Simulation et Applications Interactives

Interactives Applications

Caroline Larboulette

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Overview

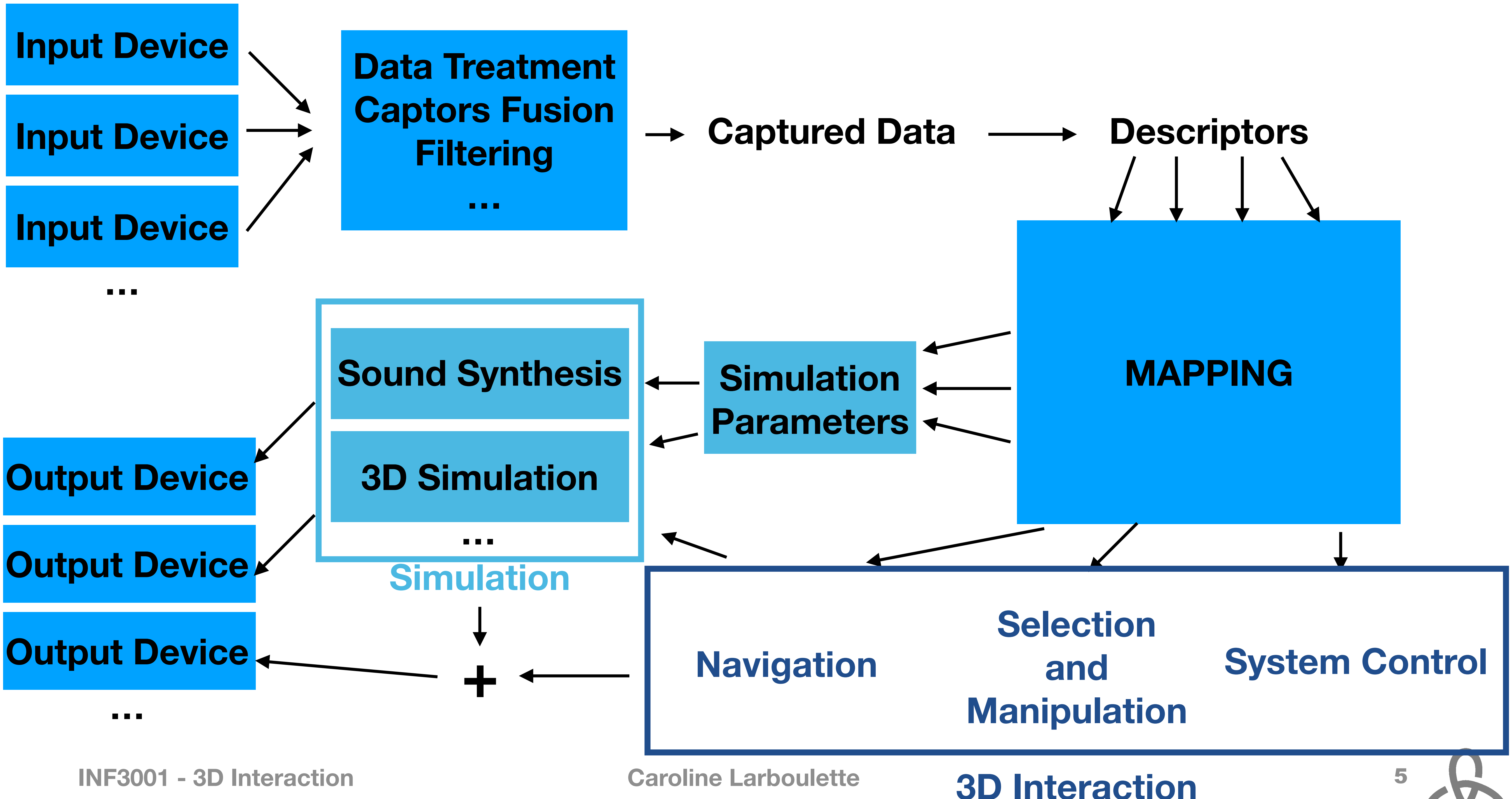
- Principle of Interactive Applications
- Motion Descriptors
- Mapping to Simulation Parameters
- 3D Interaction Techniques

Principle of Interactive Applications

Definition
Interactive Application

- Interactive means that the user interacts with the system in real-time
- Interaction in VR-AR (i.e. in the 3D world): 3D interaction

Multi-Modal Interactive Application



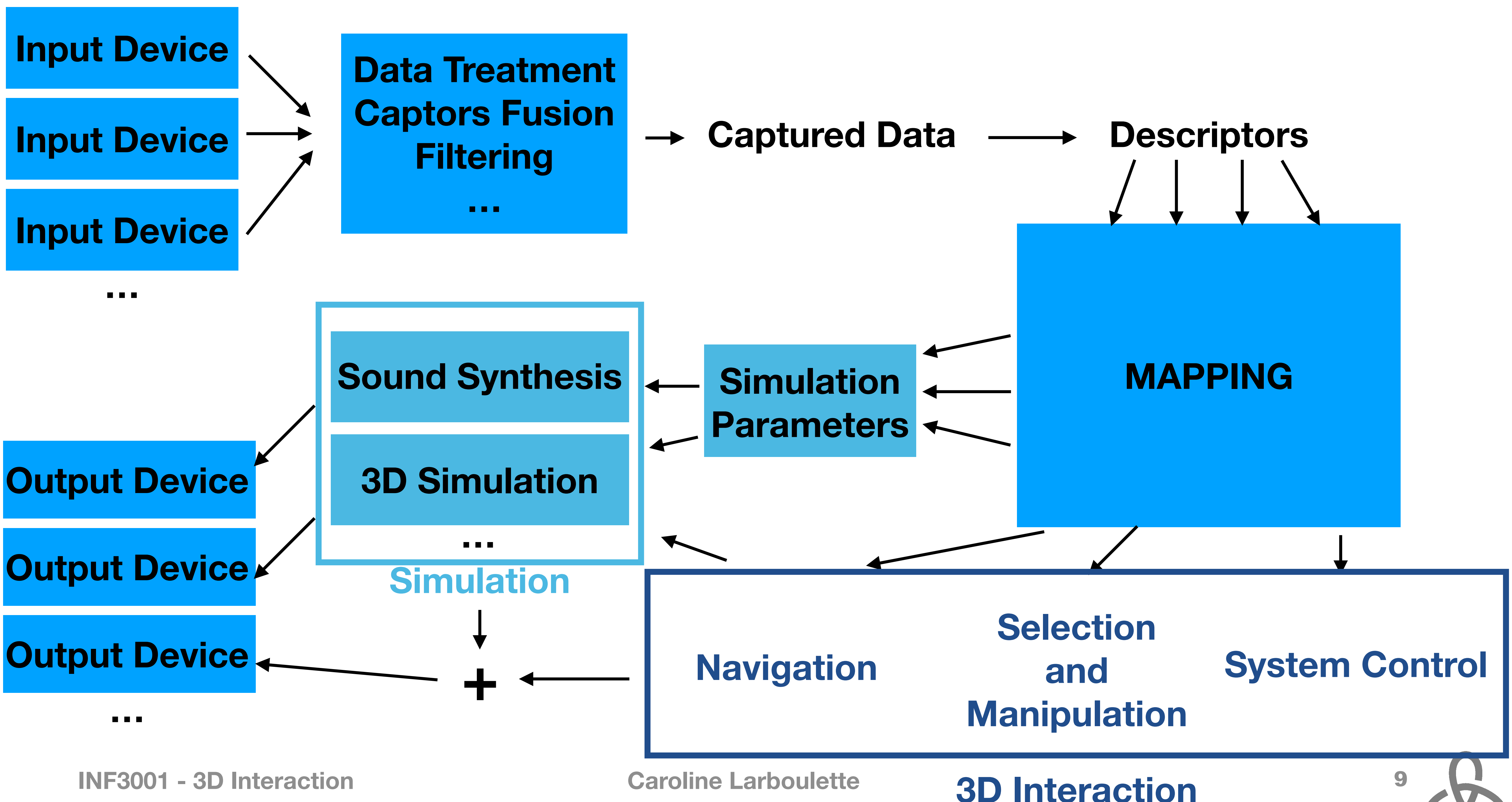
Input Devices

- Joysticks
- Tablets
- Hands / Body (through mocap, RGBD, camera or other types of sensors)
- Other

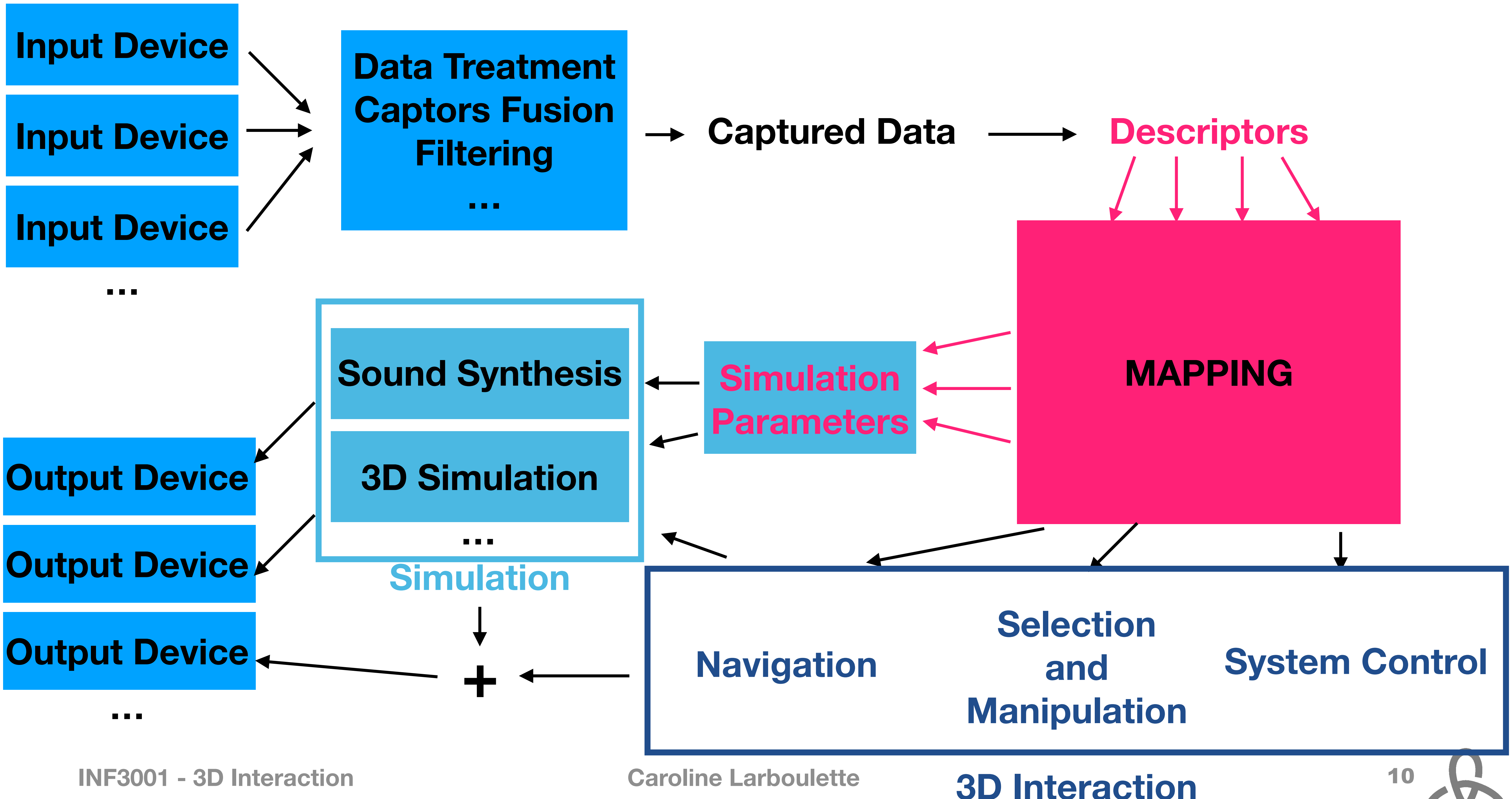
Motion Descriptors

Mapping to Simulation Parameters

Multi-Modal Interactive Application

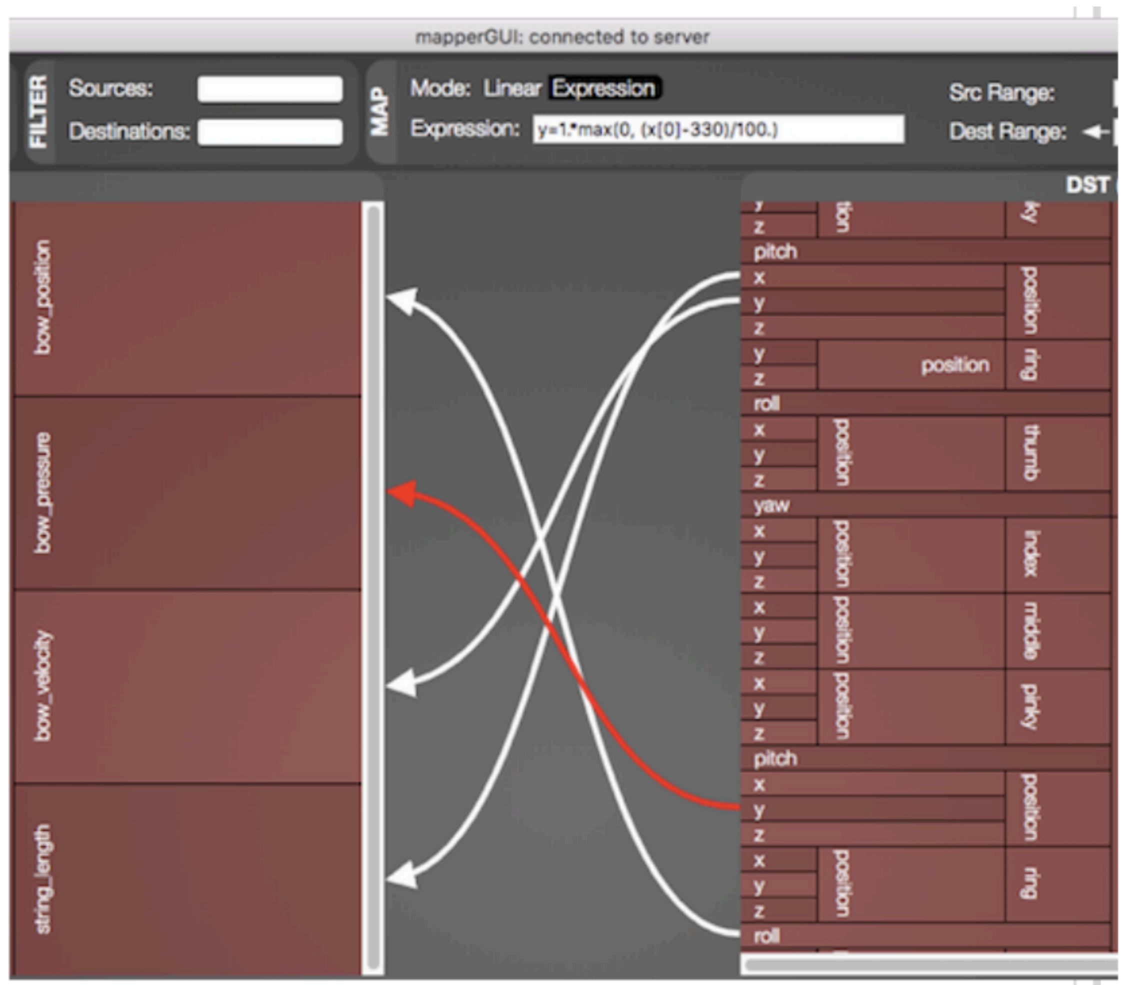


Multi-Modal Interactive Application



Mapping

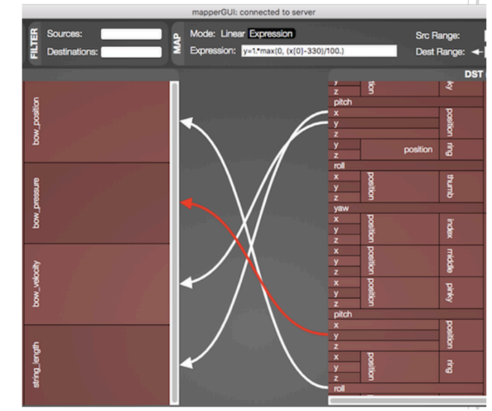
Problem Formulation



$$\textbf{Parameter}_i = f(\textbf{Descriptor}_1, \ldots, \textbf{Descriptor}_n)$$

Mapping

One-to-one vs coupled



- One-to-one mapping : function f depends on a single descriptor: $\text{Parameter}_i = f(\text{Descriptor}_j)$

- Many-to-many (coupled) : function f depends on n descriptors: $\text{Parameter}_i = f(\text{Descriptor}_1, \ldots, \text{Descriptor}_n)$

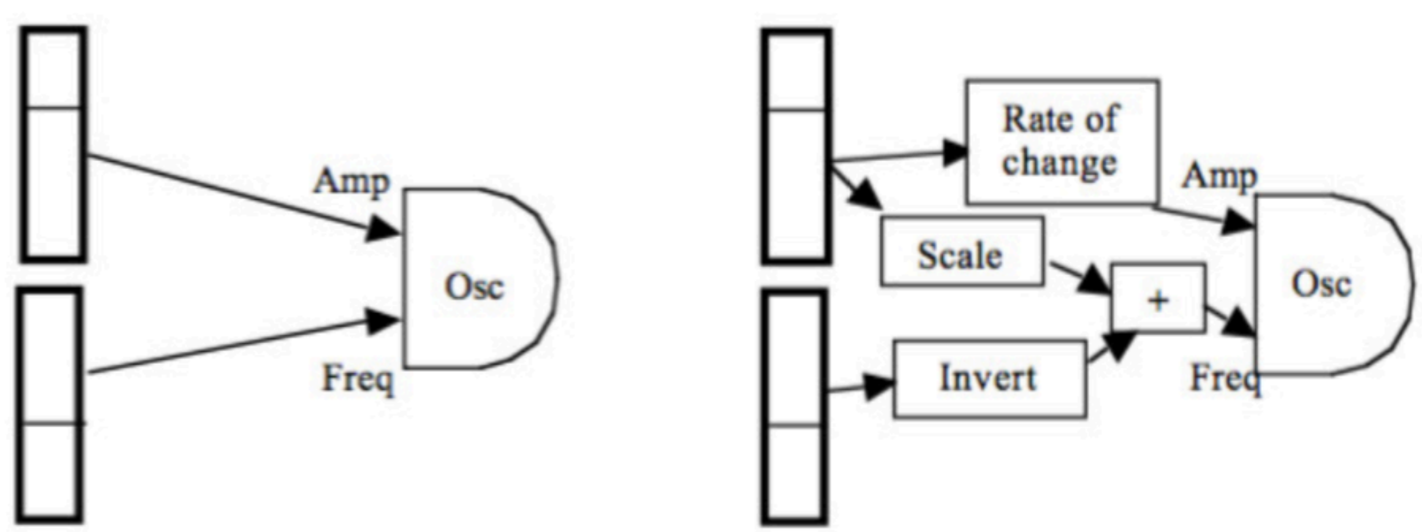
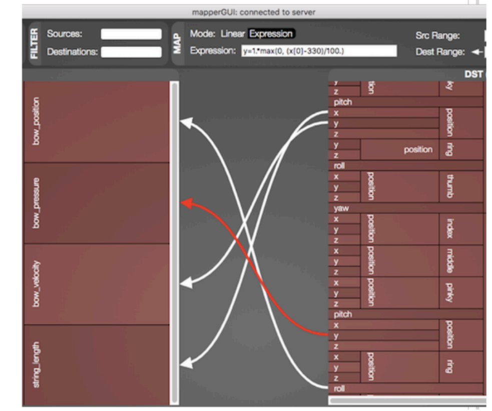


Figure 3: Left: one-to-one explicit mappings from sliders to an oscillator. Right: coupled explicit mappings. (images from [Hunt and Wanderley, 2002b])

Mapping
Explicit vs Generative



$$\text{Parameter}_i = f(\text{Descriptor}_1, \ldots, \text{Descriptor}_n)$$

- Explicit : function f is specified by hand
- Generative : function f is learned

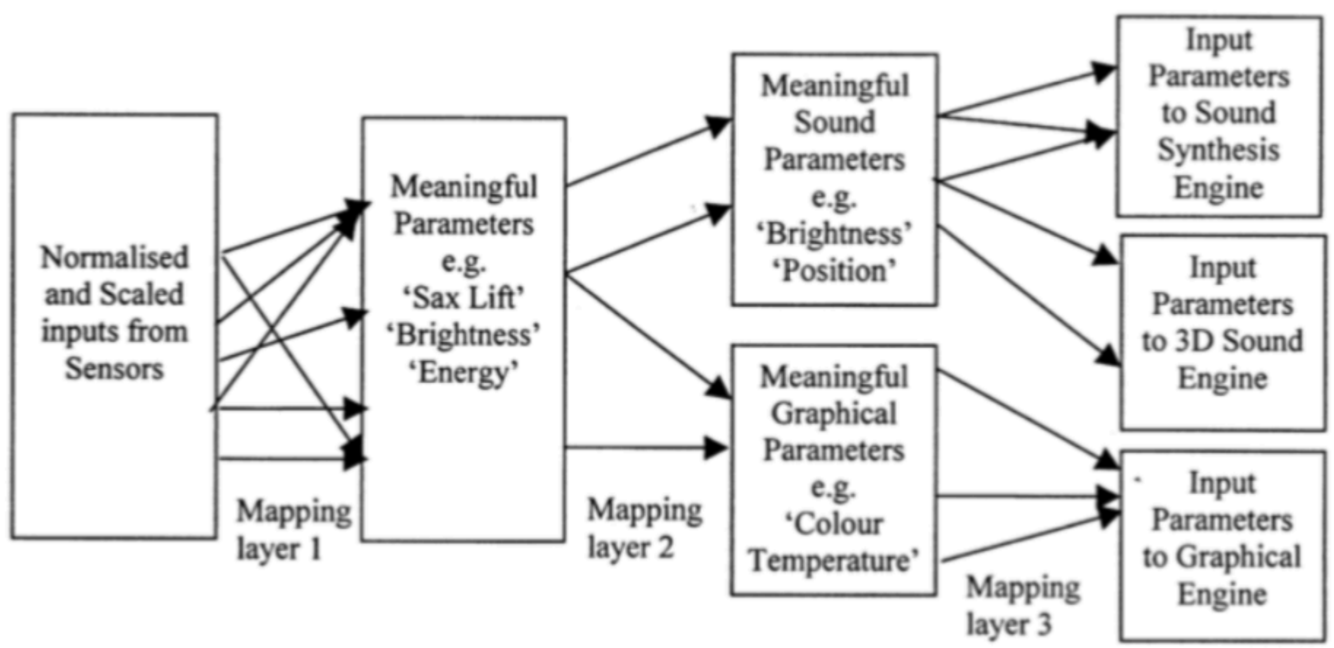
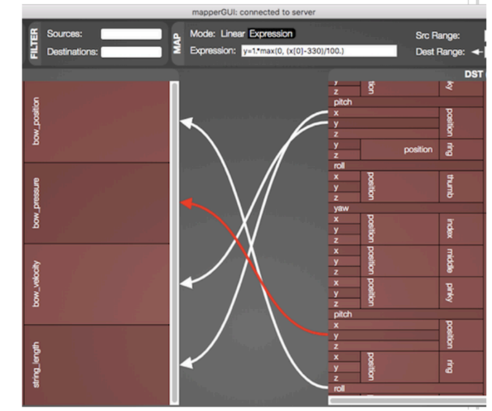


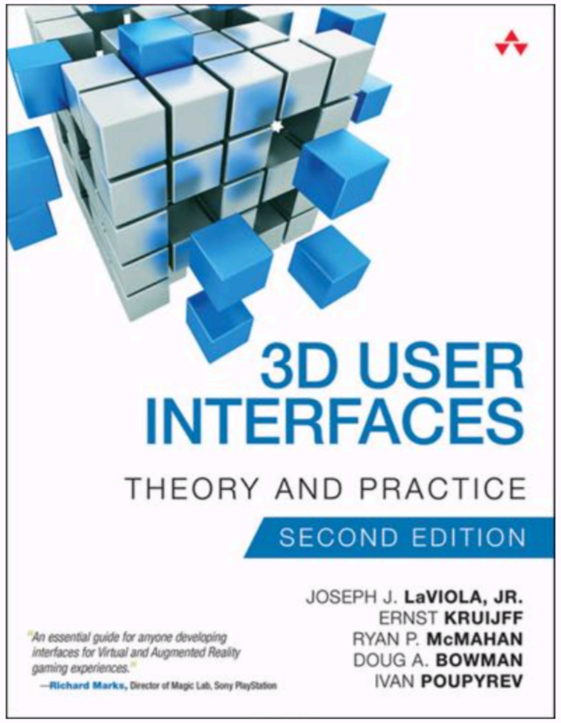
Figure 4: A three-layer concept would to abstract parameters from input and outputs and allow the insertion of other media than sound (image from [Hunt and Wanderley, 2002b]).

Mapping
Explicit vs Generative



$$\text{Parameter}_i = f(\text{Descriptor}_1, \ldots, \text{Descriptor}_n)$$

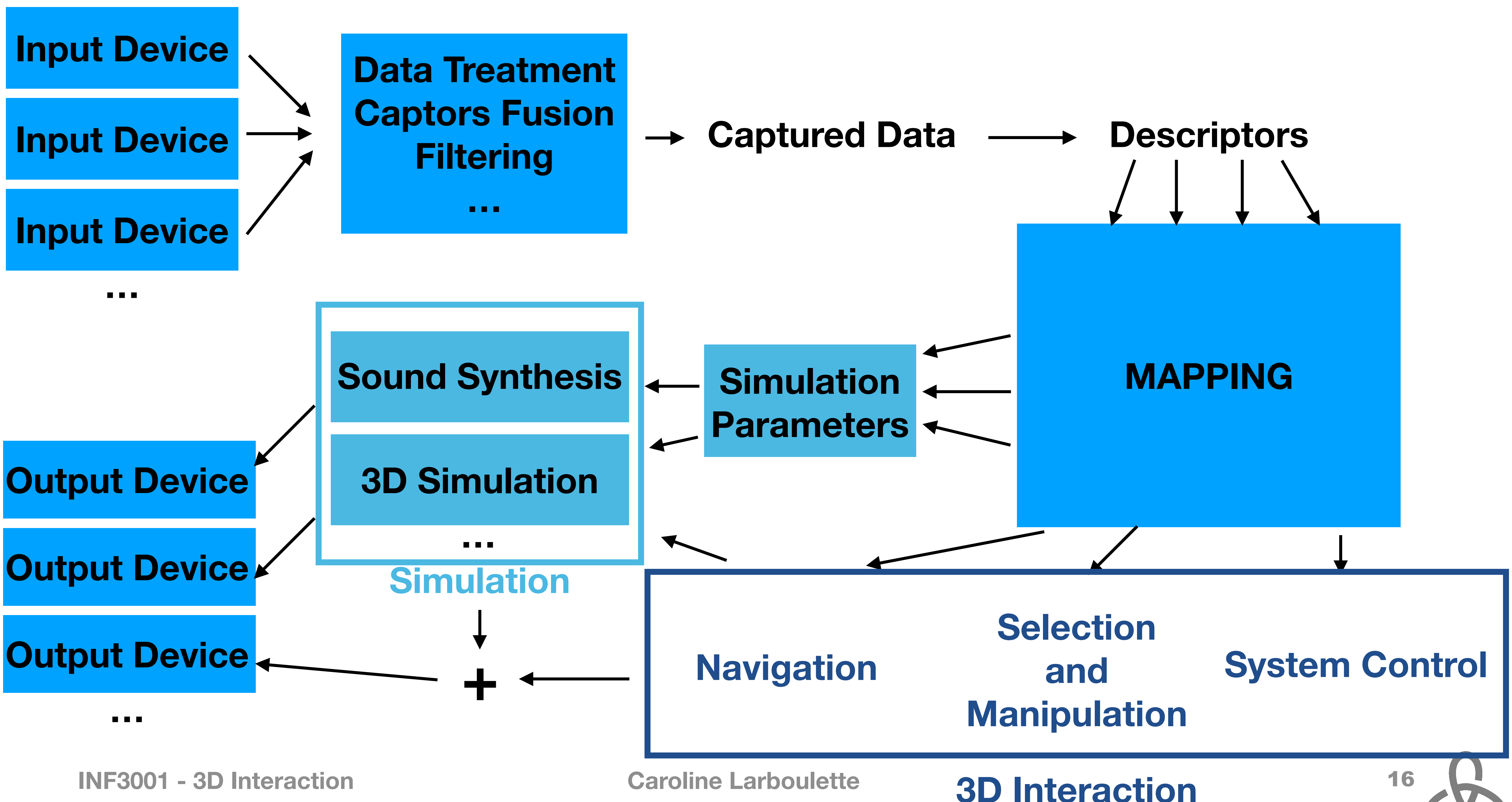
- **Expert-defined** : function f is specified by the creator of the program or an expert (explicitly of through machine learning algorithms)
- **User-defined** : function f is learned **interactively**
    - Mapping is dynamically modified during performance
    - Mapping is adapted to each user



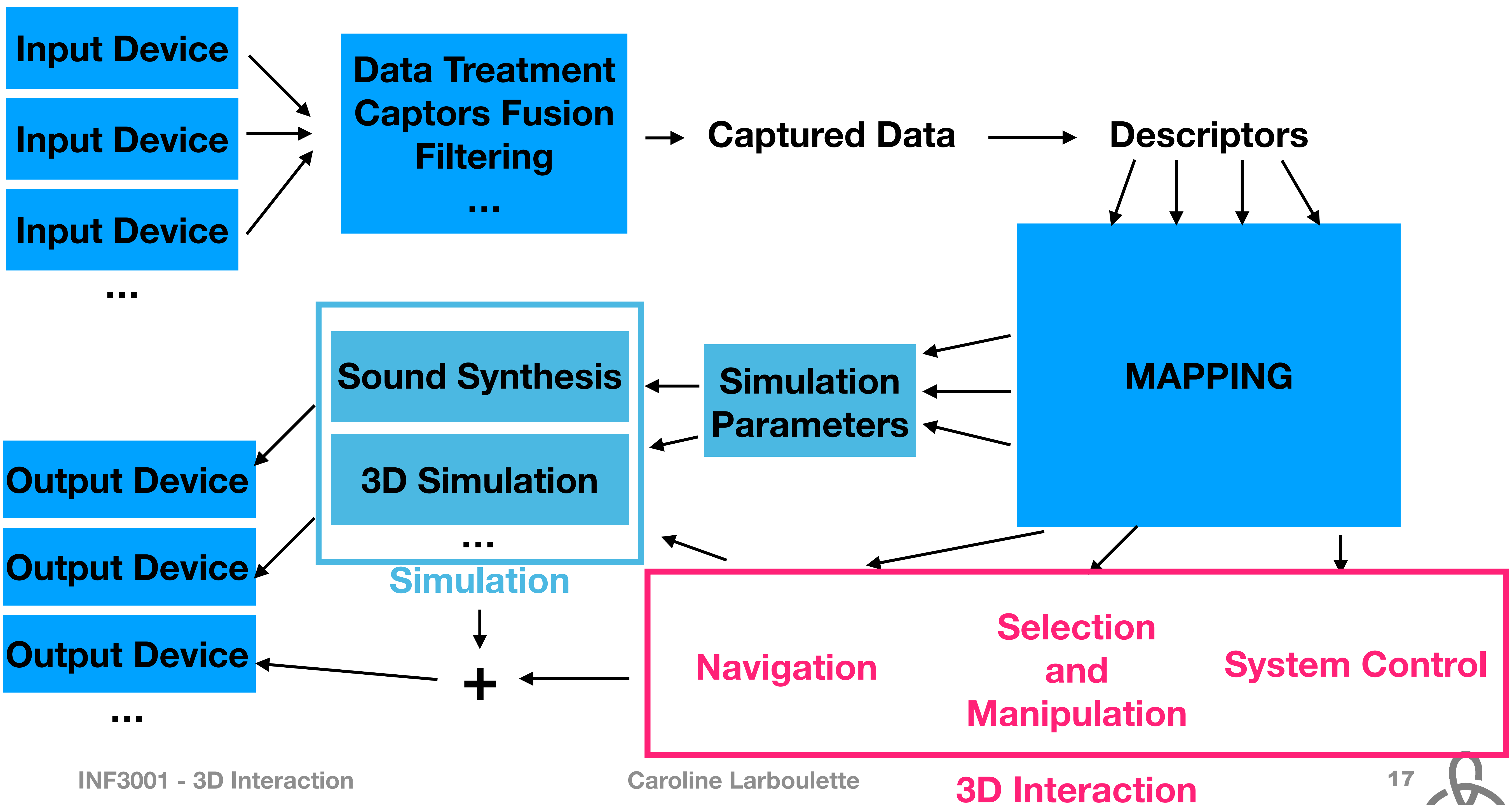
3D Interaction Techniques

Riecke, B. E., LaViola Jr., J. J., & Kruijff, E. (2018). 3D User Interfaces for Virtual Reality and Games: 3D Selection, Manipulation, and Spatial Navigation. In Proceedings of ACM SIGGRAPH 2018 Courses (SIGGRAPH' 18). Vancouver, BC, Canada.

Multi-Modal Interactive Application



Multi-Modal Interactive Application



3D Interaction Techniques

- Choosing the right input and output devices is not sufficient for an effective 3D User Interface (3DUI)
- Need to add 3D interaction techniques, i.e., methods to accomplish a task via the interface
  - Hardware components
  - Software components: control-display mappings or transfer functions
  - Metaphors or concepts

Universal 3D Interaction Tasks

- 4 Basic 3D interaction tasks
  - Navigation
  - Selection
  - Manipulation
  - System Control
- Can be combined to create more complex tasks

Universal 3D Interaction Tasks
Navigation

- Composed of two tasks
  - Travel
    - Motor component, i.e. physical movement from place to place
  - Wayfinding
    - Cognitive component, i.e. decision making component: Where am I ? Where do I want to go ? How do I get there ?

Universal 3D Interaction Tasks

Selection

- Picking object(s) from a set
- Specification of an object or a group of objects

Universal 3D Interaction Tasks

Manipulation

- Modifying object properties
  - Position
  - Orientation
  - Other attributes
- Needs selection first

Universal 3D Interaction Tasks
System Control

- Issuing a command to change
  - System state
  - System mode of interaction
- May need selection first (for example, to delete an object)

Navigation

Navigation
Travel

- Travel = viewpoint movement
- Implementation issues
  - Velocity / acceleration control
  - Is world rotation necessary ? (CAVE vs HTC)
  - Constrained motion
    - Constant height
    - Terrain following
  - Condition of input (start / stop)

Navigation
Travel

- Common travel techniques
  - Gaze-directed steering
  - Pointing
  - “Grabbing the air”
  - Locomotion devices

Navigation

Travel : Gaze-directed Steering

- Move viewpoint in direction of gaze
- Gaze direction determined from head tracker (usually no eye-tracking)
- Cognitively simple
  - Decouples navigation from pointing (manipulation)
- Doesn’t allow the user to look to the side while traveling
- Going around curves not natural

Navigation

Travel : Gaze-directed Steering

Implementation

- For each frame while moving
  - Get head tracker information
  - Transform vector [0,0,-1] in head CS to v[x,y,z] in World CS
  - Normalize v
  - Translate viewpoint by $\overrightarrow{T_i} = \overrightarrow{v} \,.\, velocity_i$
  - velocity is a scalar in units/second

Navigation

Travel : Pointing

- Steering technique using the hand
- User continuously specifies the direction of motion
- Hand's orientation is used to determine direction
- Uses hand tracker (instead of head tracker)
- More flexible but slightly more cognitively complex than gaze-directed steering
  - Requires control of two orientations simultaneously
- Allows travel and gaze in different directions (user can look around)

Navigation

Travel : Pointing

© Schulze

Navigation
Travel : Pointing

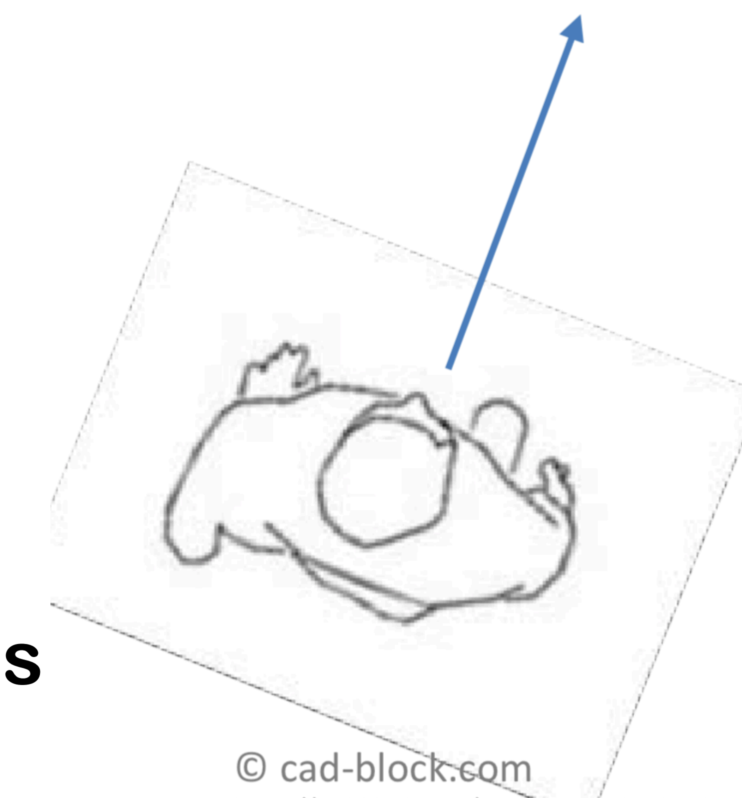
Implementation

- For each frame while moving
  - Get hand tracker information
  - Transform vector [0,0,-1] in hand CS to v[x,y,z] in World CS
  - Normalize v
  - Translate viewpoint by $\overrightarrow{T_i} = \overrightarrow{v} \,.\, velocity_i$
  - velocity is a scalar in units/second

Navigation

Travel : Torso-directed Steering

- Steering technique using the torso
- Torso's orientation is used to determine direction
  - People naturally turn their bodies to face walking direction
  - Tracker attached to user's torso, best at waist level to avoid unwanted rotations
- Decouples user's gaze and travel directions
- Can only be used on horizontal plane
- Requires an additional tracker



© cad-block.com
https://cad-block.com/5-people-in-plan.html

Navigation

Travel : Leaning-directed Steering

- Interprets leaning direction as direction for travel
  - Wii balance board
- Integrate direction and speed into a single, easy to understand, movement
  - Rely on natural proprioceptive / kinaesthetic senses
  - Mostly limited to 2D navigation
  - Can be more accurate for traveling than pointing

[von Kapri et. al 2011]   https://www.youtube.com/watch?v=9dz4S3s7KXw

Navigation

Travel : Grabbing the air

- Use hand gestures to move yourself through the world
- Metaphor of pulling a rope
- Often a two-handed technique
- May be implemented using Pinch Gloves

Navigation

Travel : Grabbing the air

Implementation

- For one hand (do the same for the other hand, make sure they are not both activated at the same time)
- On pinch, obtain initial hand position in world CS: H
- For each frame until release
  - Obtain current hand position in world CS: H'
  - Compute hand motion vector: m = H' - H
  - Translate world by m (or viewpoint by -m)
  - H = H'
- Constrained motions can be obtained by dropping a DOF

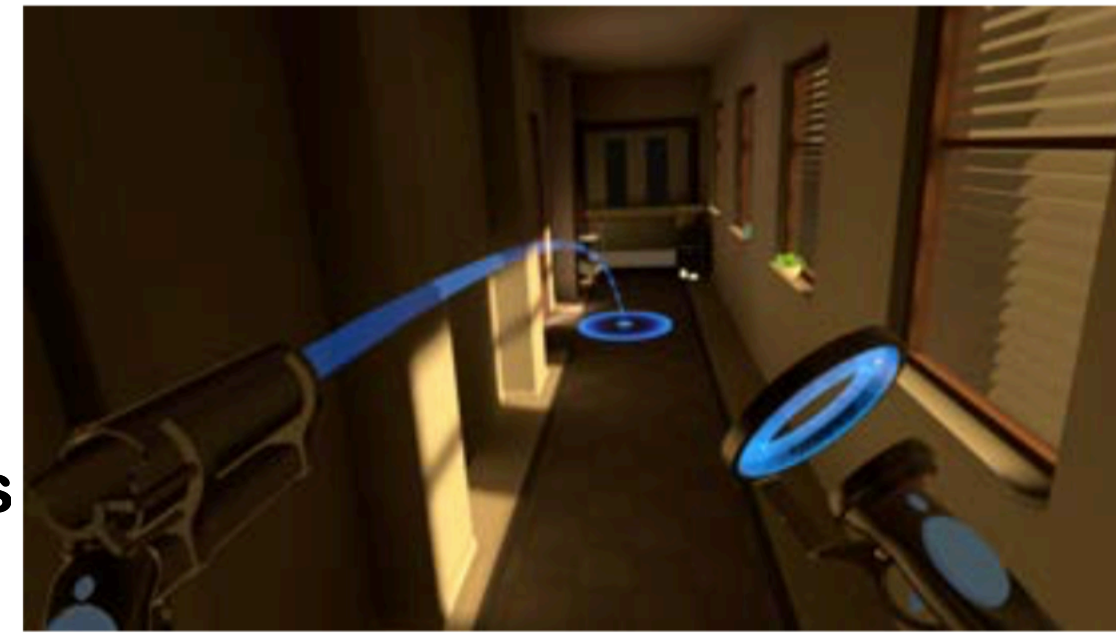
Navigation
Locomotion Devices

- Treadmills
  - Single-direction
  - Omni-directional
- Stationary cycles
- Virtual Motion Controller / magic carpet

Navigation

Travel : Teleportation

- Variant of viewpoint manipulation
- Jumping between locations, move through environment quickly
- Location selection or through portals [Bozgeyikli et al.2016, Freitag et al. 2014]
- Works surprisingly well
- However
  - Can disturb spatial orientation
  - Blink-mode (fast transition) recommended over immediate position change



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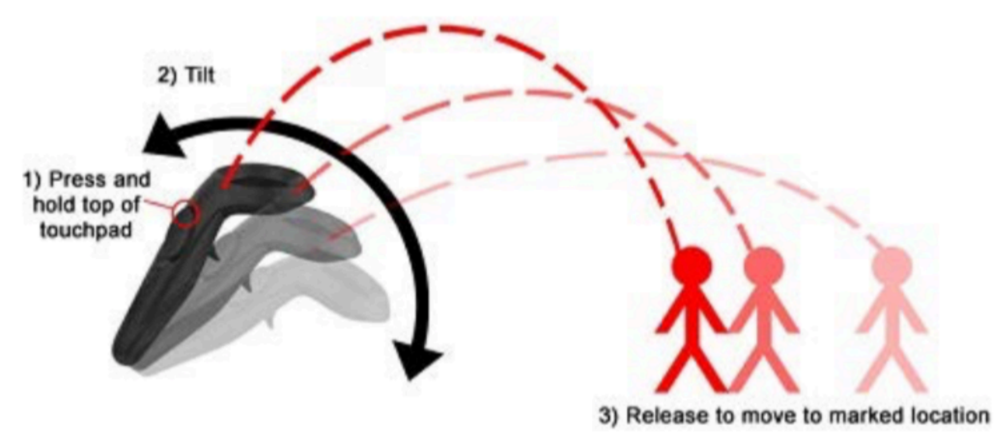
https://o.aolcdn.com/images/dims?quality=100&image_uri=http%3A%2F%2Fo.aolcdn.com%2Fhss%2Fstorage%2Fmidas%2F736a2c6418392731c8c255cbc51f4165%2F204430761%2Fss_5c73165c7fa91e2446342f091ce4a3e5b70969b6.1920x1080-ed.jpg&client=cbc79c14efcebee57402&signature=d6



© Fuzor
http://images.kalloctech.com/Vive_1.jpg

Navigation

Travel Tasks (1)

- Travel (and navigation in general) often supports another task rather than being an end unto itself
- Exploration / browsing
  - Often no explicit goal
  - Gathering information about space / objects, learning environment
  - Need for a continuous and direct control + ability to stop

Navigation

Travel Tasks (2)

- Travel (and navigation in general) often supports another task rather than being an end unto itself
- Exploration / browsing
- Search
  - Has specific target / goal
  - Might not know how to get there

Navigation

Travel Tasks (3)

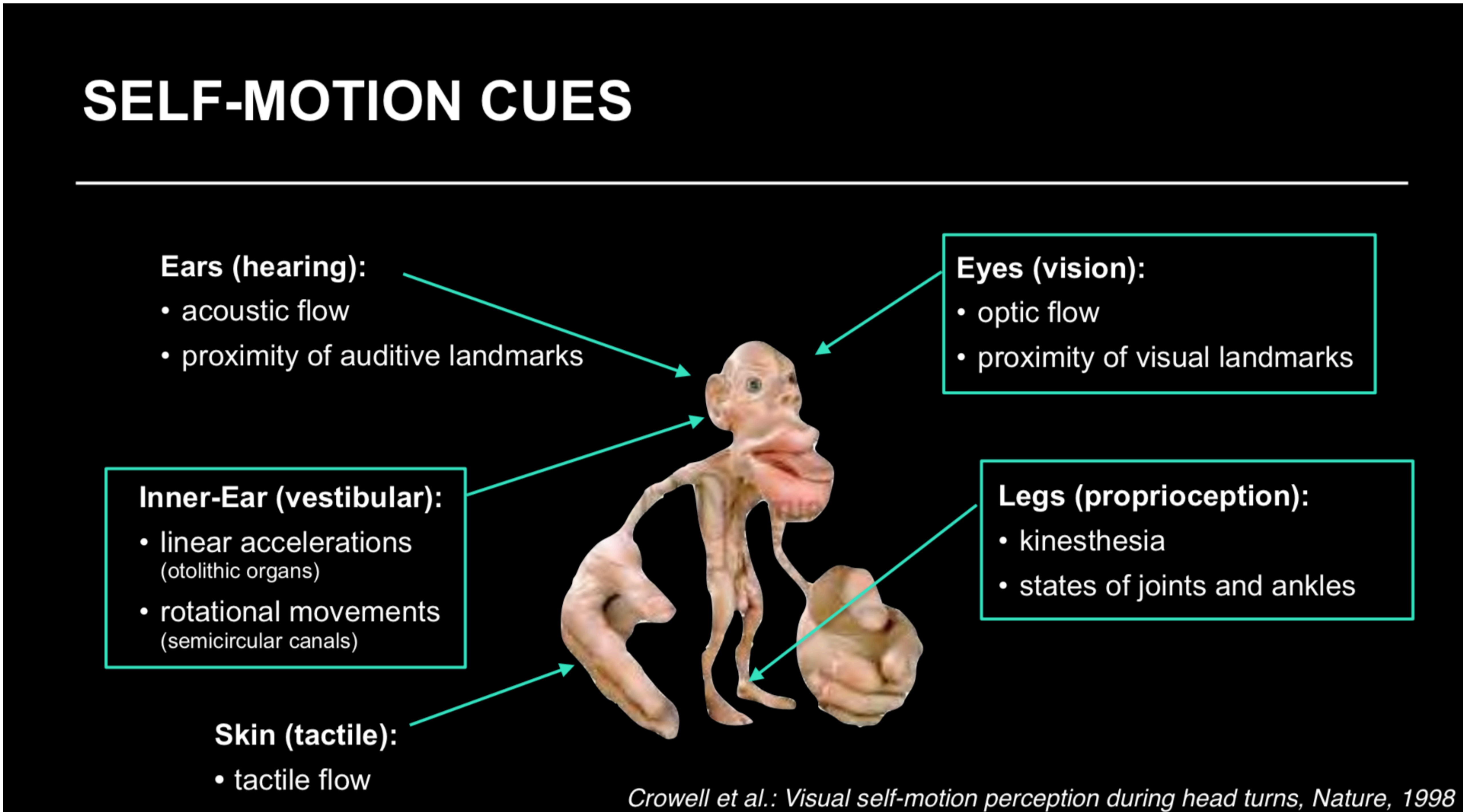
- Travel (and navigation in general) often supports another task rather than being an end unto itself
- Exploration / browsing
- Search
- Maneuvering
  - Involves small and precise movement (local task)
  - Can be time-consuming and frustrating
  - Need to provide balance between precision and speed + high usability

Navigation

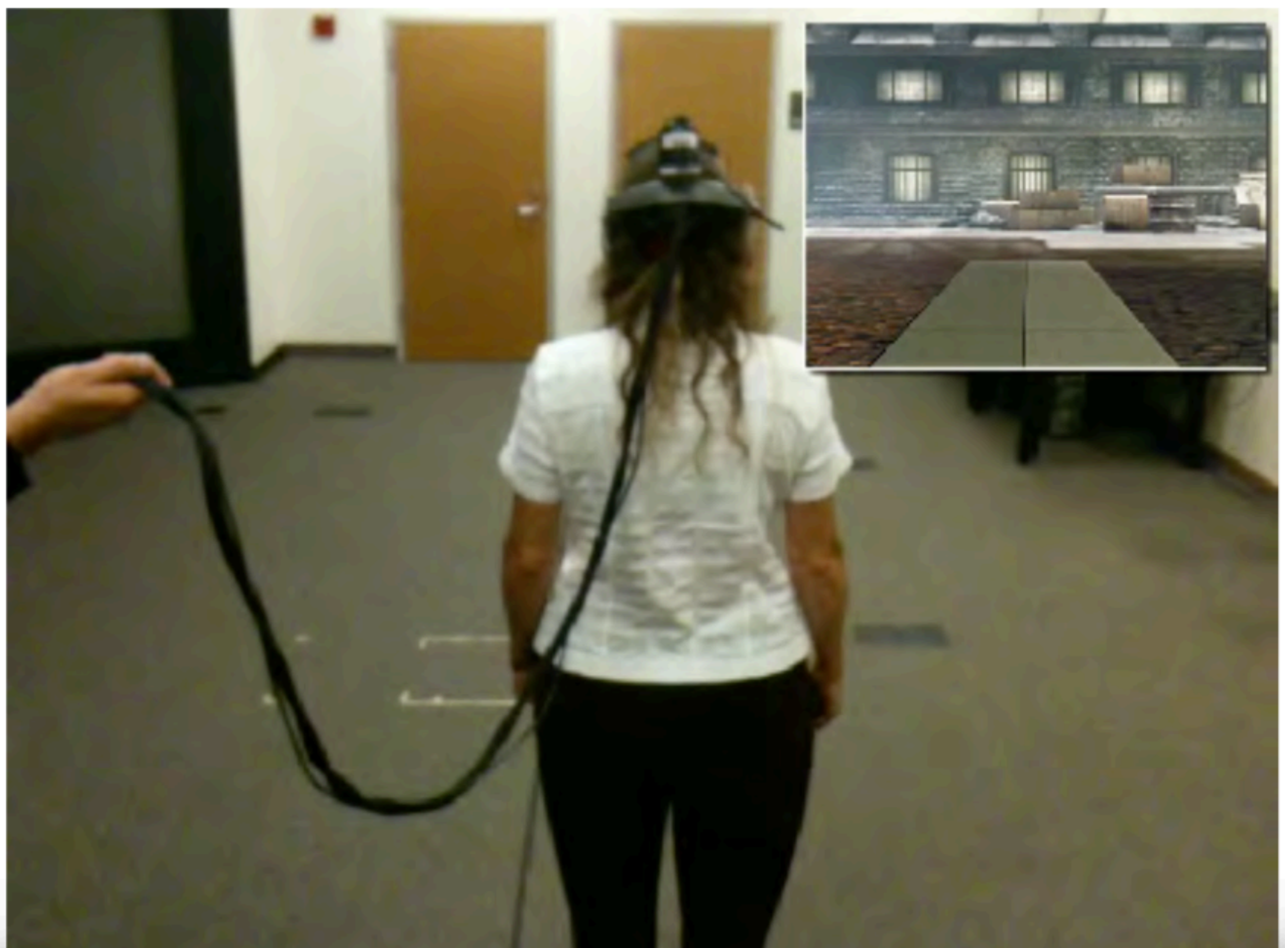
Travel Design Guidelines

- Make simple travel tasks simple (target-based techniques for motion to an object, steering techniques for search).
- Provide multiple travel techniques to support different travel tasks in the same application.
- Use graceful transitional motions if overall environment context is important.
- Train users in sophisticated strategies to help them acquire survey knowledge.
- Consider integrated (“cross-task”) ITs if travel is used in the context of another task (e.g. manipulation).

Navigation
Redirected walking



Navigation
Redirected walking



vestibular + proprioceptive

vestibular

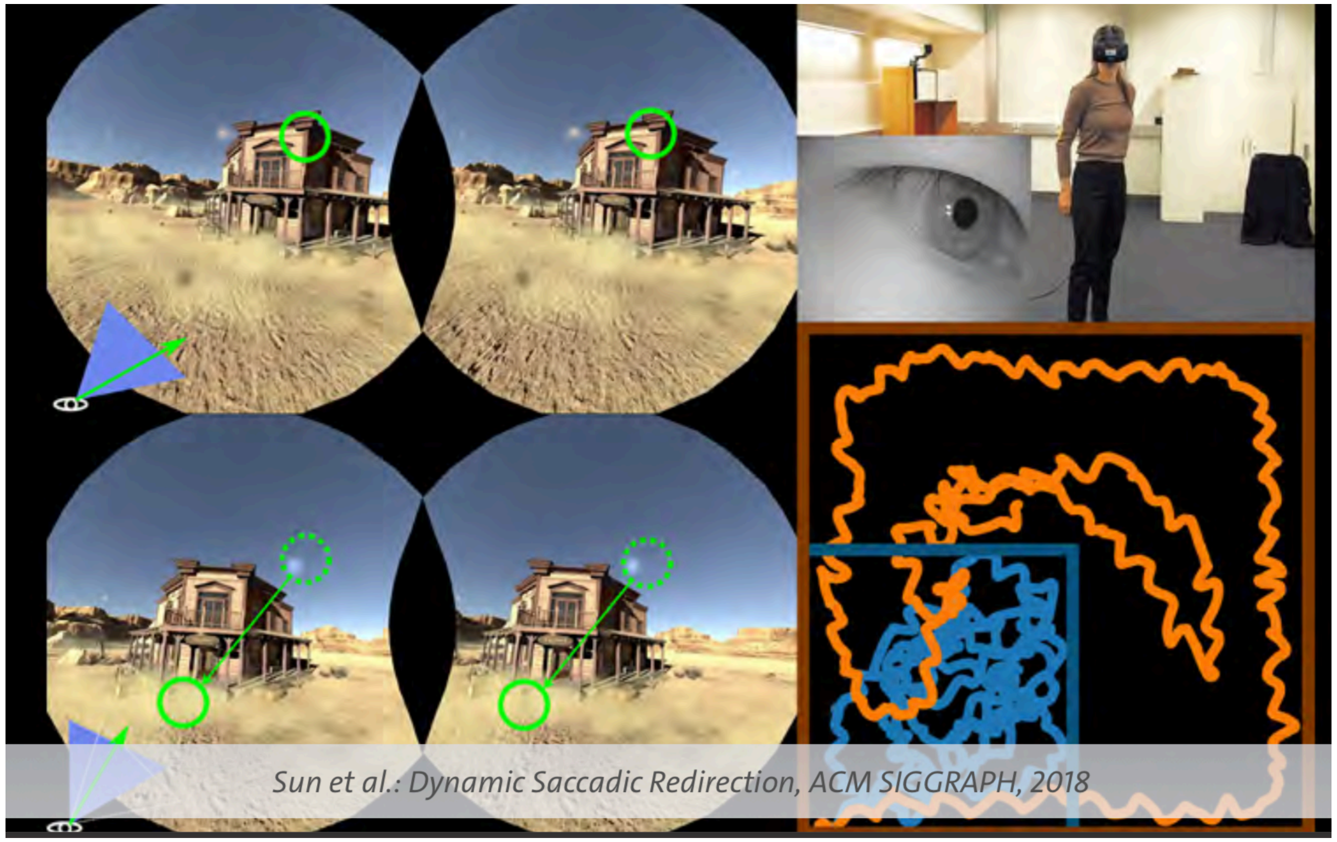
Navigation
Redirected walking

- Problem: in a limited space, how can the user move like the space is much bigger ?
  - Scaling the user
  - Teleportation

https://www.youtube.com/watch?v=8j844h-I_i4

Navigation

Redirected walking



Towards Virtual Reality Infinite Walking: Dynamic Saccadic Redirection - SIGGRAPH 2018

- **Cheating during saccades**

https://www.youtube.com/watch?v=eDk4HrEtGrM

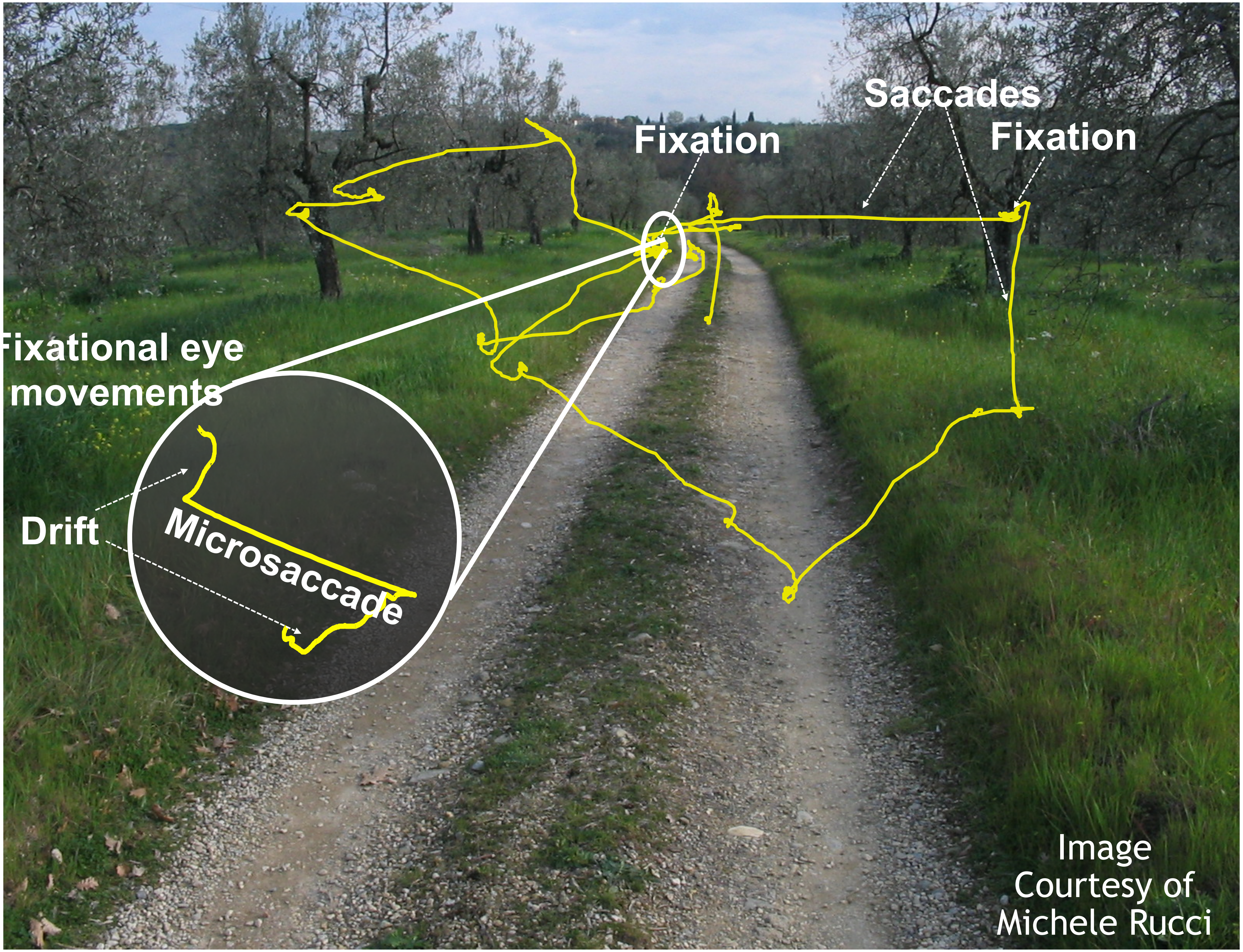
Navigation
Saccades

- Saccade : quick, simultaneous movement of both eyes between two or more phases of fixation in the same direction
- In smooth pursuit movements, the eyes move smoothly instead of in jumps.

Navigation

Saccades

Speed: 200 deg/sec (avg), 700 deg/sec (max)
Duration: 20 ~ 200 ms
Size: Mostly < 20 deg
Frequency of occurrence: roughly 2 / sec


Saccades
Fixation
Fixation
Fixational eye
movements
Drift
Microsaccade
Image
Courtesy of
Michele Rucci

BEFORE, DURING, AND AFTER A SACCADE

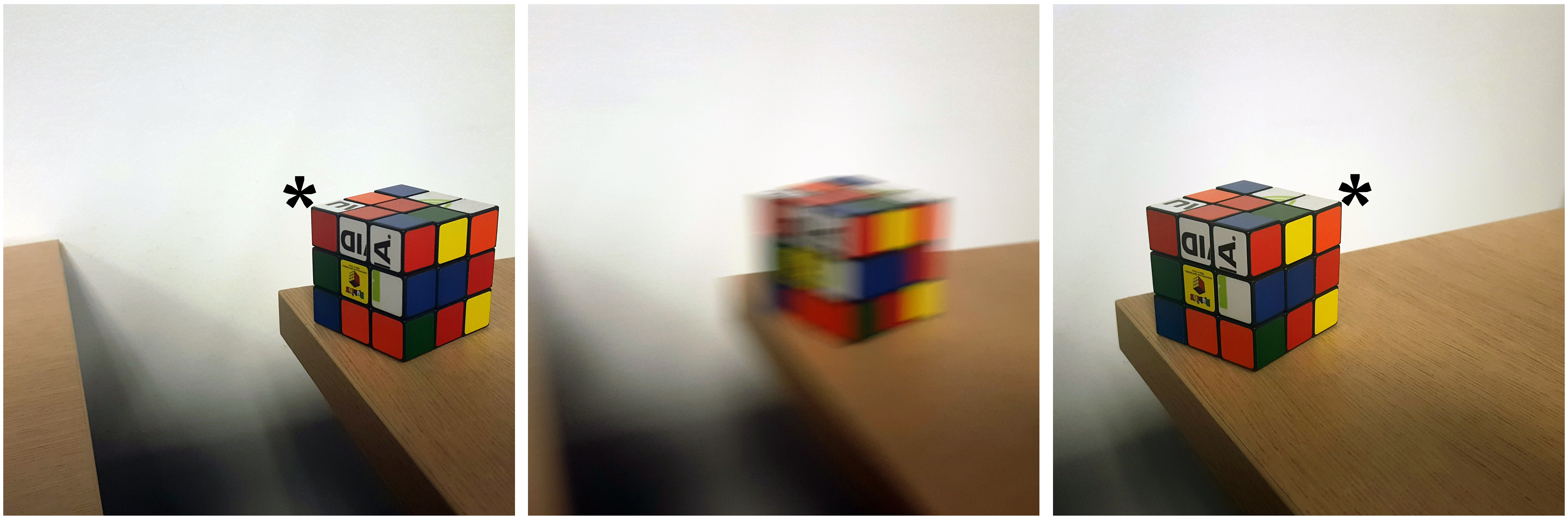
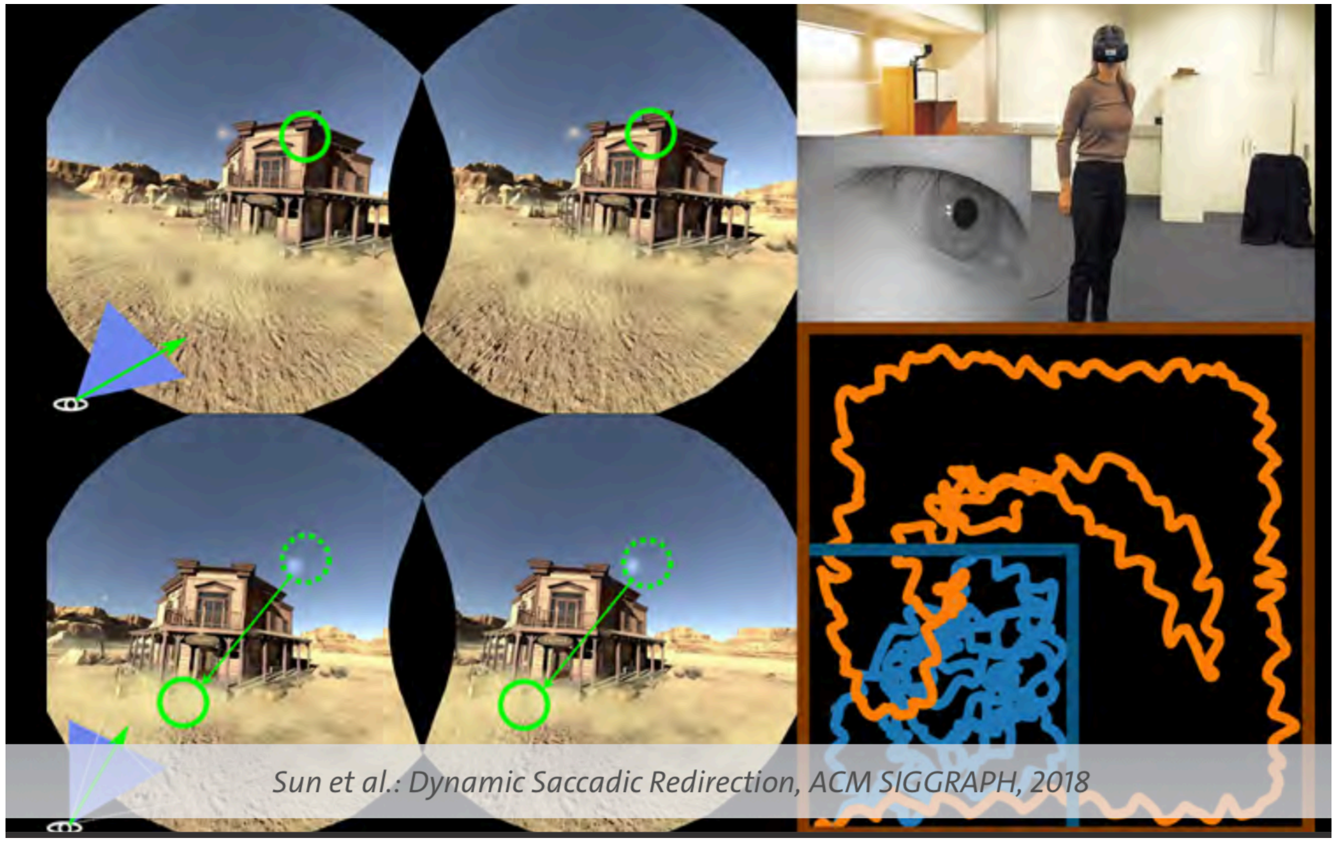


Image courtesy of Rachel Albert

Navigation

Redirected walking



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- **Cheating during saccades**

https://www.youtube.com/watch?v=eDk4HrEtGrM

https://www.youtube.com/watch?v=KEdrBMZx53w

Navigation
Redirected walking

Langbehn et al.: Bending the Curve, TVCG, 2017

- **Bending the curve**

https://github.com/klngbhn/RDW_CurvedPathConfigurator

Navigation
Wayfinding

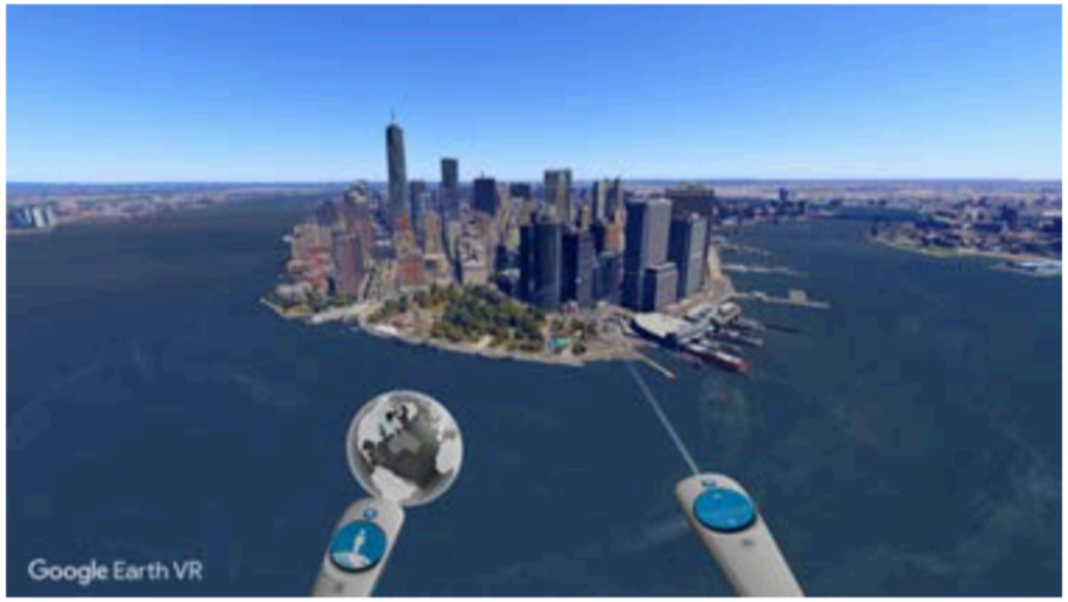
- **Wayfinding** is the cognitive process of determining and following a route between an origin and a destination (Passini 1981)
  - Cognitive component of navigation - travel is the physical counterpart
  - High-level thinking, planning, and decision-making related to user movement

© wikimedia commons
https://commons.wikimedia.org/wiki/File:Oldmexicocity.jpg

Navigation
Wayfinding

- Wayfinding involves spatial understanding and planning tasks
  - Determining current location within environment
  - Determining a path from current to a goal location
  - Building a cognitive map
- Real-world wayfinding has been researched extensively (Wiener 2003)

- In (large) virtual worlds, wayfinding can be crucial (Darken 1998)
- Travel and wayfinding can be combined (Bowman 1997)
  - Can reduce cognitive load
  - Can reinforce user's spatial knowledge



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Navigation

Wayfinding

- **Situation awareness:** internalized model of current state of the user's environment (Endsley 2012)
  - Perception of elements in the environment within a volume of time and space
  - Comprehension of their meaning, projection of their status in the near future

- **Spatial orientation:** knowledge of our location and viewing direction

- Environmental information is stored in our long-term memory
  - Referred to as **cognitive map** (Golledge 1999)
  - Mental hierarchical structure of information representing spatial knowledge (exocentric)
  - During wayfinding, we make use of existing spatial knowledge, acquire new spatial knowledge, or use a combination of both (Thorndyke 1982)

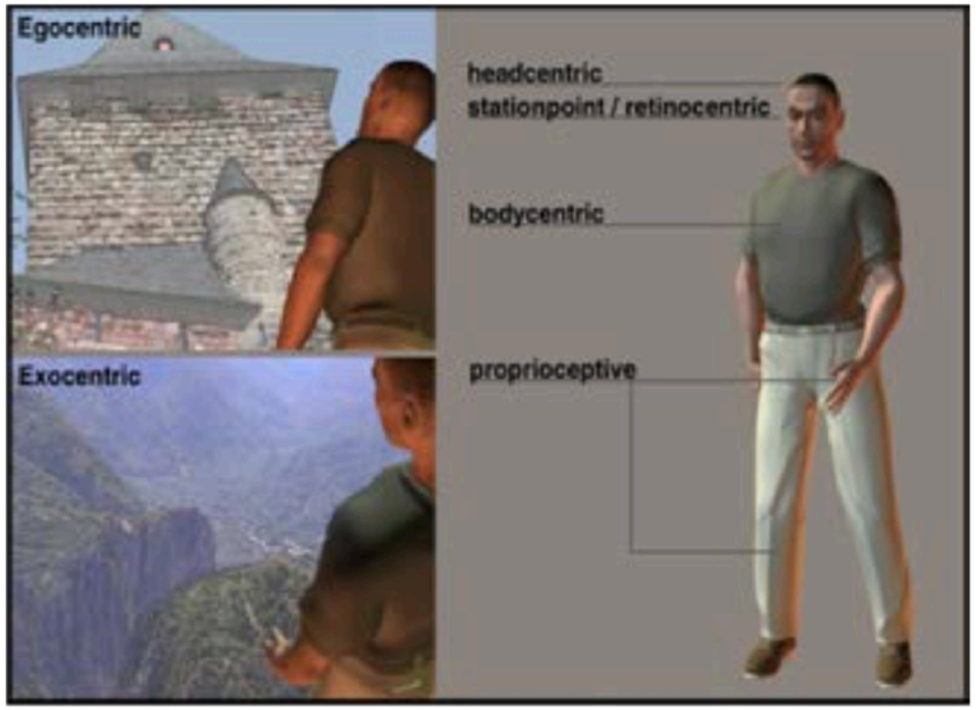
Navigation
Wayfinding

- During wayfinding, people obtain different kinds of spatial knowledge (Thorndyke 1982, Giraudo 1988)
    - Landmark knowledge
    - Procedural knowledge (or route knowledge)
    - Survey knowledge

- Search strategies and movement parameters influence the effectiveness of **spatial knowledge acquisition**

Navigation
Wayfinding

- During real-life motion, we feel as if we are in the center of space (ego/self-motion)
  - During such motion, we need to map ego/exocentric information (Howard 1991)
  - **Egocentric** reference frame is defined relative to a certain part of the human body, provides distance and orientation cues
  - **Exocentric** reference frame is object- or world-relative



Human reference frames (right) and associated views (left). In an egocentric view (top left), the user is inside the environment, while in exocentric view (bottom left), the user is outside the environment, looking in. © Ernst Kruijff (3DUI book)

Navigation
Wayfinding

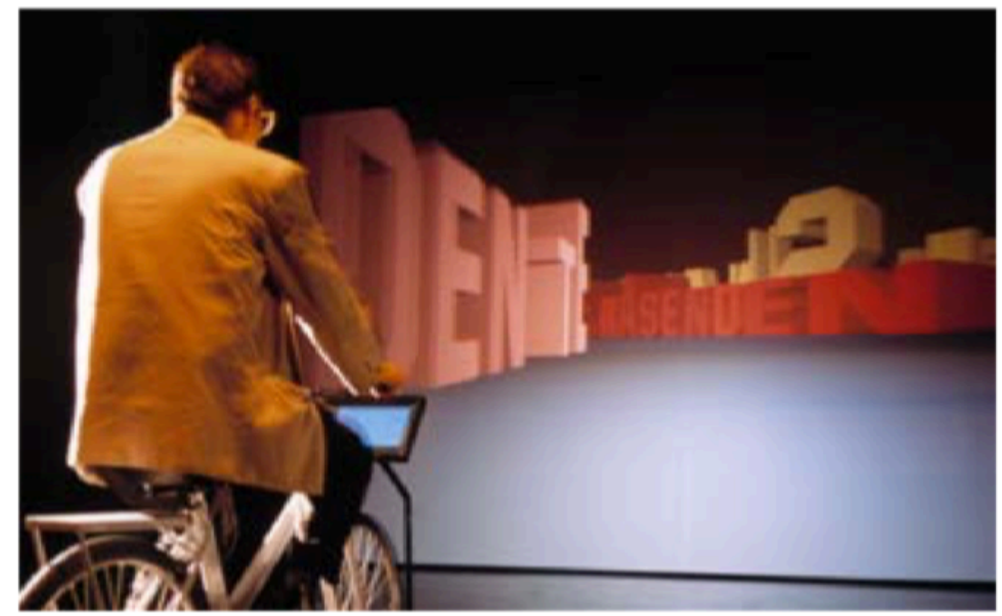
- Amount of cognitive work / effort required by a task or situation
  - User abilities and skills can reduce cognitive load
  - Often assessed using subjective measures (Hart 1988)
  - Can greatly influence wayfinding (Spiers & Maguire 2008)

Navigation

Wayfinding

Effectiveness of wayfinding depends on number and quality of wayfinding **cues** or **aids** provided to users

- Use real-world wayfinding principles to built up your environment, supporting spatial knowledge acquisition
  - Design *legible* environments (Lynch 1960)
- Natural environment principles
  - Horizon, atmospheric perspective / fog
- Architectural design principles
  - Lighting, texture, colour, ..
- Artificial cues
  - Signs, trails, maps, compass, grid.. (Darken & Cevik 1998)

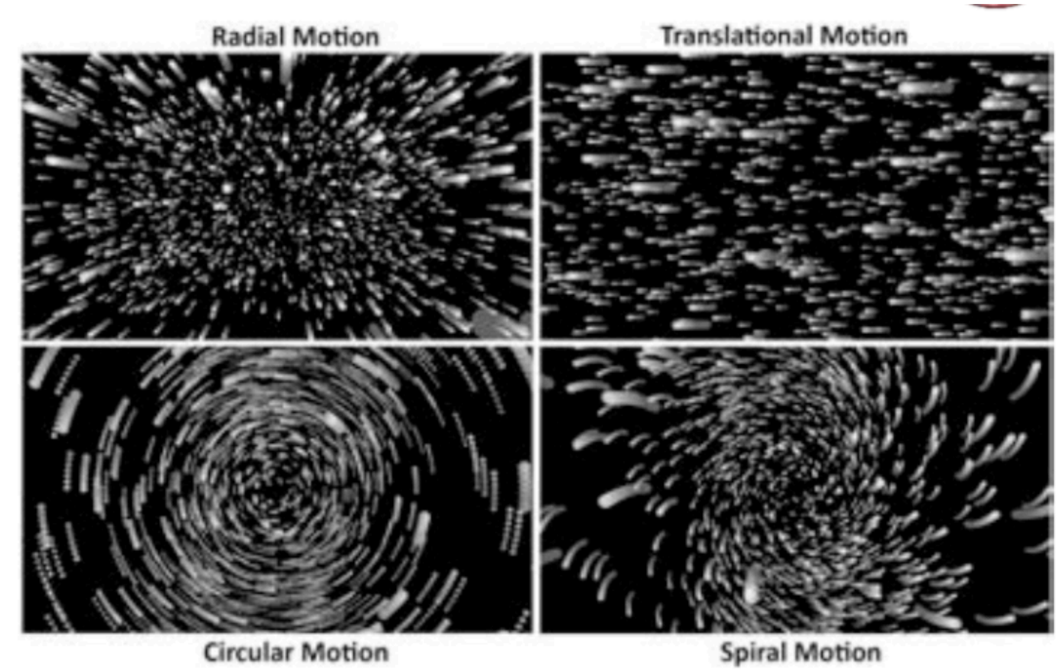


Jeffrey Shaw's Legible city. © Jeffrey Shaw.
http://www.jeffreyshawcompendium.com/wpcontent/uploads/2015/03/js44w1989LegibCit1_o018_r.jpg

Navigation
Wayfinding

- Navigation in a 3D environment involves the processing of **multiple sources of sensory information** that we receive from the environment and the use of this information to execute a suitable travel trajectory

- Key to spatial perception
  - Multitude of depth cues, such as motion parallax, shadows, ..
  - Visual patterns can provide strong motion cues (Palmisano et al. 2015)
  - Also specific illusions, like train illusion or waterflow



© Palmisano et al. 2015.
Future challenges for vection research: definitions, functional significance, measures, and neural bases. Front. Psychol., 27 February 2015
http://www.frontiersin.org/files/Articles/129184/fpsyg-06-00193-r2/image_m/fpsyg-06-00193-g007.jpg

- **Note**: auditory cues can also aid in wayfinding tasks (church bells, train stations)

Selection

Selection

- Specification of an object or a group of objects
- Implementation issues
  - How to indicate that object is selected (event) ? button press, voice command, specific gesture … or automatic
  - Efficient object intersection computations
  - Feedback
    - Graphical, tactile
  - Virtual hand avatar representation of the user’s
  - Keep list of selectable objects for efficiency

Selection

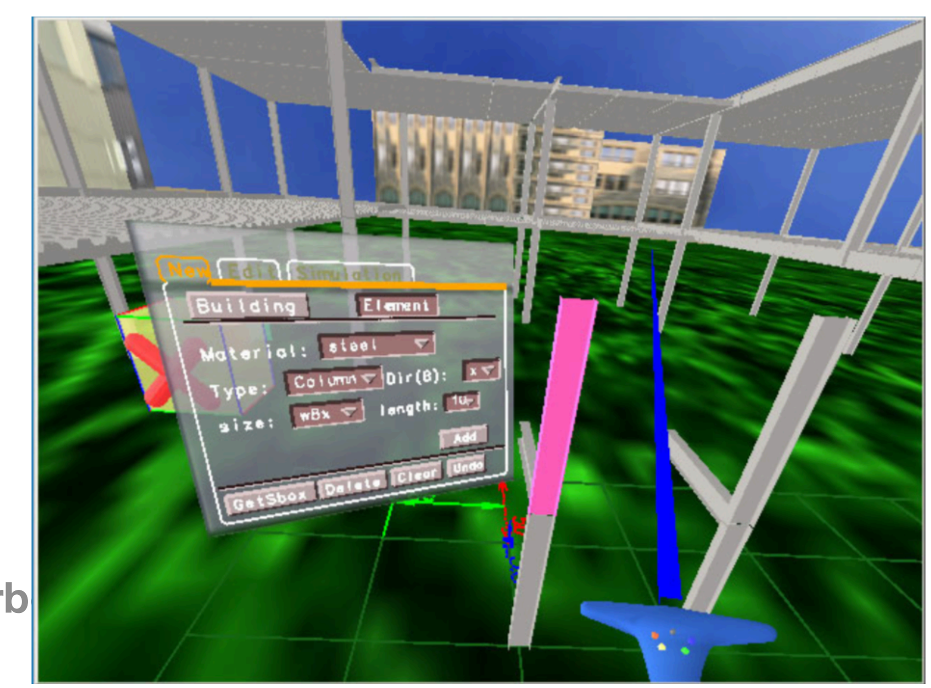
- Common selection techniques
  - Simple virtual hand
  - Ray-casting
  - Sticky finger (occlusion)
  - Go-go (arm extension)

Selection
Simple Virtual Hand

- One-to-one mapping between physical and virtual hands
- Object can be selected by “touching”, intersecting virtual hand with object
- Natural mapping if good collision detection technique
- Need to walk a lot if objects are far away

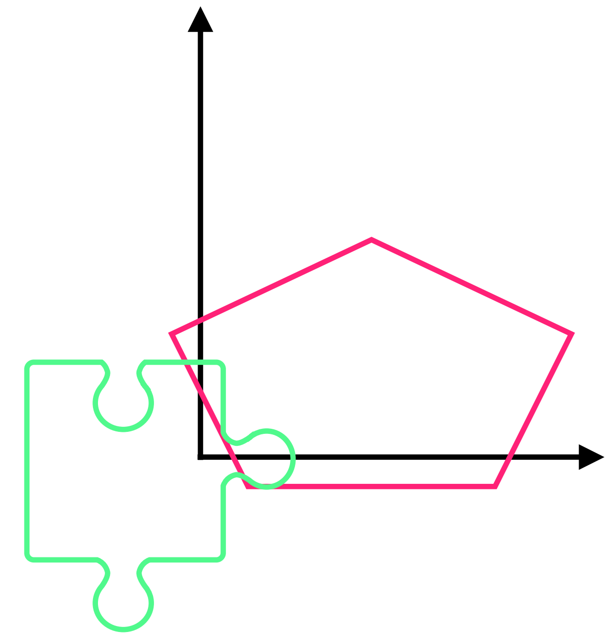
Selection
Ray-Casting

- Acts like a laser pointer is attached to virtual hand
  - Semi-infinite ray extending from virtual hand
- First object intersected by ray is selected
- Only 2 DOF to control (pitch and yaw of the hand)
- Empirically proven to perform well for remote selection
- Variants
  - Cone casting
  - Snap-to-object rays



Selection

Ray-Casting



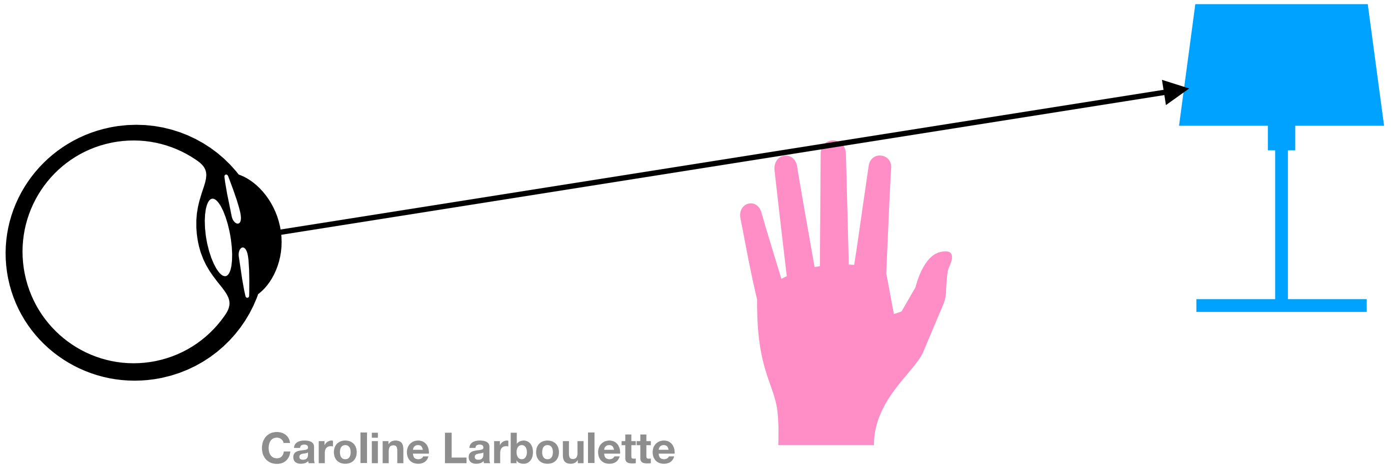
Implementation

- Solution 1: Intersect ray with each polygon
  - Use parametric equation for the ray (direction is [0,0,-1] in hand CS)
  - Only keep intersections with $t > 0$
- Solution 2: Transform vertices to hand's CS
  - Ray direction is [0,0,-1].
  - Drop the z coordinate
  - Ray intersects polygon iff (0,0) is inside the polygon

Selection

Sticky finger (occlusion)

- Technique that works in the image-plane (2D)
- Cover desired object with selector object (e.g., a finger)
- Object is thus occluded from user's point of view
- Nearest object along ray from eye through finger is selected

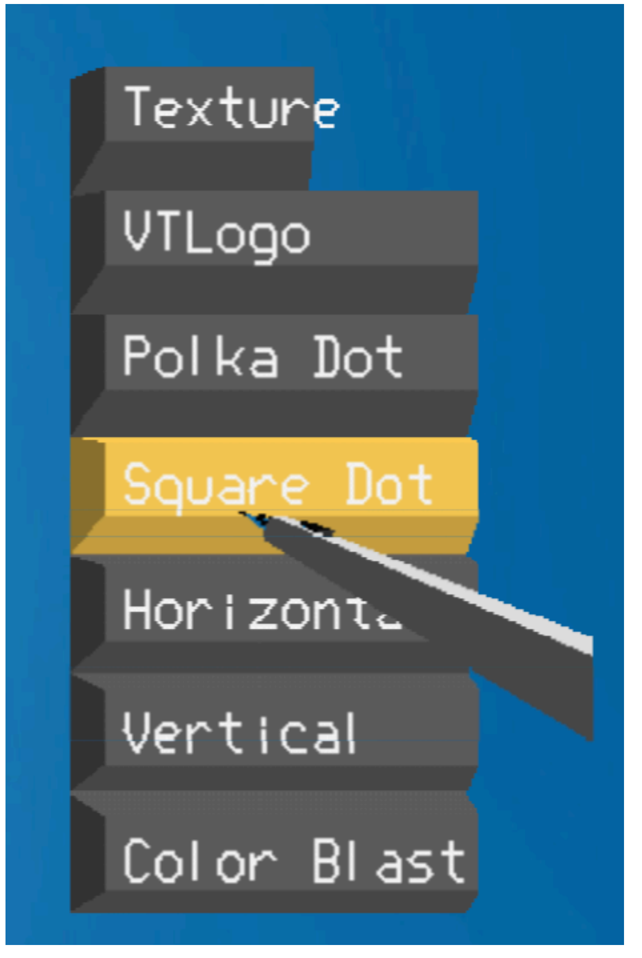


Selection

Sticky finger (occlusion)

Implementation

- Special case of ray-casting
- Must consider position of eye/camera in addition to hand CS
- Ray direction is eye position - hand position
- Need to define a ray coordinate system



Selection

Go-Go (arm extension)

- Arm extension technique
- Like simple virtual hand, touch objects to select them
- Adds a non-linear mapping between physical and virtual hand positions that extends the user’s reach

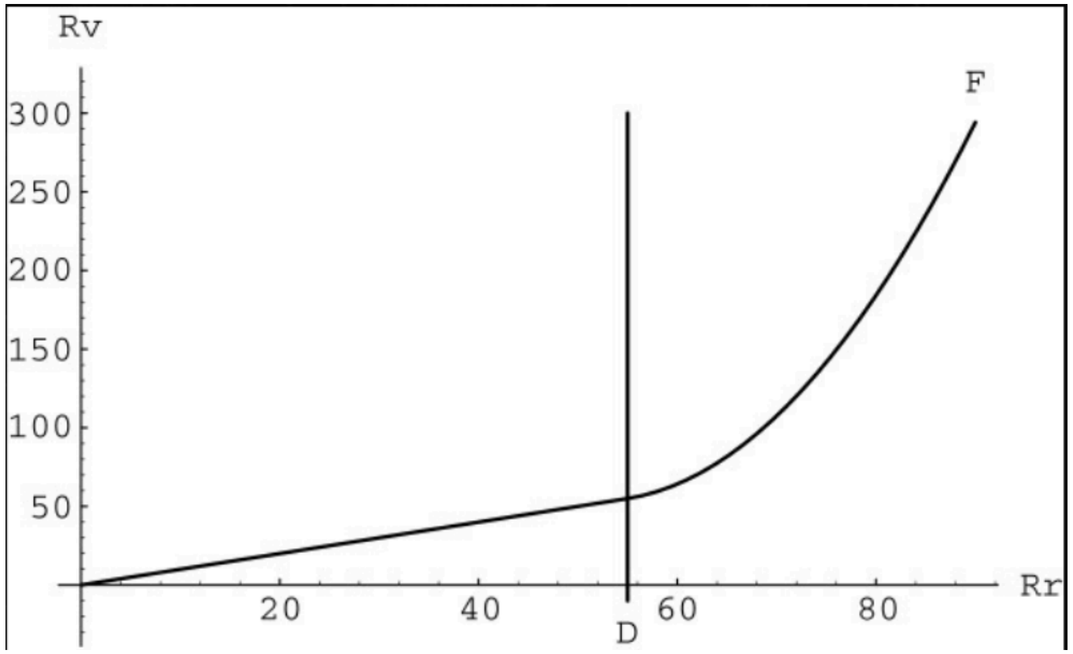
Selection

Go-Go (arm extension)

- Adds a non-linear mapping between physical and virtual hand positions that extends the user's reach:

When the physical hand is at a depth less than a threshold 'D', the one-to-one mapping applies. Outside D, a non-linear mapping is applied, so that the farther the user stretches, the faster the virtual hand moves away.

Virtual hand distance from the body



Physical hand distance from the body

Selection

Go-Go (arm extension)

- Adds a non-linear mapping between physical and virtual hand positions that extends the user's reach
- Can reach local and distant regions

Selection
Go-Go (arm extension)

Implementation

- Requires torso position (tracked or computed): T
- For each frame
  - Get physical hand position H in world CS
  - Calculate physical distance from torso dp = distance(H,T)
  - Calculate virtual hand distance dv = gogo(dp)
  - Normalize torso-hand vector to position the virtual hand on the vector issuing from the torso and going through the physical hand $\overrightarrow{TH}$
  - Virtual hand position = T + dv. $\overrightarrow{TH}$

Manipulation

Manipulation

- Modifying object properties
- A fundamental task in both physical and virtual environments
- Classification of manipulation techniques by metaphor
  - Grasping
  - Pointing
  - Indirect
  - Bi-manual
  - Hybrid

Manipulation
Canonical Tasks

- **Selection: acquiring or identifying an object or subset of objects**
- **Positioning: changing object's 3D position**
- **Rotation: changing object's 3D orientation**
- **Scaling: uniformly changing the size of an object**

Manipulation
Application Specific Tasks

- Canonical tasks can fail to capture important task properties for real applications
- Example: positioning a medical probe relative to virtual models of internal organs in a VR medical training application
- Techniques must capture and replicate minute details of such manipulation tasks

Manipulation
Implementation Issues

- Implementation issues
  - Input devices should be chosen carefully (control dimensions)
  - Integration with selection technique
  - Disable selection and selection feedback while manipulating
  - What happens upon release ?

Manipulation

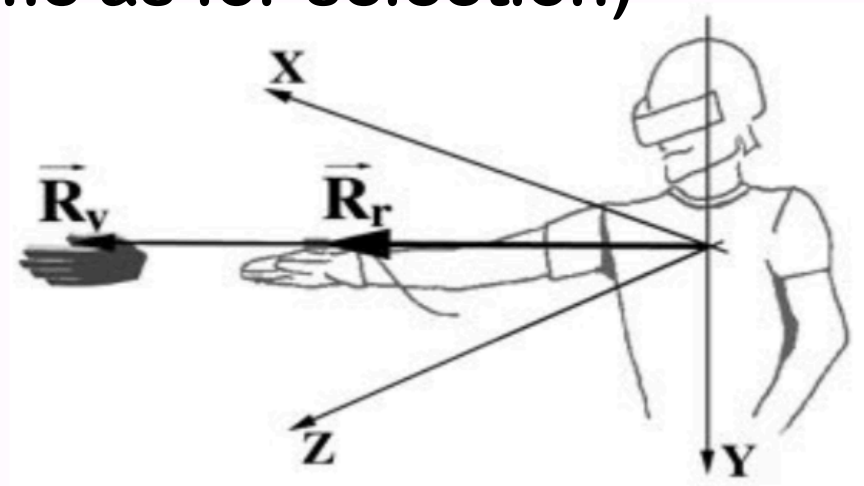
- Common manipulation techniques
  - Grasping metaphors
    - Simple virtual hand or go-go
  - Pointing metaphors
  - Indirect Bi-manual hybrid
  - HOMER
  - Scaled-world grab
  - Wold-in-miniature

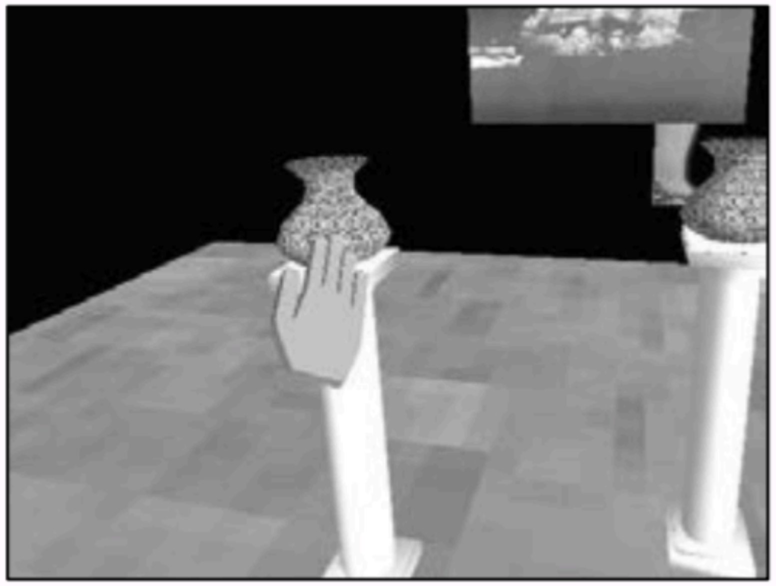
Manipulation
Grasping Metaphors

- **Attach object to virtual hand**
- **Move object directly (same as for selection)**

Hand-Based Grasping

- Simple virtual hand
- Go-Go





$$r_v = F(r_r) = \begin{cases} r_r & \text{if } r_r \le D \\ r_r + \alpha(r_r - D)^2 & \text{otherwise} \end{cases}$$

$$\text{where } r_r = \text{length of } \overrightarrow{\boldsymbol{R}_r}$$
$$r_v = \text{length of } \overrightarrow{\boldsymbol{R}_v}$$
$$D, \alpha \text{ are constants}$$

Images courtesy of Ivan Poupyrev

Manipulation
Grasping Metaphors

- Simple grasping
- https://youtu.be/xCGv1dbnn8Y

- Go-Go
- https://youtu.be/WhA8n4lXeoY

Manipulation
Grasping Metaphors

Finger-Based Grasping

- Rigid-body fingers
- Soft-body fingers
- god fingers

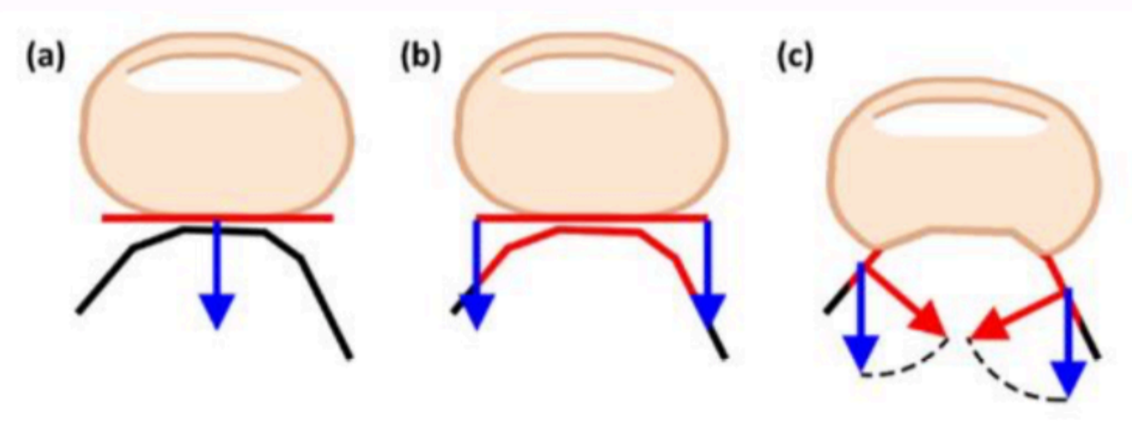


Image adapted from Talvas et al. 2013

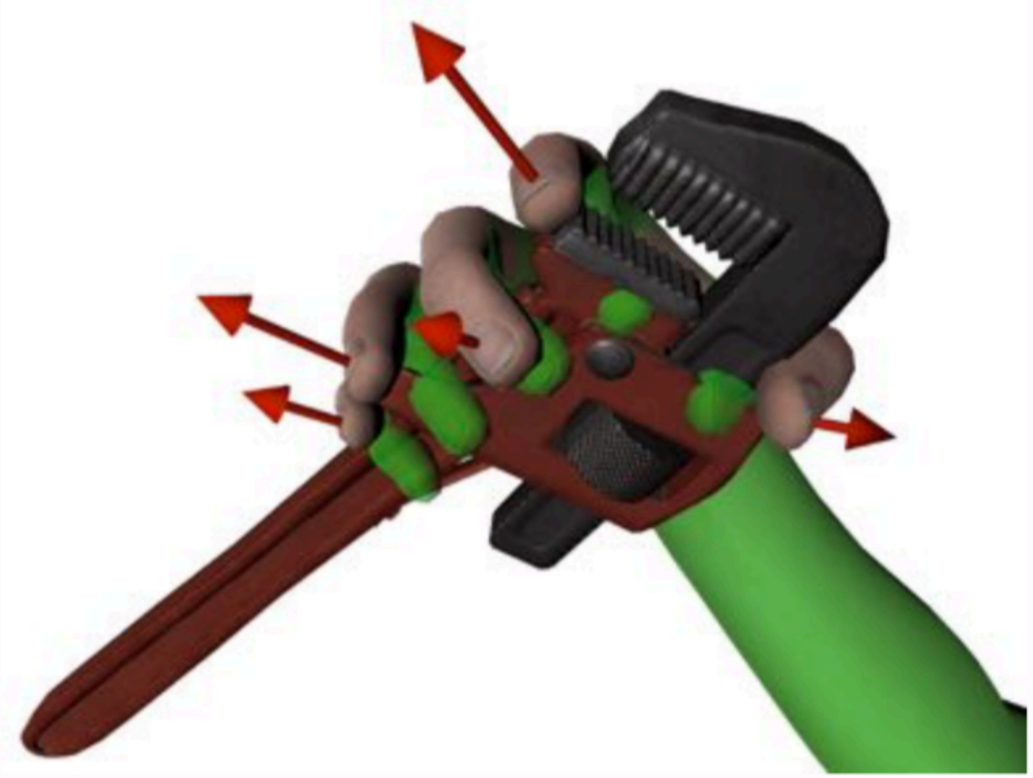


Image adapted from Borst and Indugla 2005

Manipulation
Grasping Metaphors

Rigid-body fingers (Borst and Indugla 2005)

- Need to track the hands and fingers (e.g., bend sensing glove or 3D depth camera)
- Map hand and finger positions to virtual hand and fingers
- Physics-based interactions
  - use virtual torsional and linear spring dampers
  - dynamically influence mapping between real and virtual hands
- Can be "sticky" – difficult to precisely release objects
- Sticky object problem can be reduced with better heuristic-based release functions

Manipulation
Grasping Metaphors

Soft-Body Fingers (Jacobs and Froehlich 2011)

- Use deformable representations for virtual fingers
- Lattice shape matching algorithm
  - deform the pads of virtual fingers to dynamically adapt to shapes of grasped objects
  - when real fingers initially collide with virtual objects, virtual finger pads deform slightly
  - when real fingers penetrate inner space of virtual objects, more points of collision produced for virtual fingers
- Implicit friction model compared to rigid body model

Manipulation
Grasping Metaphors

God Fingers (Talvas et al. 2013)

- god object – a virtual point that adheres to rigid body physics and never penetrates virtual objects (remains on their surface)
  - force direction can be easily calculated
- Goal is to use god-objects for finger grasping and manipulation
  - compute contact area about god-object point as if surface was flat
  - contact area fitted to geometry of the object based on god object force direction
  - odd deformations are prevented by using angular threshold between force directions and surface normals

Manipulation
Grasping Metaphors

3D Bubble Cursor (Vanacken et al. 2007)

- Semi-transparent sphere that dynamically resizes itself to encapsulate the nearest virtual object
- Designed for selecting a single object
- When sphere is too large and begins to intersect a nearby object a second semi-transparent sphere is created to encapsulate that object

https://youtu.be/-xKwjYYlpCE

Manipulation
Grasping Metaphors

PRISM (Frees and Kessler 2005)

- Precise and Rapid Interaction through Scaled Manipulation
- Apply scaled down motion to user's virtual hand when the physical hand is moving below a specified speed
  - decreased control to display gain
  - increased precision
- Causes mismatch between virtual and physical hand location
  - use offset recovery mechanism based on hand speed
  - allows virtual hand to catch up to physical

Manipulation
Grasping Metaphors

Hook (Ortega 2013)

- Supports object selection of moving objects
- Observe relationship between moving objects and the hand to develop tracking heuristics
  - compute distance of hand to each virtual object
  - orders and scores targets based on increasing distance
  - close targets have scores increased, far targets have scores deceased
- When selection is made, target with highest score is selected

https://youtu.be/I62DIeEFZA0

Manipulation
Grasping Metaphors

Intent-Driven Selection (Periverzov and Llies 2015)

- Use posture of virtual fingers as confidence level in object selection
- Proximity sphere is positioned within grasp of virtual hand
  - virtual fingers touch the sphere
  - anything within the sphere is selectable
- As hand closes, additional proximity spheres are made to specify a smaller subset of selectable objects until one target is selected

Manipulation

Pointing Metaphors

- Pointing is powerful for selection
  - remote selection
  - fewer DOFs to control
  - less hand movement required
- Pointing is poor for positioning
- Design variables:
  - how pointing direction is defined
  - type of selection calculation

Manipulation
Pointing Metaphors

Vector-Based Pointing Techniques

- Ray-casting
- Fishing reel
- Image-plane pointing

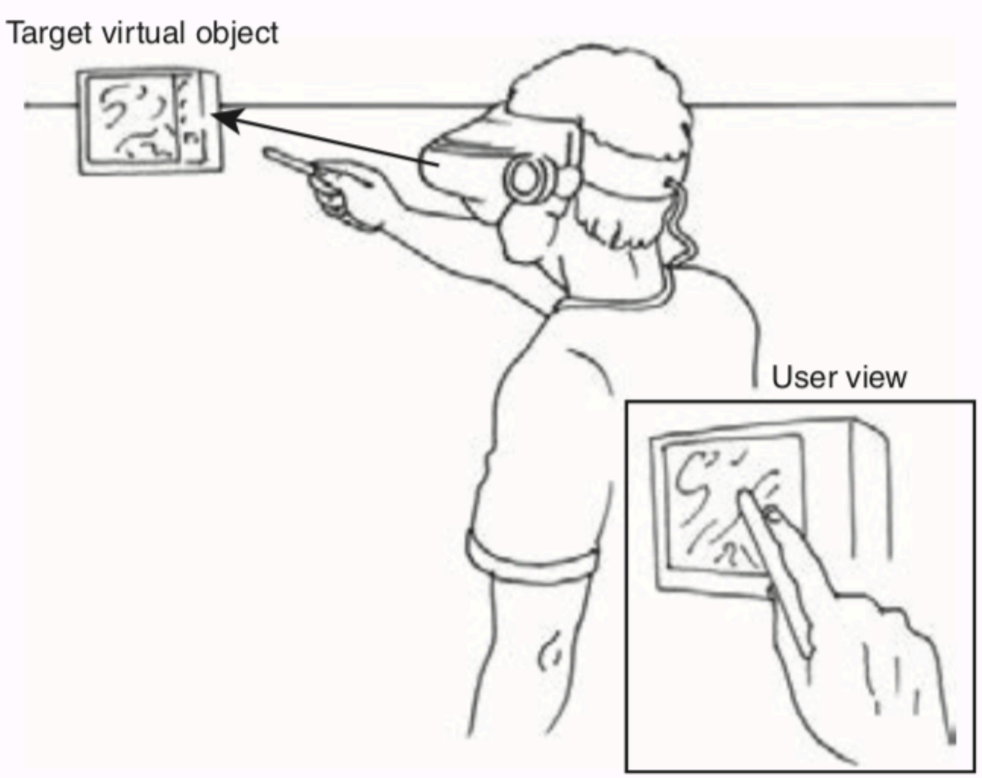


Image curtesy of LaViola et al:
LaViola, J. J., Kruijff, E., McMahan, R. P., Bowman, D., & Poupyrev, I. P. (2017). *3D User Interfaces: Theory and Practice* (2nd edition). Addison-Wesley.

Manipulation
Pointing Metaphors

Ray-casting

- Simple pointing technique
- Point at object with virtual ray
  - virtual line indicates direction (e.g., laser pointer)
  - size of the virtual line can vary
- Perform ray casting to select desired object
- Precision can be compromised with far away objects

https://youtu.be/BjYDIypx2kA

Manipulation
Pointing Metaphors

Fishing Reel

- Additional input mechanism to control the virtual ray
- Select with ray casting and reel the object back and forth using additional input (e.g., slider, gesture)

Manipulation
Pointing Metaphors

Image Plane Pointing (Pierce et al. 1997)

- Image plane techniques simplify object selection by using 2 DOF
  - select and manipulate objects with their 2D projections
  - use virtual image plane in front of user
  - simulate direct touch
- Used to manipulate orientation, not position
- Examples include Head Crusher, Lifting Palms, Sticky Finger, and Framing

https://youtu.be/QFXPJcGdhe4

Manipulation
Pointing Metaphors

Volume-Based Pointing Techniques

- Flashlight
- Aperture
- Sphere-casting

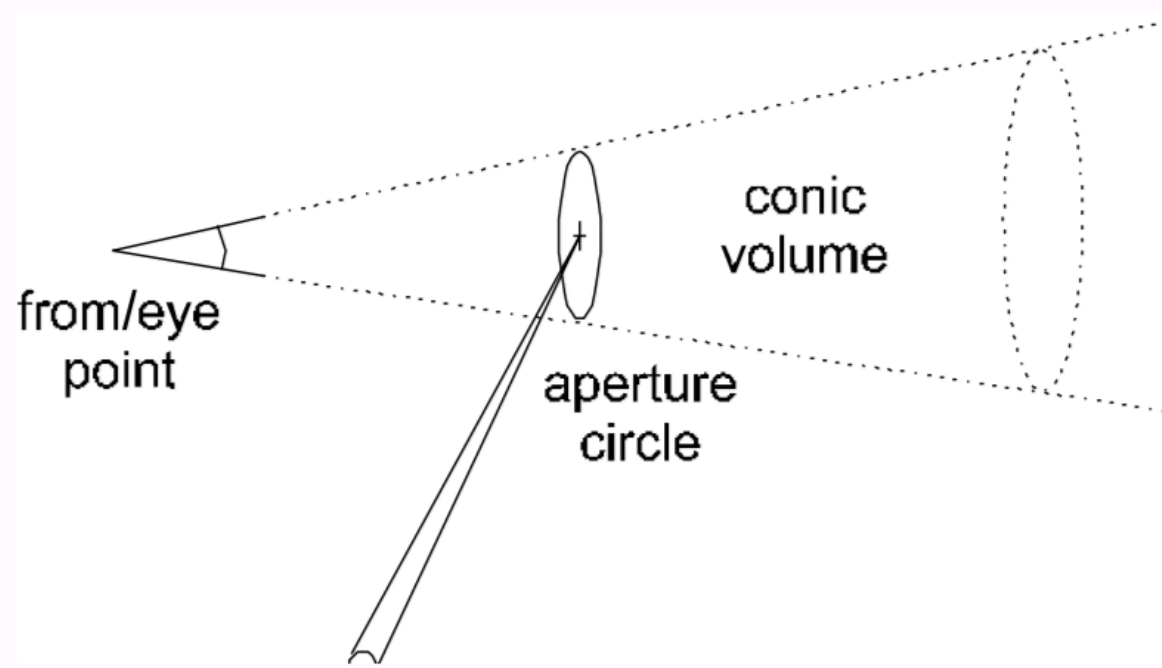


Image courtesy of Andrew Forsberg

Manipulation
Pointing Metaphors

Flashlight

- Provides soft selection and does not require as much precision
- Instead of using a ray, a conic selection volume is used
- Apex of cone is at the input device
- Object does not have to be entirely within the cone
- Must deal with disambiguation issues
  - choose object closer to the centerline

https://youtu.be/s8ykYYENge4

Manipulation
Pointing Metaphors

Aperture Selection (Forsberg et al. 1996)

- Modification of flashlight technique
- User can interactively control the spread of the selection volume
- Pointing direction defined by 3D position of user's viewpoint (tracked head location) and position of a hand sensor
- Moving hand sensor closer or farther away changes aperture

https://youtu.be/u4HLLf8iT_g

Manipulation
Pointing Metaphors

Sphere Casting

- Define position of predefined volume at the intersection of a vector used for pointing and the VE
- Modified version of ray casting
  - casts sphere onto nearest intersected surface

Manipulation
Pointing Metaphors

Enhancements for Pointing Metaphors

- Bendcast
- Depth ray
- Absolute and relative mapping

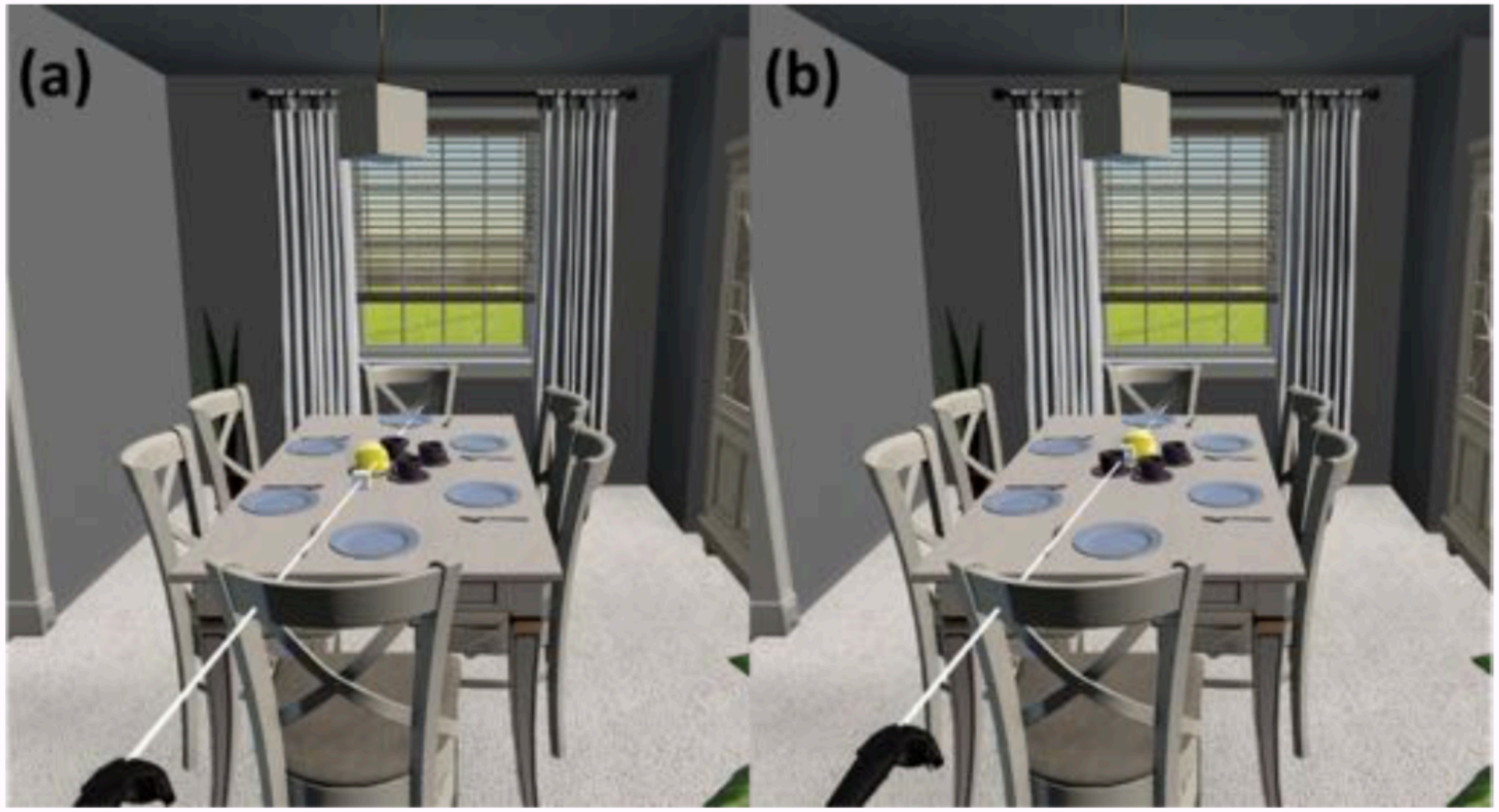


Image Courtesy of Ryan McMahan

Manipulation
Pointing Metaphors

Bendcast (Riege et al. 2006)

- Pointing analog to 3D bubble cursor
- Bends the pointing vector toward object closet to the vector's path
  - point line distance from each selectable object is calculated
  - circular arc used to provide feedback

Manipulation
Pointing Metaphors

Depth Ray (Vanacken et al. 2007)

- Used to disambiguate which object the user intends to select when pointing vector intersects multiple targets
- Uses depth marker along the ray length
- Object closest to the marker is selected
- User can control marker by moving a tracked input device back or forward

https://youtu.be/-tFcfA4kQdw

Manipulation
Pointing Metaphors

Absolute and Relative Mapping (Kopper et al. 2010)

- Useful in dense environments
- Provides manual control of control to display gain ratio of pointing
  - lets users increase the effective angular width of targets
- Can give user impression of slow motion pointer

Manipulation
Indirect Metaphors

Indirect Control-Space Techniques

- Indirect touch
- Virtual interaction surface
- Levels-of-precision cursor
- Virtual pad

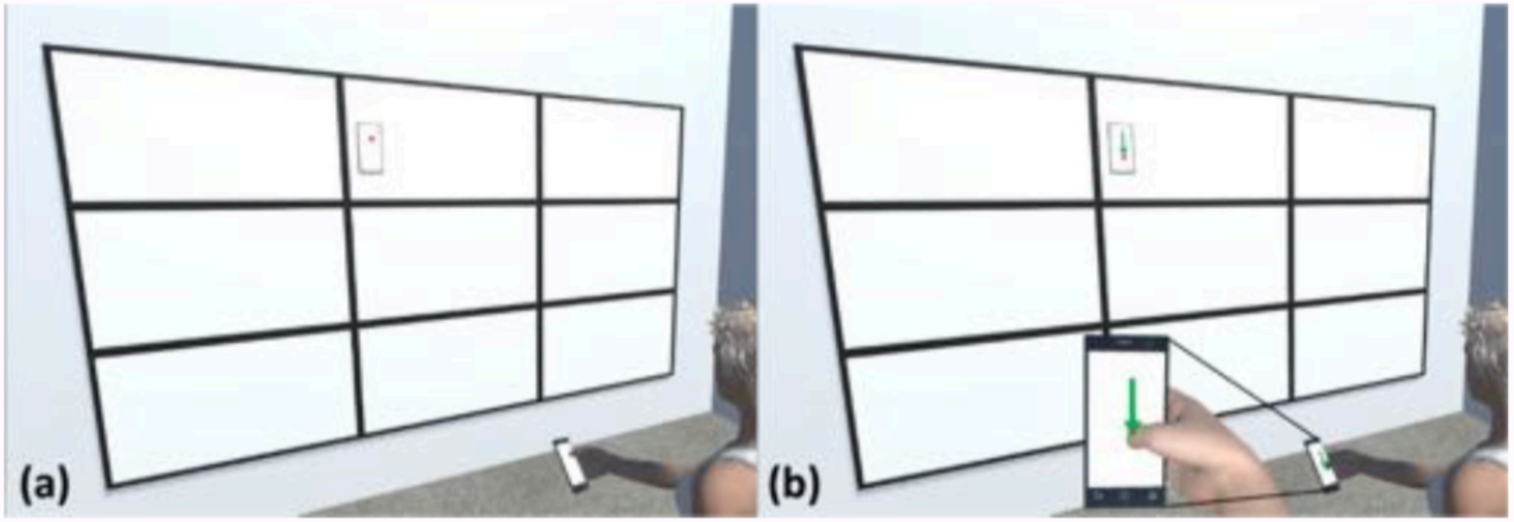


Image adapted from Debarba et al. 2012

Manipulation
Indirect Metaphors

Indirect Touch (Simeone 2016)

- Touch multi-touch surface to control cursor on primary display
- With second finger touch the surface to select an object under the cursor
- Use surface-based techniques for manipulation
- Choice of absolute or relative mapping

Manipulation
Indirect Metaphors

Virtual Interaction Surfaces (Ohnishi et al. 2012)

- Extension of indirect touch
- Mapping of multi-touch surface to nonplanar surfaces in VE
- Allow user to manipulate objects relative to desired paths or other objects
- Supports drawing directly on complex 3D surfaces

Manipulation
Indirect Metaphors

Levels-of-Precision Cursor (Debarba et al. 2012)

- Extends indirect touch with physical 3D interactions
- Uses smartphone
  - affords multi-touch and 3D interaction using inertial sensors and gyroscopes
- Map smaller area of smartphone to larger area of primary display
- Determine orientation for pointing operations

Manipulation
Indirect Metaphors

Virtual Pad (Andujar and Argelaguet 2007)

- Does not require multi-touch surface
- Virtual surface within the VE is used
- Similar to image plane methods

Manipulation
Indirect Metaphors

Indirect Proxy Techniques

- World in miniature
- Voodoo Dolls

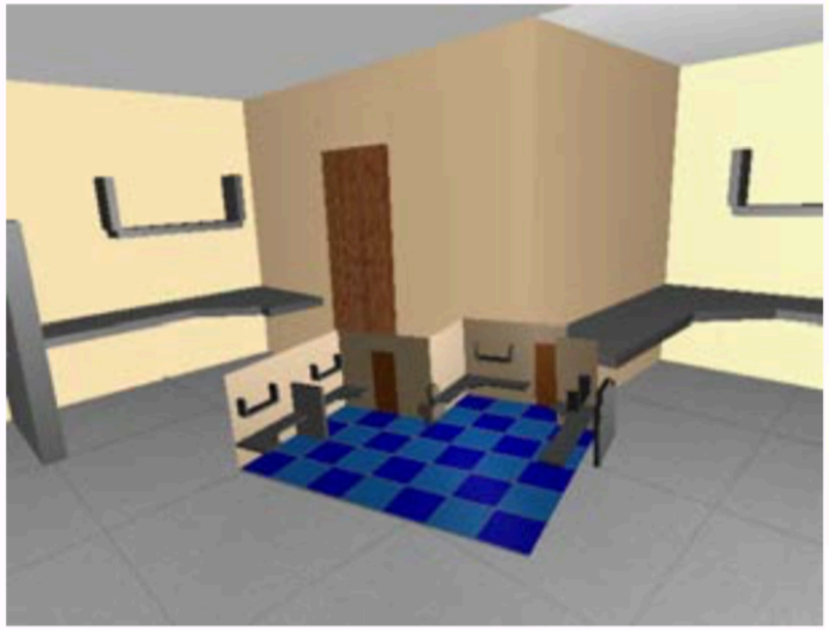


Image courtesy of ACM

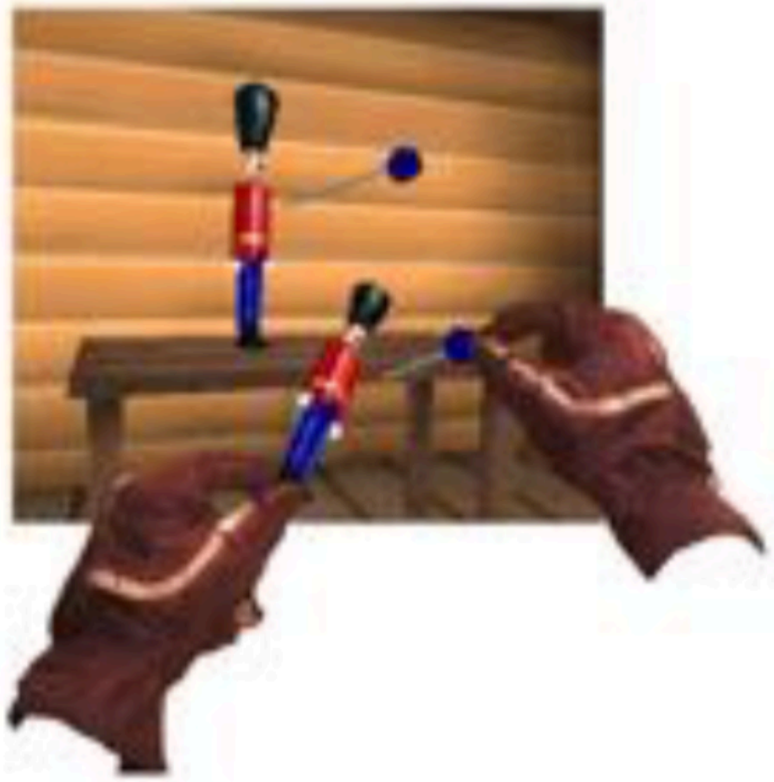


Image courtesy of ACM

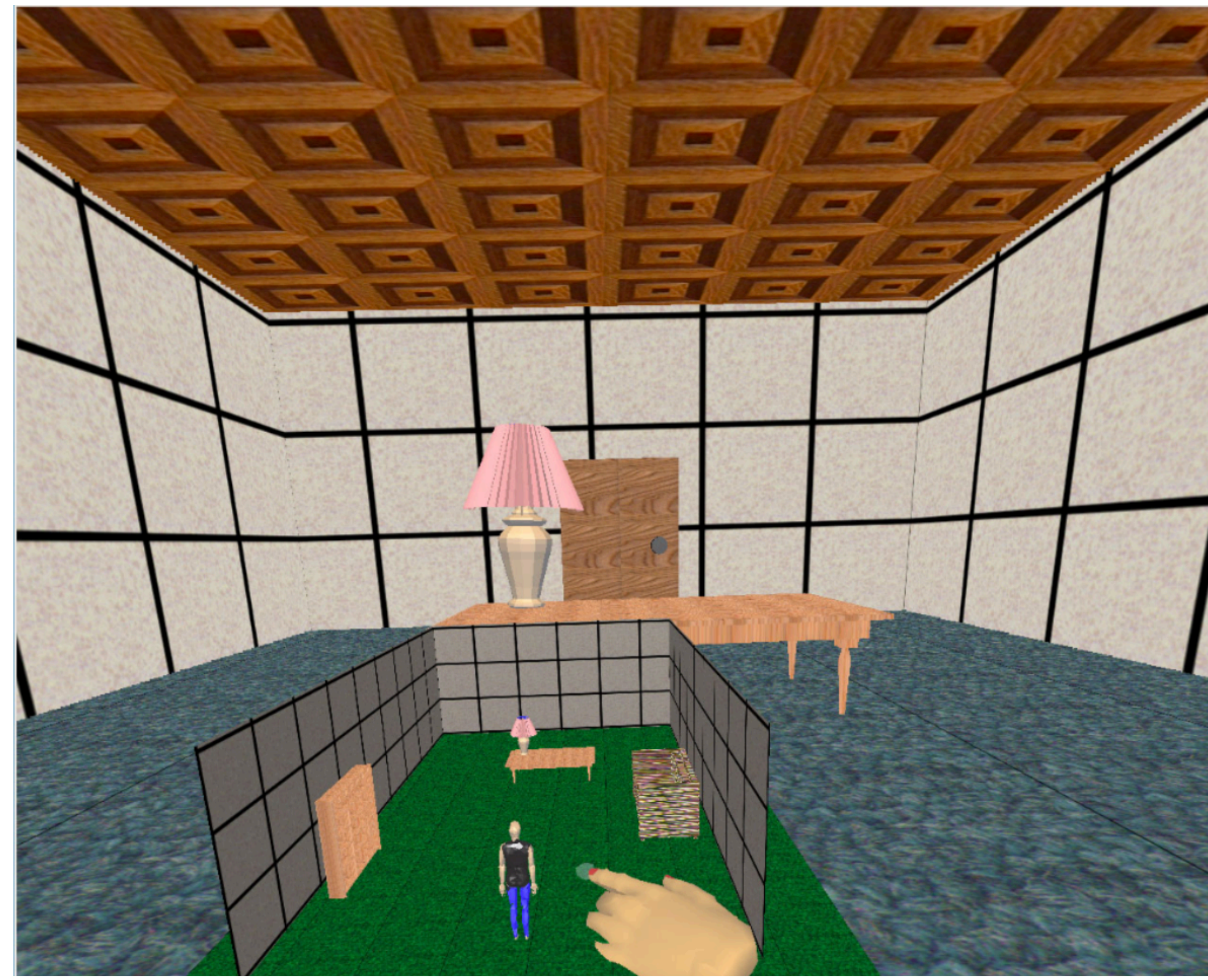
Manipulation
Indirect Metaphors

World in Miniature (Stoakley et al. 1995)

- Scale entire world down and bring within user's reach
- Miniature hand held model of the VE (exact copy)
- Manipulating object in WIM indirectly manipulates object in the VE
- Many design decisions for implementation
  - has scaling issues

Manipulation
Indirect Metaphors

- “Dollhouse” world held in user’s hand
- Miniature objects can be manipulated directly
- Moving miniature objects affects full-scale objects
- Can also be used for navigation



https://youtu.be/dTzIyNHJ4jE

Manipulation
Indirect Metaphors

Voodoo Dolls (Pierce et al. 1999)

- Builds upon WIM and image plane techniques
- Seamless switching between different reference frames for manipulation
  - manipulate objects indirectly using temporary handheld copies of objects (dolls)
  - user can decide which objects to manipulate by using image plane selection (no scaling issues)
- Two handed technique
  - non-dominant hand represents a stationary reference frame
  - dominant hand defines position and orientation of object relative to stationary reference frame
  - user can pass doll from one hand to the other

https://youtu.be/5tN_13ZlscY

Manipulation
Bi-manual Metaphors

- Dominant and non-dominant hands
- Symmetric vs. asymmetric
- Synchronous vs. asynchronous
- Examples
  - symmetric-synchronous – each hand performing same movement at same time
  - symmetric-asynchronous – identical hand movements at different times
  - asymmetric-asynchronous – different hand movements at different times

Manipulation
Bi-manual Metaphors

Symmetric Bimanual Techniques

- Spindle
- iSith

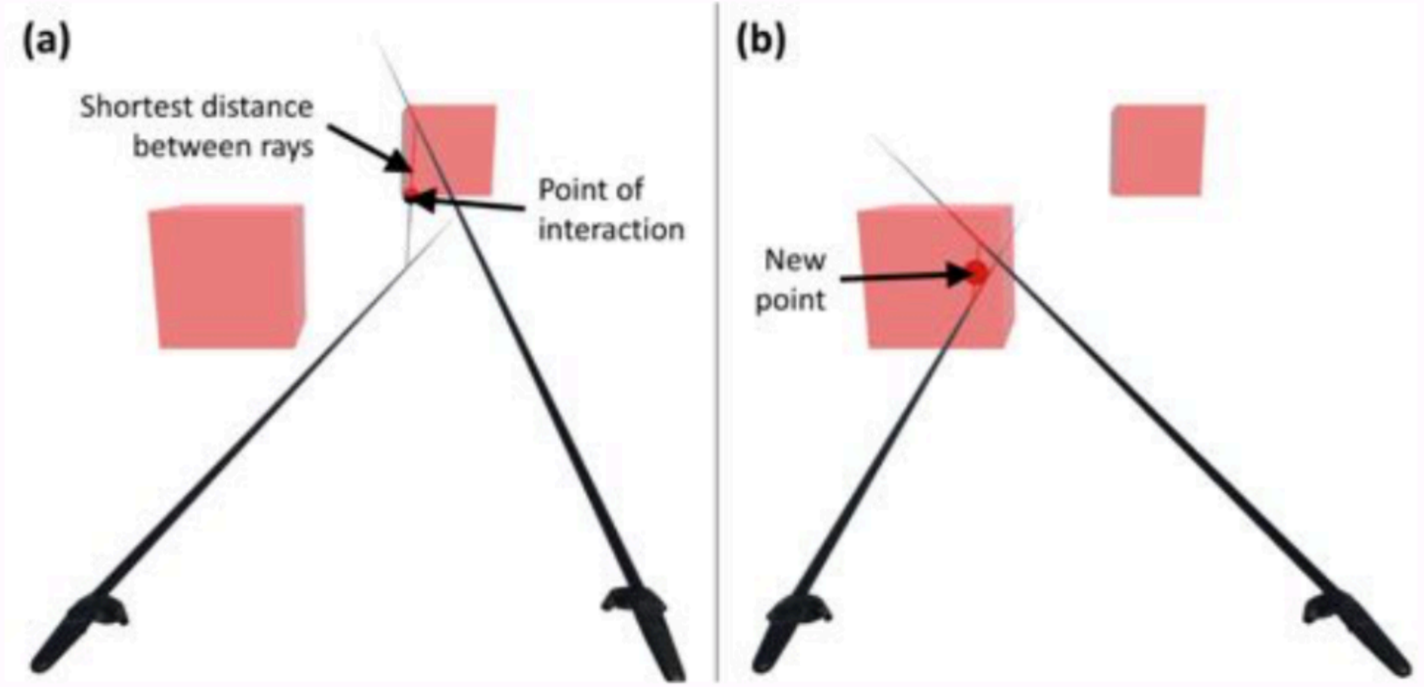


Image adapted from Wyss et al. 2006

Manipulation
Bi-manual Metaphors

Spindle (Mapes and Moshell 1995)

- Two 6 DOF controllers used to define a virtual spindle that extends from one controller to another
  - center of spindle represents primary point of interaction
- Translation – move both hands in unison
- Rotation – yaw and roll by rotating hands relative to each other
- Scale – lengthen or shorten distance of hands

https://youtu.be/75_lpFBQiuo

Manipulation
Bi-manual Metaphors

iSith (Wyss et al. 2006)

- Intersection-based Spatial Interaction for Two Hands
- Two 6 DOF controllers define two separate rays
  - ray-casting with both hands
  - shortest line between two rays is found by crossing two vectors to find vector perpendicular to both
  - known as projected intersection point (point of interaction)

https://youtu.be/9wCubwGjFLE

https://youtu.be/th9L72dnRgI

Manipulation
Bi-manual Metaphors

Asymmetric Bimanual Techniques

Spindle + Wheel (Cho and Wartell 2015)

- Extended Spindle to include rotating pitch of virtual object
- Uses virtual wheel collocated with dominant hand cursor
  - twist dominant hand for rotation

Flexible Pointer (Olwal and Feiner 2003)

- Make use of two handed pointing
- Curved ray that can point at partially occluded objects
  - implemented as quadratic Bezier spline

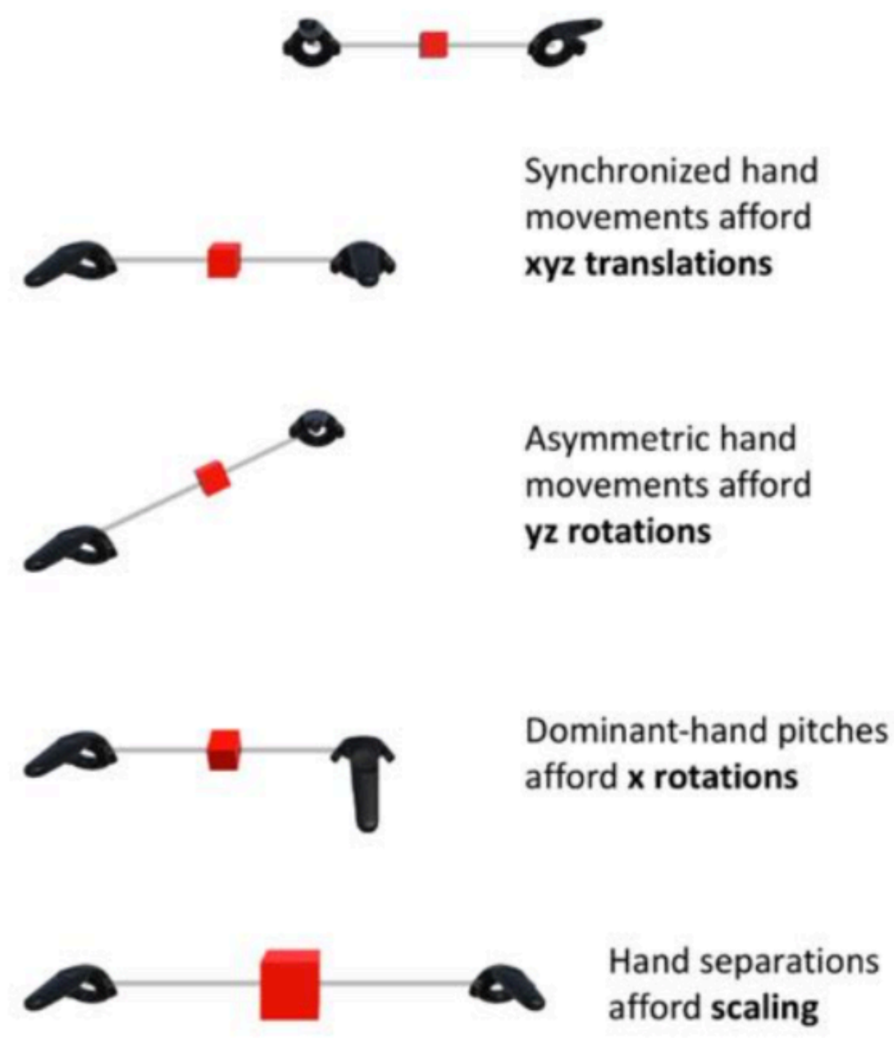
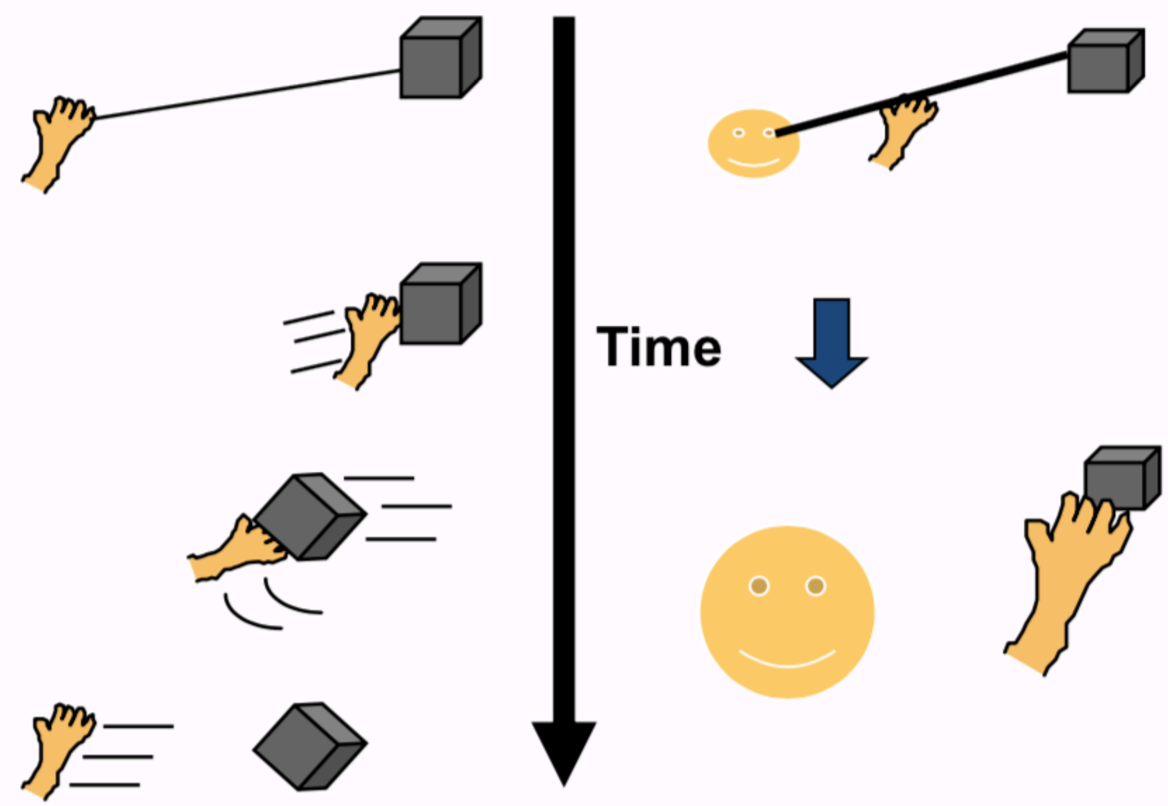


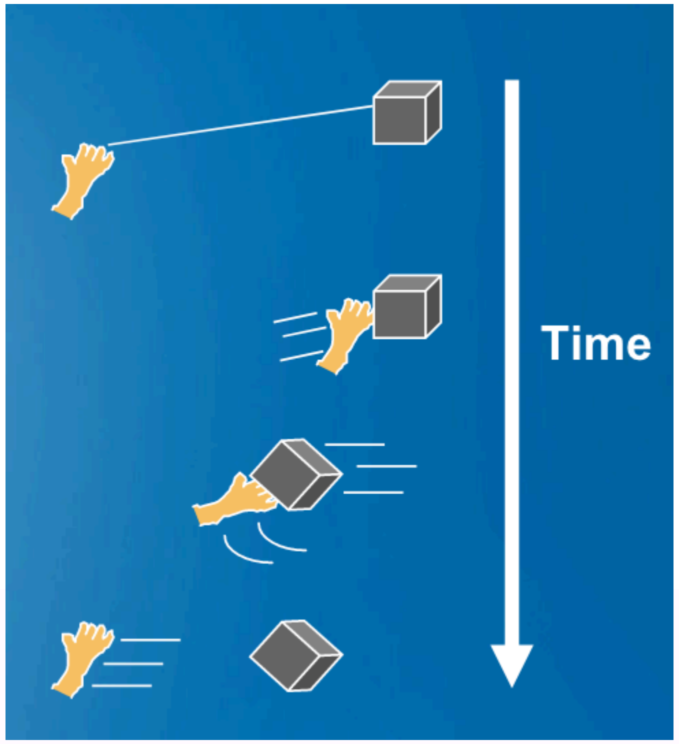
Image courtesy of Ryan McMahan

Manipulation
Hybrid Metaphors

- Aggregation of techniques
- Integration of techniques
  - HOMER
  - Scaled-world grab



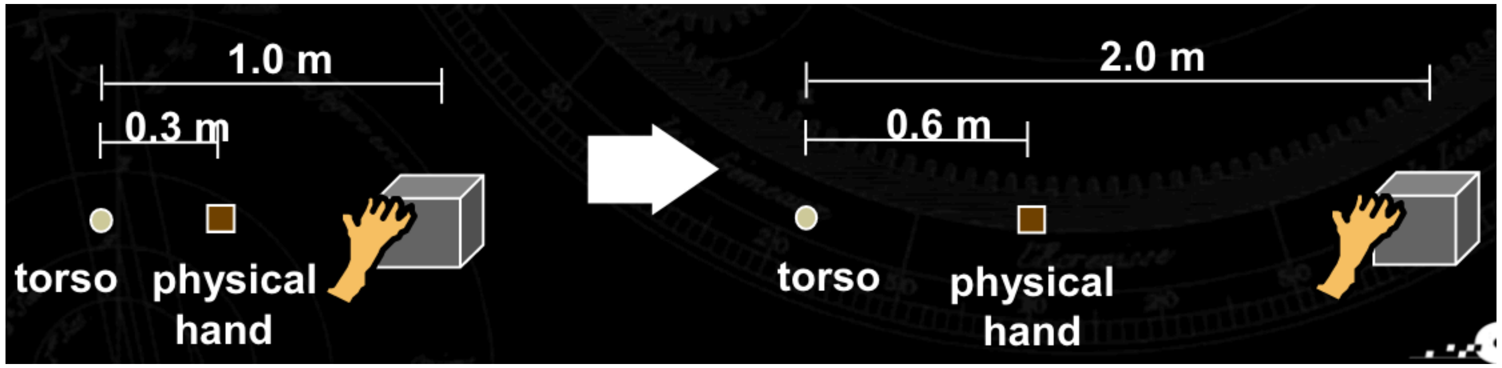
Manipulation
Hybrid Metaphors



HOMER (Bowman and Hodges 1997)

- Hand-centered Object Manipulation Extended Ray-Casting
- Select object using ray casting
- Users hand then attaches to the object
- User can then manipulate object (position and orientation) with virtual hand

- **Includes linear mapping to allow wider range of placement in depth**



https://youtu.be/AeD-rS2sofk

Manipulation
Hybrid Metaphors

HOMER Implementation

- Requires torso position *t*
- Upon selection, detach virtual hand from tracker, move v. hand to object position in world CS, and attach object to v. hand (w/out moving object)
- Get physical hand position *h* and distance
  $d_h = dist(h, t)$
- Get object position *o* and distance $d_o = dist(o, t)$

Manipulation
Hybrid Metaphors

HOMER Implementation

- **Each frame:**
  - Copy hand tracker matrix to v. hand matrix (to set orientation)
  - Get physical hand position h_{curr} and distance:

    $d_{h\text{-}curr} = dist(h_{curr,}\ t)$
  - V. hand distance $$d_{vh} = d_{h-curr} \times \left(\frac{d_o}{d_h} \right)$$
  - Normalize torso-hand vector $$th_{curr} = \frac{h_{curr} - t}{\left\| h_{curr} - t \right\|}$$
  - V. hand position $vh = t + d_{vh}{}^*(th_{curr})$

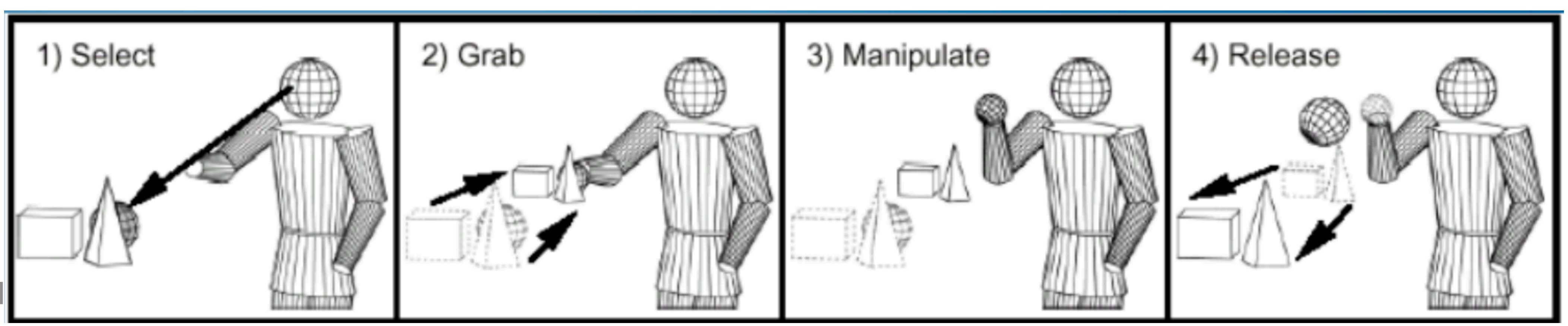
Manipulation

https://youtu.be/Jwy2AI6WB-Y

Hybrid Metaphors

Scaled World Grab (Mine et al. 1997)

- User selects object with selection technique (often used with occlusion selection)
- At selection, scale user up (or VE down) so that virtual hand is actually touching selected object
- If center of scaling is midway between user's eyes, he doesn't notice a change until he moves



Scaled-world grab implementation

- **At selection:**
  - Get world CS distance from eye to hand d_{eh}
  - Get world CS distance from eye to object d_{eo}
  - Scale user (entire user subtree) uniformly by d_{eo} / d_{eh}
  - Ensure that eye remains in same position
  - Attach selected object to v. hand (w/out moving object)
- **At release:**
  - Re-attach object to world (w/out moving object)
  - Scale user uniformly by d_{eh} / d_{eo}
  - Ensure that eye remains in same position

SIGGRAPH

Manipulation
Other Approaches

Nonisomorphic 3D rotation

- Amplifying 3D rotations to increase range and decrease clutching
- Slowing down rotation to increase precision
- Absolute vs. relative mappings
  - Absolute mappings can violate *directional compliance*
  - Relative mappings do not preserve *nulling compliance*

Manipulation
Other Approaches

Multiple Object Selection

- Serial selection mode
- Volume-based selection techniques
  - e.g., flashlight, aperture, sphere-casting
- Defining selection volumes
  - e.g., two-corners, lasso on image plane
- Selection-volume widget
  - e.g., PORT

Manipulation
Other Approaches

Progressive Refinement

- Gradually reducing set of objects till only one remains
- Multiple fast selections with low precision requirements
- SQUAD
- Expand
- Double Bubble

Image courtesy of Ryan McMahan

Manipulation
Other Approaches

SQUAD (Kopper et al. 2011)

- Sphere-casting refined by QUAD menu
  - progressive refinement for dense VEs
- User specifies initial subset of environment using sphere cast
- Selectable objects laid out in QUAD menu
- Use ray-casting to select one of the four quadrants
  - selected quadrant is laid out in four quadrants
  - repeat until one object is selected

Manipulation
Other Approaches

Expand (Cashion et al. 2012)

- Similar to SQUAD
- User selects collection of objects
- User's view expands this area and creates clones of the selectable objects (laid out in grid)
- User uses ray-cast to select object

https://youtu.be/DdPnobANDwo

Manipulation
Other Approaches

Double Bubble (Bacim 2015)

- Both SQUAD and Expand suffer from initial selection containing large set of objects
- 3D bubble cursor is used upon initial selection
  - bubble not allowed to shrink beyond a certain size
- Objects laid out in a menu and selected using 3D bubble cursor

Manipulation
Design Guidelines

- Use existing manipulation techniques unless a large amount of benefit might be derived from designing a new application specific technique
- Match the interaction technique to the device
- Use techniques that can help to reduce clutching
- Nonisomorphic (“magic”) techniques are useful and intuitive
- Use pointing techniques for selection and grasping techniques for manipulation
- Reduce degrees of freedom when possible

Universal 3D Interaction Tasks
System Control

- Common system control techniques
  - Virtual menus
  - Tool selectors
  - Speech commands
- For the most part, only requires a selection technique
- Good visual feedback is necessary

System Control

Pen & Tablet

System Control

Design Guidelines

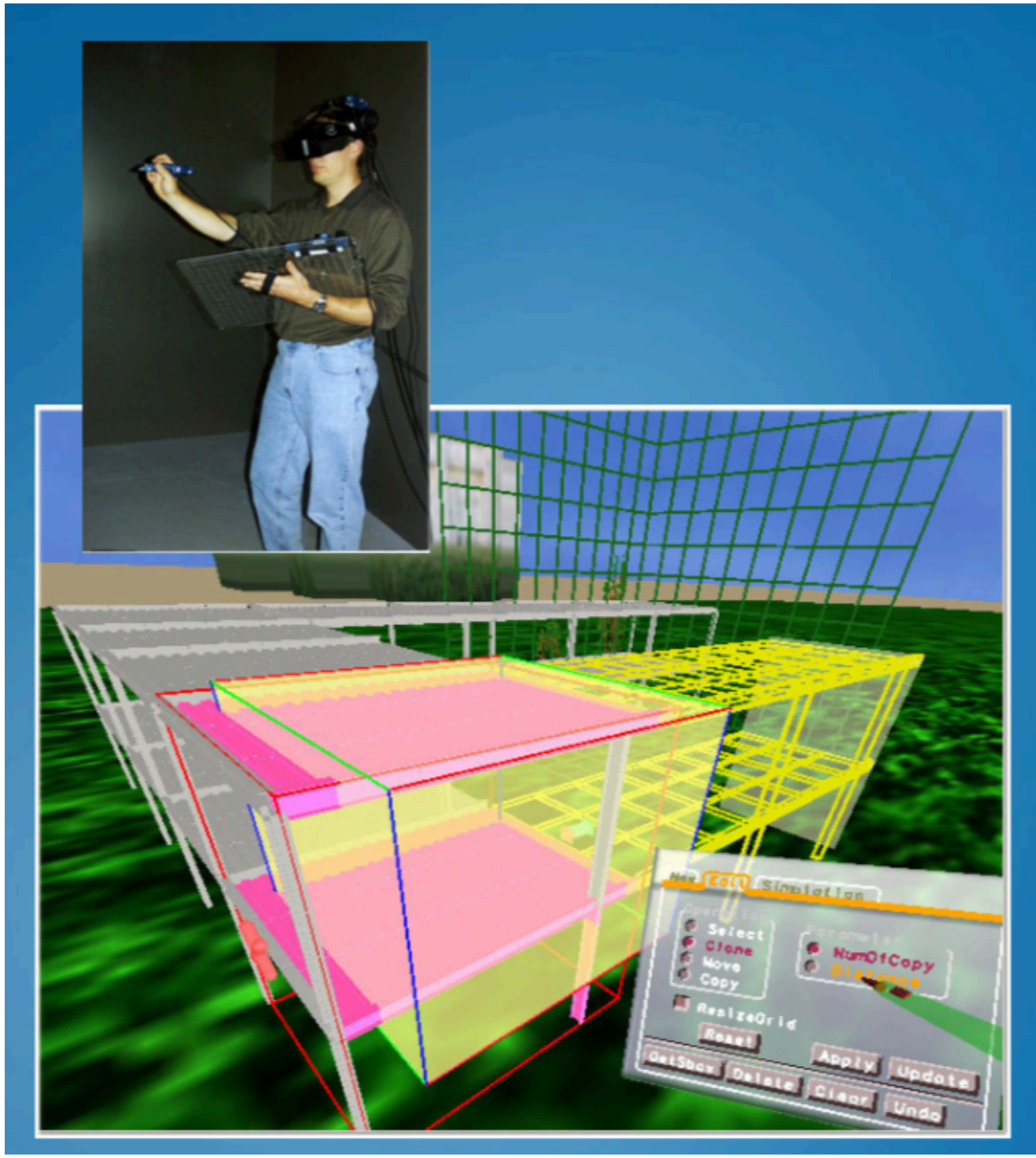
- Don’t disturb flow of action
- Use correct spatial reference
- Allow multi-modal input
- Structure available functions when there are many
    - Context-sensitivity
    - Hierarchy of menus (with sub-menus)
- Prevent mode errors by giving feedback during and after the selection of a command

Example

- Application Virtual-SAP
- Aim: allow structural engineers to construct 3D building structures in a virtual environment

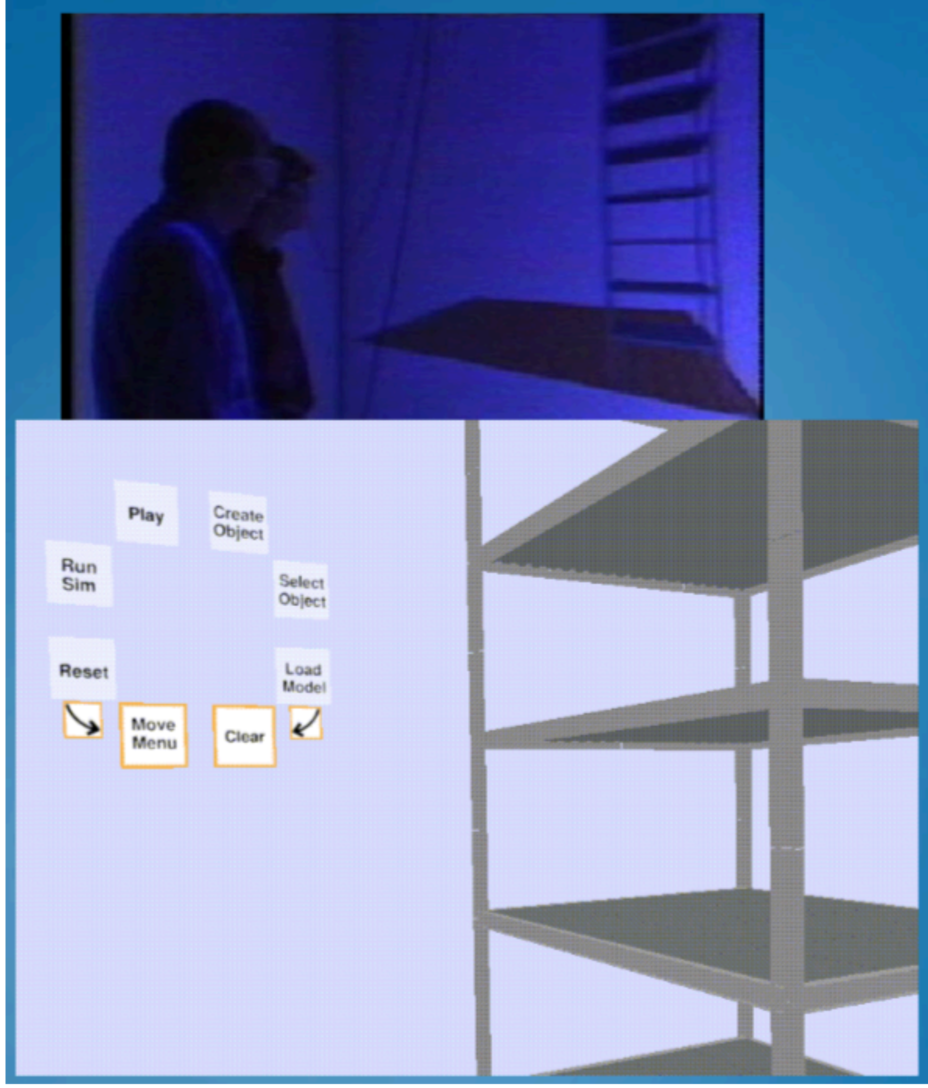
Example

Solution 1



- Head Mounted Display (HMD)
- Virtual Pen & Tablet
  - Tracked stylus with 2 buttons
- System control using pen & tablet
- Navigation: fly through the world using a pointing technique with the pen
- Selection and Manipulation using the HOMER with the pen

Example
Solution 2



- CAVE (4-screens)
- Tracked wand, 4 buttons, joystick
- System control through a circular menu
  - Rotation in either direction with 2 buttons
  - Selection of one of the two selectable items with 2 buttons
- Selection and Manipulation with a pointing Go-Go technique with a snapping feature for precision

Example
Solution 3

- Low-cost Head Mounted Display
- 3 DOF orientation tracker on the HMD
- Keyboard with 12 buttons
- System Control though a menu selected with the keyboard ("remote control" metaphor)
- Travel with gaze-directed steering
- Selection and Manipulation based on head orientation instead of hand movements with gaze-based ray-casting with snap