  - Search
  - Maneuvering

- Other relevant characteristics:
  - distance to be traveled, curvature or turns, target visibility from the starting point

- Different taxonomies of travel techniques :
  - Active *vs* passive
  - Physical *vs* virtual
  - Metaphor
  - Subtasks

Travel – taxonomy of techniques concerning subtasks



(Bowman *et al.*, *2005*)

A study on taxonomies

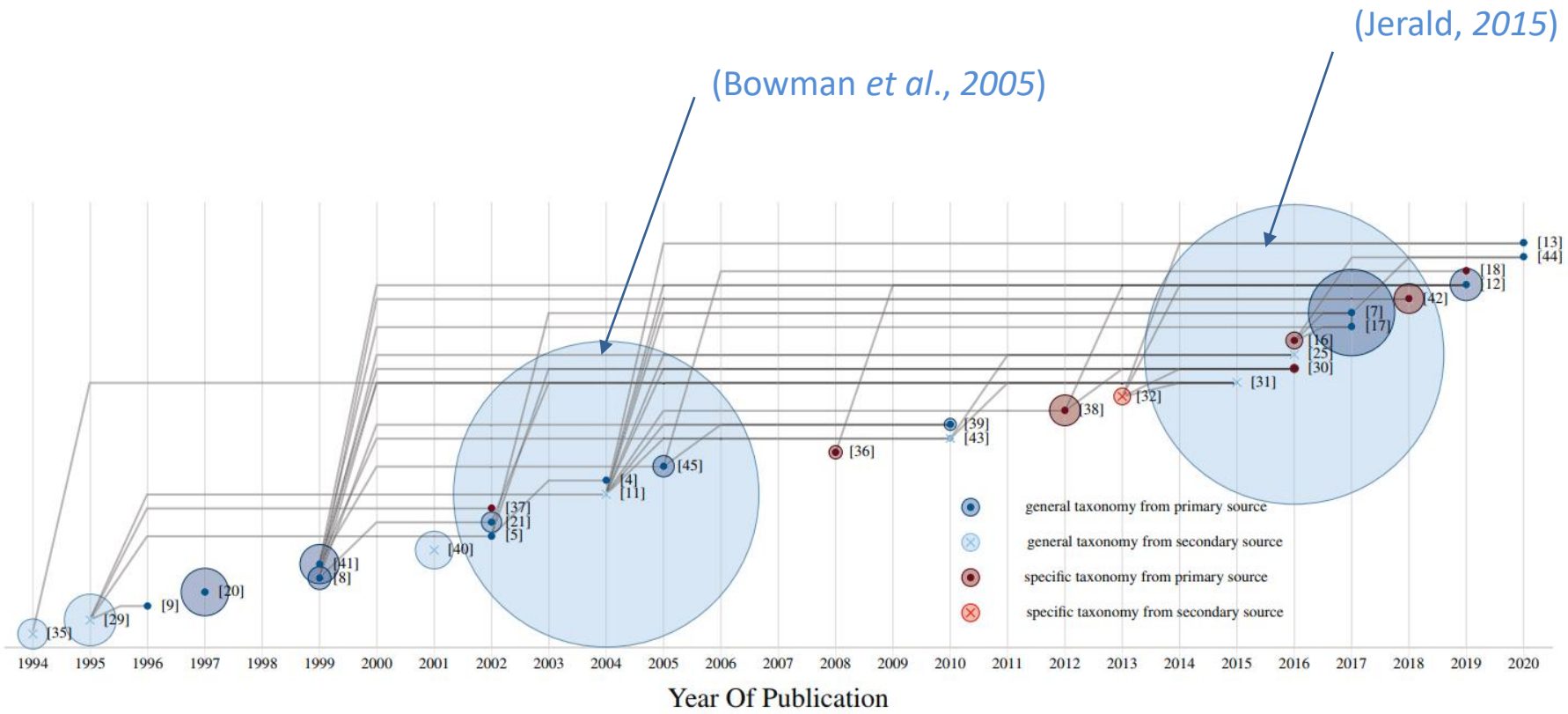


Figure 1: Scope and impact of the identified taxonomies. The radius of the circles is proportional to the overall citations per year (C_Y). Lines visualise citations between the publications (C_T).

[An Overview and Analysis of Publications on Locomotion Taxonomies 2024 IEEE VR]

Still a research topic…

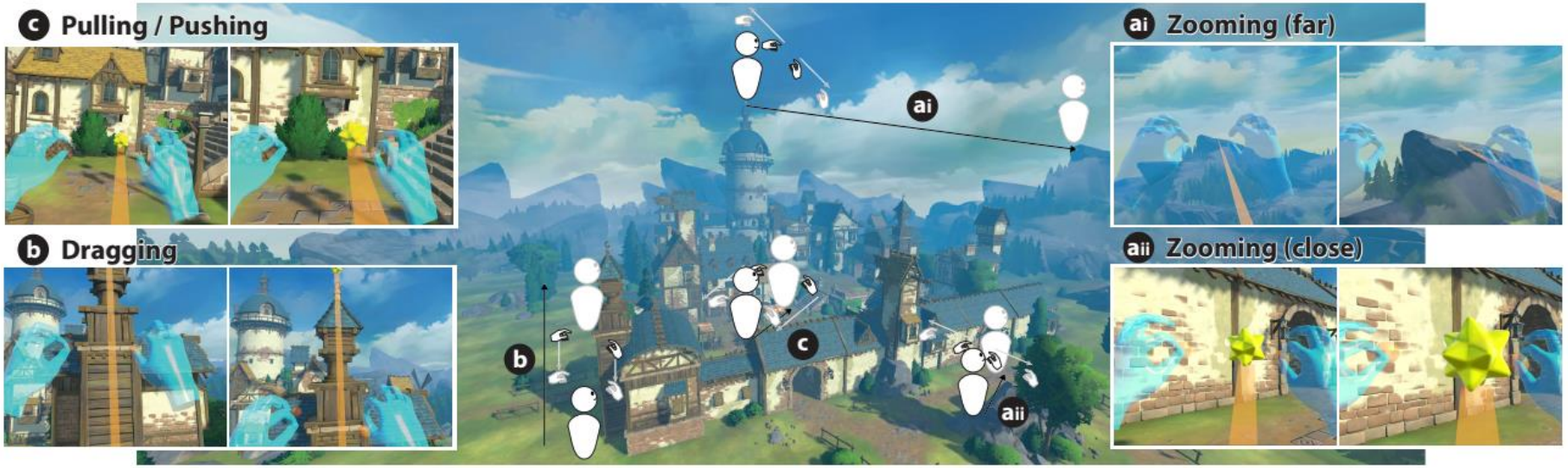
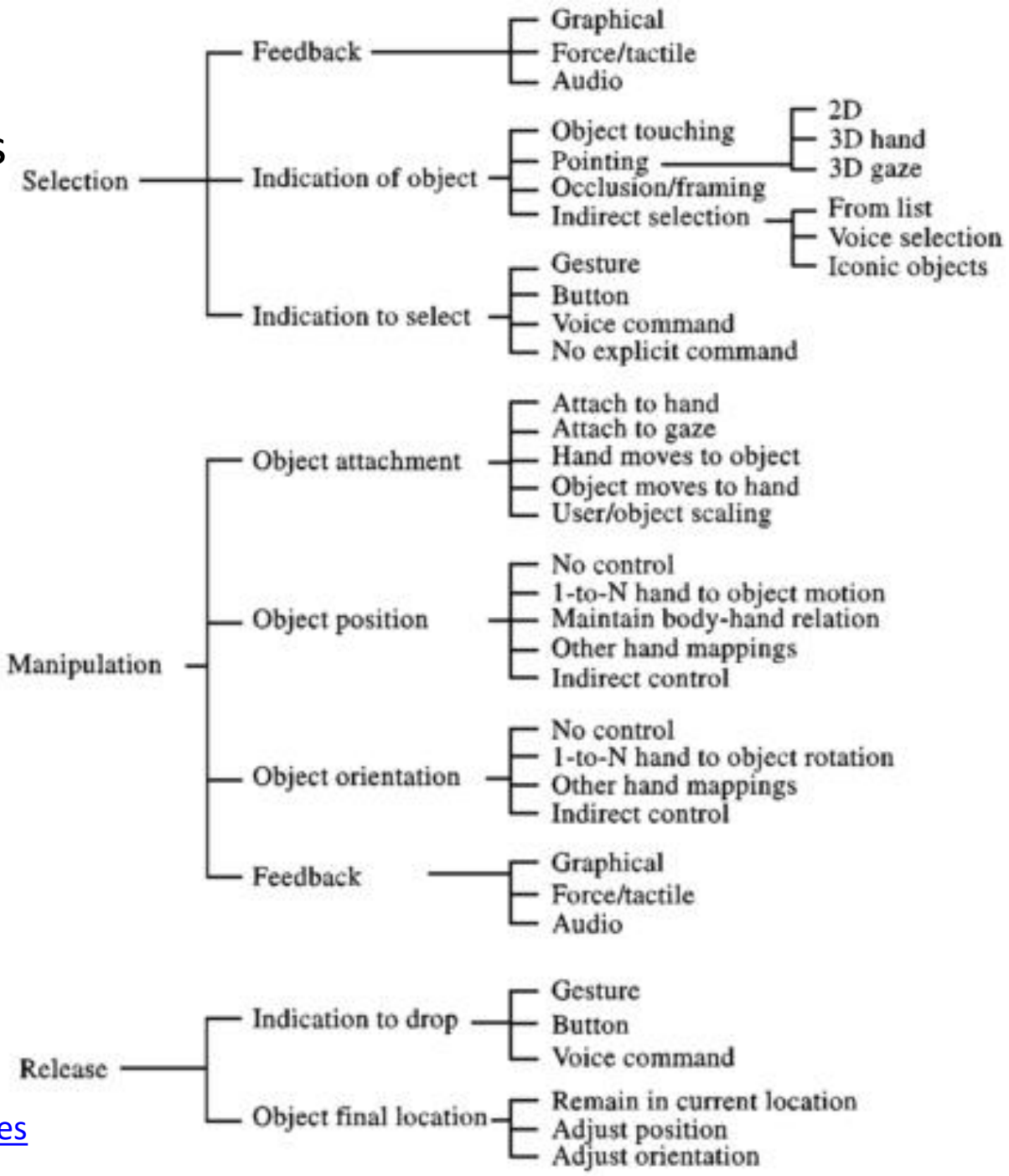


Figure 1: *illumotion* is a locomotion technique based on optical manipulation. The user can use (*a*) zooming, (*b*) dragging and (*c*) pulling/pushing to move around a scene with 3D movement. As an optically-driven method, it tunes the speed based on the target; (*ai*) targets further away will lead to faster movement and vice versa, (*aii*) for closer targets.

illumotion: An Optical-illusion-based VR Locomotion Technique for Long-Distance 3D Movement 2024 | IEEE VR

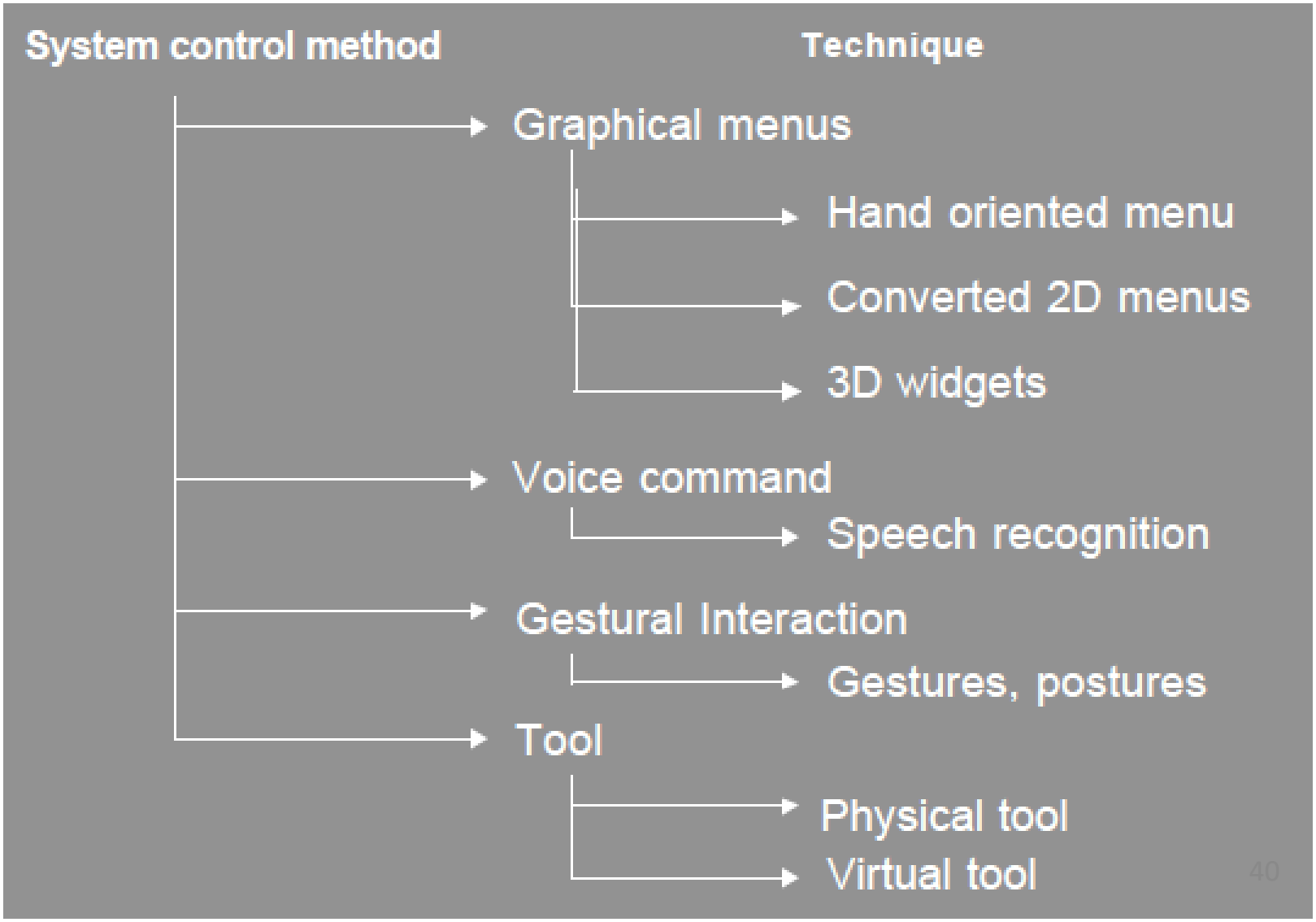
Selection/ Manipulation Taxonomy of techniques

(Bowman et al. , 2005)



A Comprehensive Classification of 3D Selection and Manipulation Techniques | MuC 2019

Classification of system control techniques (Bowman *et al.*, 2008)



- System control – involves changing the mode or de state of the VE

- Some design guidelines:

  - Don’t disturb flow of action
  - Use consistent spatial reference
  - Allow multimodal input
  - Structure available functions
  - Prevent mode errors by giving feedback

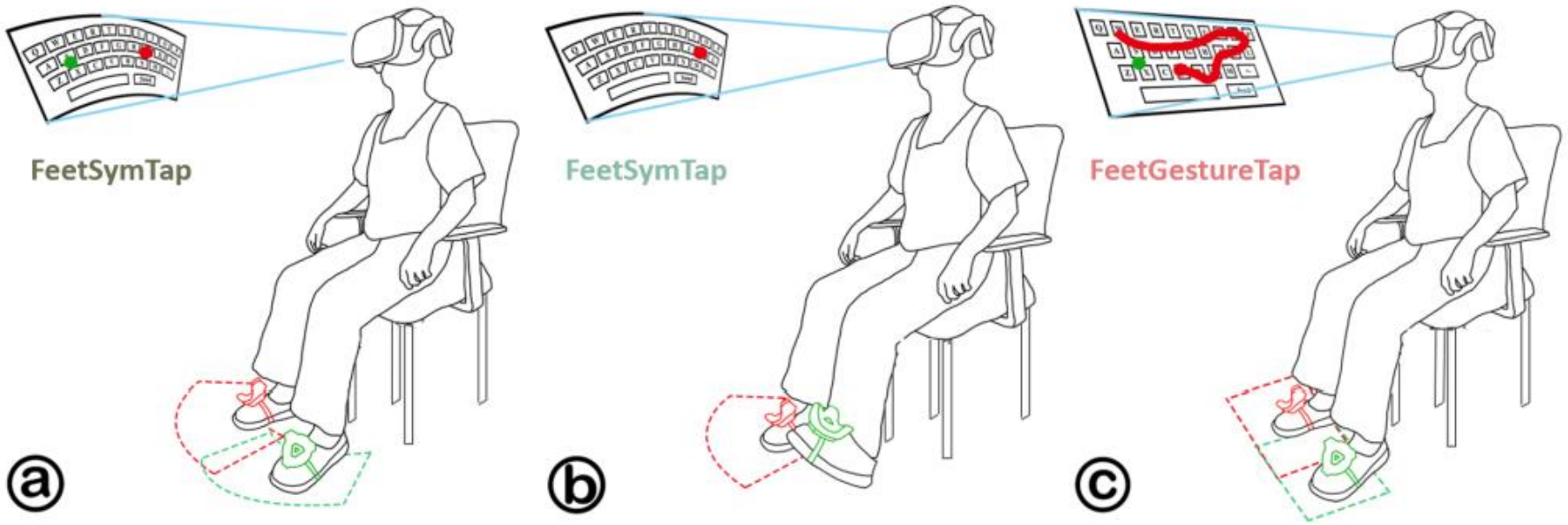
Symbolic input techniques

- Keyboard-based
  (Miniature, Chord, Soft keyboards, …)
- Gesture-based
  (Sign language gestures, other gestures)
- Speech-based
  (word/command recognition)

…

Text input is still a challenge

A recent proposal …



[Exploration of Foot-based Text Entry Techniques for Virtual Reality Environments | 2024 ACM CHI]

Strategies in Designing 3D User Interfaces for VEs

- There are some general high-level strategies and principles
  - Can be used in a wide variety of 3D tasks and applications
  - Some are based on the characteristics of human psychology and physiology
  - Others are based on common sense and cultural metaphors

- Examples:
  - Feedback
  - Constraints
  - Two hand interaction

Constraints

- Artificial limitations designed to help users interact more precisely or efficiently

- Examples:

  - Snap-to grid
  - Intelligent objects
  - Single DOF controls

Passive haptic Feedback

- Props or “near-field” haptics

- Examples:
  - Flight simulator controls
  - Steering wheel

- Increase presence, improve interaction

J. C. Mcclelland, R. J. Teather, “HaptoBend : Shape-Changing Passive Haptic Feedback in Virtual Reality,” in *ACM Symp. on Spatial User Interaction SUI’17*, 2017, pp. 82–90. https://dl.acm.org/doi/pdf/10.1145/3131277.3132179

Passive haptic Feedback
another example:

Haptic feedback in immersive VEs in a simple and cost-effective way

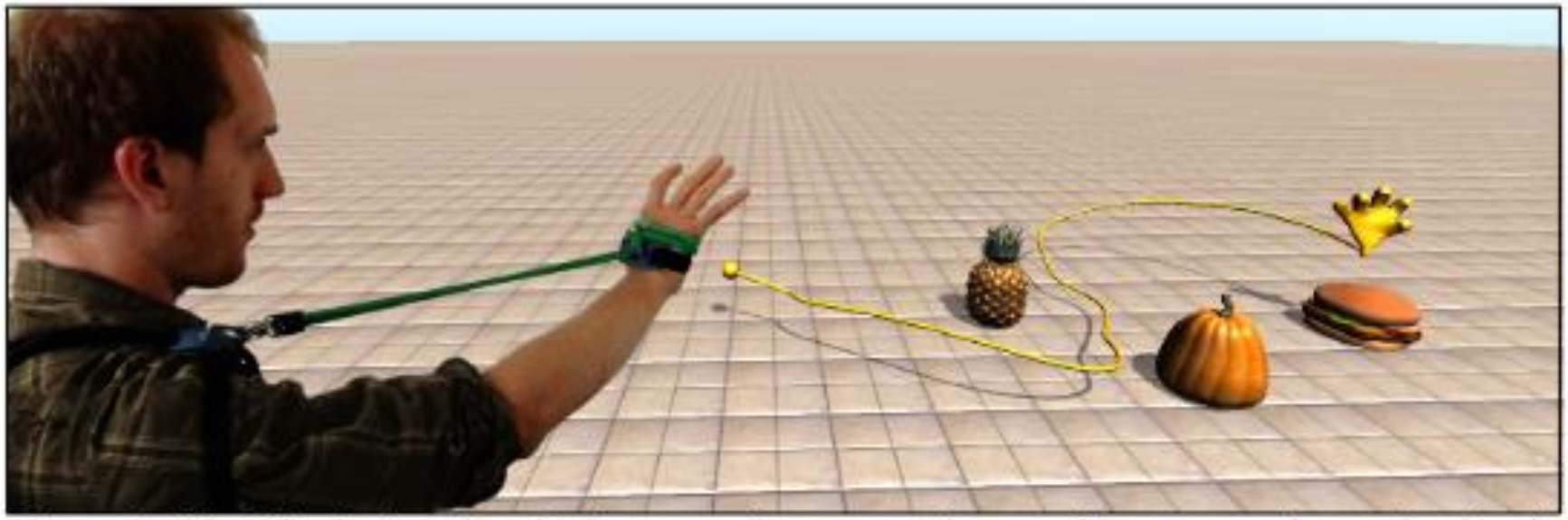


Figure 1. The Elastic-Arm is a body-mounted armature that provides egocentric passive haptic

M. Achibet *et al.*, "Leveraging Passive Haptic Feedback in Virtual Environments with the Elastic-Arm Approach," *Presence Teleoperators Virtual Environ.*, vol. 25, no. 1, pp. 17–32, 2016. https://doi.org/10.1162/PRES_a_00243

Combining Dynamic Passive Haptics and Haptic Retargeting for Enhanced Haptic Feedback in Virtual Reality 2021 IEEE TVCG

Two-handed interaction

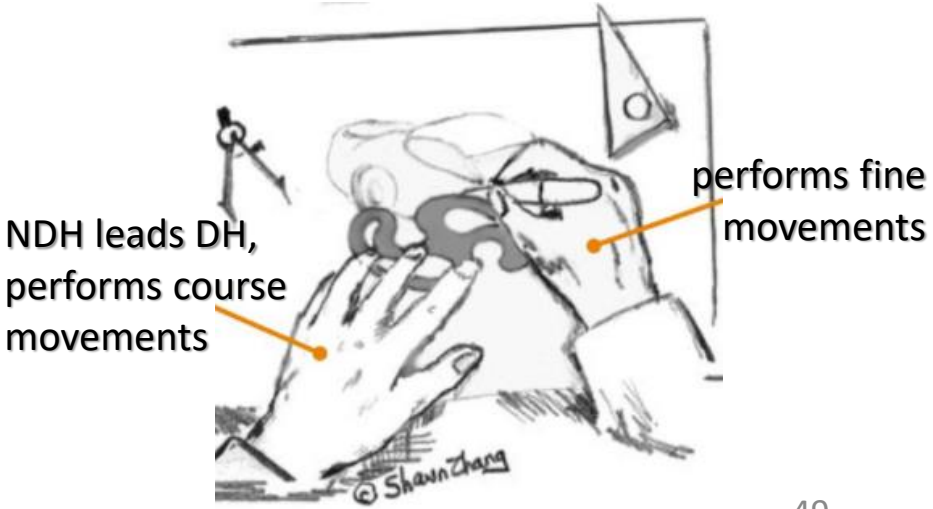
- Symmetric vs. Asymmetric
- Dominant vs. non-dominant hand
- Manipulation initiated by ND hand
- Guiard's principles

  - ND hand provides frame of reference
  - ND hand used for coarse tasks,

    D hand for fine grained tasks

(ND – Non-Dominant)

A virtual training simulator for learning cataract surgery with phacoemulsification - ScienceDirect



(MacKenzie, 2003)

Interaction Patterns for VR

"Generalized **high interaction concept** that can be used over and over again across different applications to achieve common user goals" (Jerald , 2016)

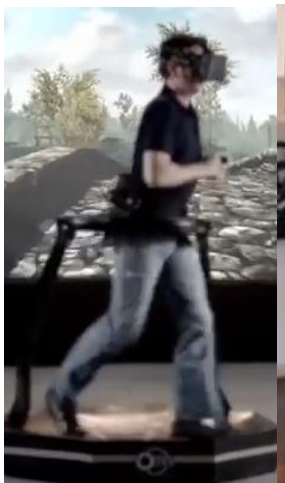
- Common approaches to general problems:
  - described from the user's point of view,
  - ≈ implementation independent

- **Interaction techniques** are more specific and technology dependent

- Similar techniques may be grouped

  under the same interaction pattern

  e.g. Walking pattern -> real walking and walking in place



Interaction Patterns for VR

- Interaction patterns and interaction techniques provide conceptual models to experiment with, and starting points for innovative designs (Jerald , 2016)

- Designers should not fall into the trap that there is a single best interaction pattern or technique.

- Each pattern and technique has strengths and weaknesses depending on the users and application goals

- Understanding distinctions and managing trade-offs is essential to creating high-quality interactive experiences

Interaction Patterns for VR

- Distinguishing between interaction patterns and techniques is useful:
  - There are many existing interaction techniques and many more will be developed
  - Higher-level groupings **enable easier systematic analysis and comparison** …

- Important interaction patterns:
  - Selection Patterns
  - Manipulation Patterns
  - Viewpoint Control Patterns
  - Indirect Control Patterns
  - Compound Patterns

- **Selection** - specification of one or more objects from a set in order to state an object to which a command will be applied, to denote the beginning of a manipulation task, or to specify a target to travel toward
  - Hand Selection Pattern,
  - Pointing Pattern,
  - Image-Plane Selection Pattern,
  - Volume-Based Selection Pattern

- **Manipulation** - modification of attributes for one or more objects such as position, orientation, scale, shape, color, and texture
  - Direct Hand Manipulation Pattern,
  - Proxy Pattern,
  - 3D Tool Pattern

- **Viewpoint control** - task of manipulating one's perspective and can include translation, orientation, and scale (equivalent to moving, rotating, scaling the world)
  - Walking Pattern,
  - Steering Pattern,
  - 3D Multi-Touch Pattern,
  - Automated Pattern

- **Indirect Control -** provides control through an intermediary to modify an object, the environment, or the system. Is more abstract than previous patterns
  - Widgets and Panels Pattern and Non-Spatial
  - Control Pattern

- **Compound Patterns -** combines two or more patterns into more complicated patterns
  - Pointing Hand Pattern,
  - World-in-Miniature Pattern,
  - Multimodal Pattern.

Example of a Pattern: The Walking Pattern

- **Uses motion of the feet to control the viewpoint**
- Includes everything from real to mimicking walking
- Advantages:
  - provides a high degree of interaction fidelity
  - enhances presence and ease of navigation
  - spatial orientation and movement understanding
  - ideal for navigating small to medium-size spaces
  - results in no motion sickness if implemented adequately
- Limitations:
  - not appropriate for rapid or distant navigation
  - may require a large tracked space
  - cable can be a tripping hazard

Guidelines for Easy-to-Use 3D Interaction Techniques

- Floating objects are the exception
- Objects don’t interpenetrate
- Interaction should be only with Visible Objects
- Perspective and occlusion are the strongest depth cues
- People see the object, not the cursor
- ….

What future to 3DUI?

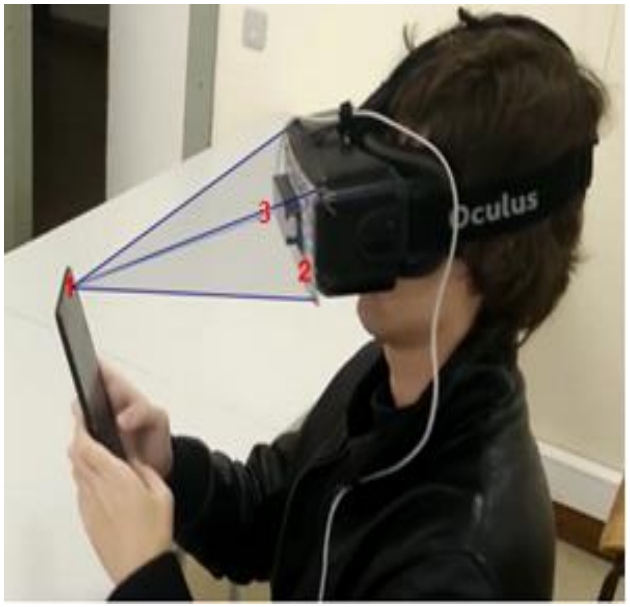
- The design domain of 3D UI is rapidly expanding due to recent technology advancements and new interaction techniques
- **No single configuration is right for all conditions**
- **3D UX crucial**
- **Excellent opportunities to 3DUI:**
  - Simulators
  - Games
- **Emerging topic: Hybrid User Interfaces**

  Opportunities and Challenges of HUIs for Optimization of MR Interfaces | IEEE (2023)

Hybrid User Interfaces

- Combine the visual and interaction spaces of complementary device technologies (such as augmented reality headsets and handheld devices) to take advantage of the strong points of each

  ISMAR 2023 Workshop on Hybrid UIs



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