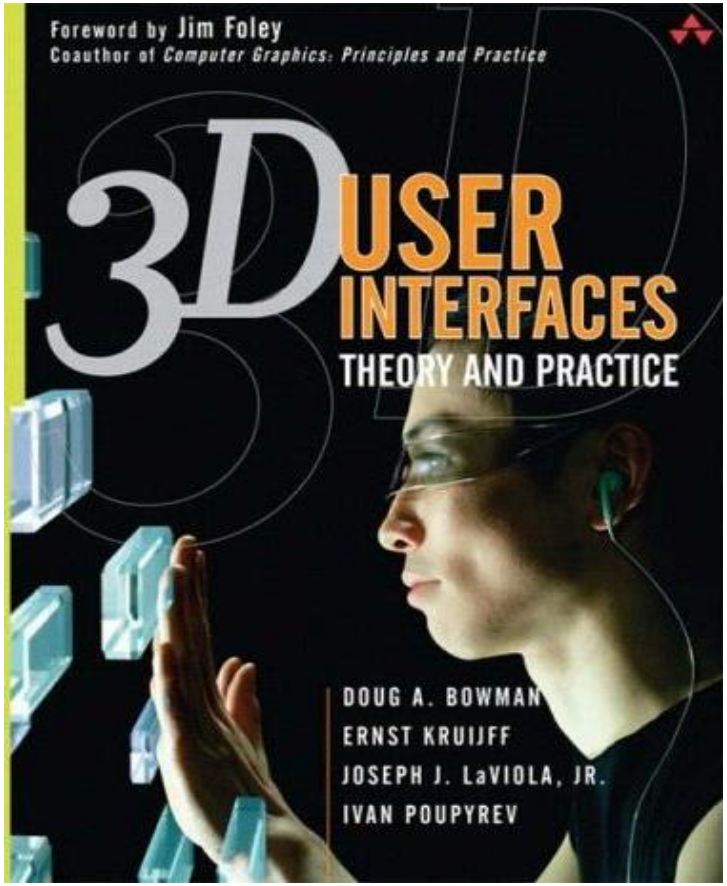
Course on Virtual Reality

3D Interaction Techniques

Literature

- Doug A. Bowman, Ernst Kruiff, Joseph J. LaViola Jr., Ivan Poupyrev: **3D User Interfaces**, Addison-Wesley, 2004



- Conference Proceedings:
  - IEEE VR
  - IEEE 3DUI
  - ICAT / EGVE
  - VRST
  - (ACM CHI, SUI, etc.)

Outline

- 3D Interaction Techniques: Definitions and Basics
- Manipulation Tasks
- Navigation
- System Control

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Definitions

- **3D Interaction**: „Human-computer interaction in which the user‘s tasks are performed directly in a 3D spatial context.“ (Bowman et al. 2004)
- **3D User Interface (3DUI)**: A UI that involves 3D interaction.
- Not every 3D graphics application uses a 3DUI.
- 3D interaction does not necessarily require a 3D input device.

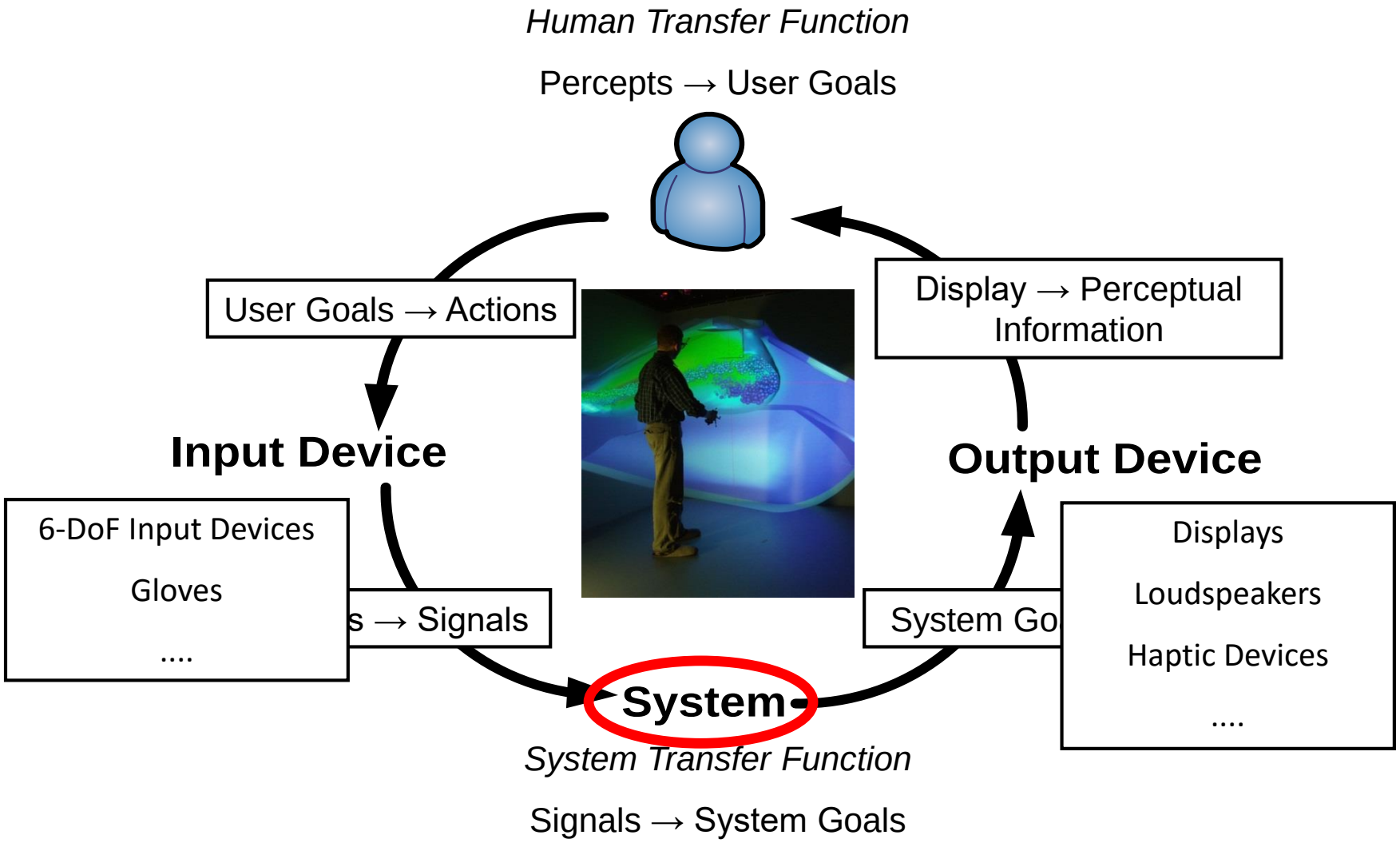
Definitions

- **3D interaction technique**: method used to accomplish a given task via a 3D user interface.

- Consists of
  - Hardware components
    - One or more input devices
    - One or more output devices
  - Software components
    - Map information from input devices to system actions
    - Map system‘s output to a form that can be displayed by the output devices

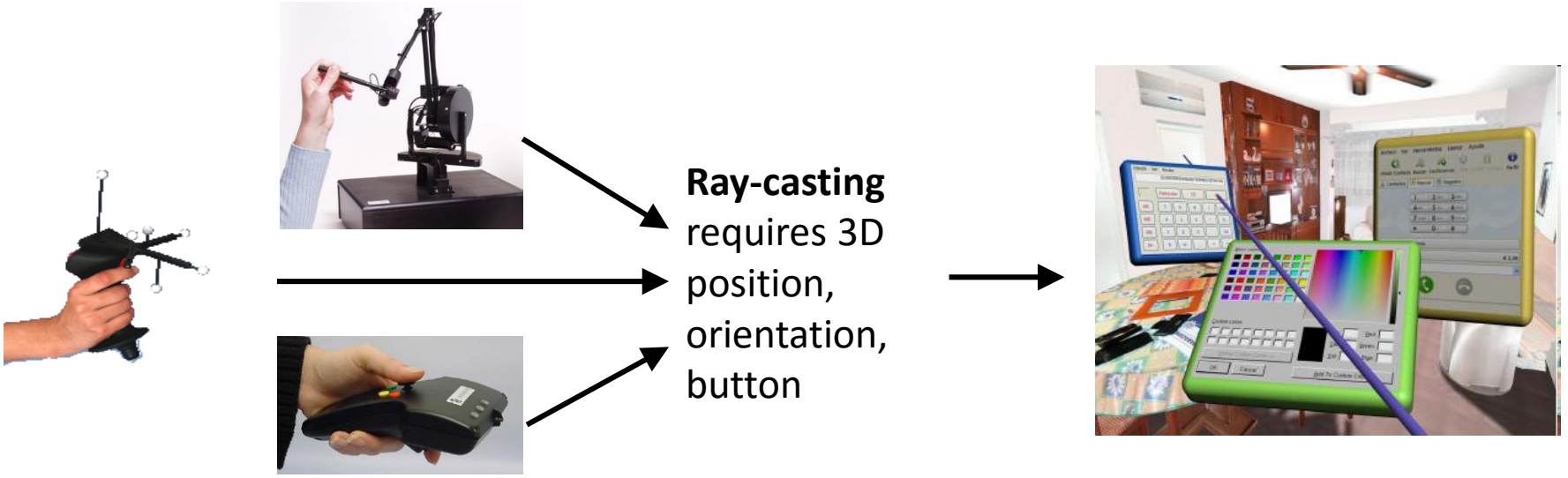
- **Interaction metaphor**:
  - Mental model/concept of a technique
  - Particular techniques can be different implementations of the same metaphor

Components of 3D Interaction



Software Components of Interaction

- also: „Control-Display Mapping“
- Information from input device → system actions → display
- Different input/output devices possible for same interaction concept.



Why Not Only Natural Interaction?

- Term “VR” implies replication of real world

- Why not use well-developed human skills to accomplish tasks in VEs?
  - travel: walking or driving
  - selection & manipulation: grasp and place

⇒These mappings are intuitive, but sometimes too limited

⇒Is natural interaction ergonomic?

[Movie Iron Man]

Outline

- 3D Interaction Techniques: Definitions and Basics
- Manipulation Tasks
- Navigation
- System Control

Manipulation Tasks

- Manipulation fundamental task for physical and virtual environments

- Canonical tasks
  - simple manipulation tasks
  - generally applicable

- Application-specific tasks
  - problem-specific
  - details important

Canonical Manipulation Tasks

- Two specific types of tasks:
  - Selection (or target acquisition)
    - Acquire or identify particular object for further manipulation
  - Manipulation
    - Change 3D position
    - Change 3D orientation

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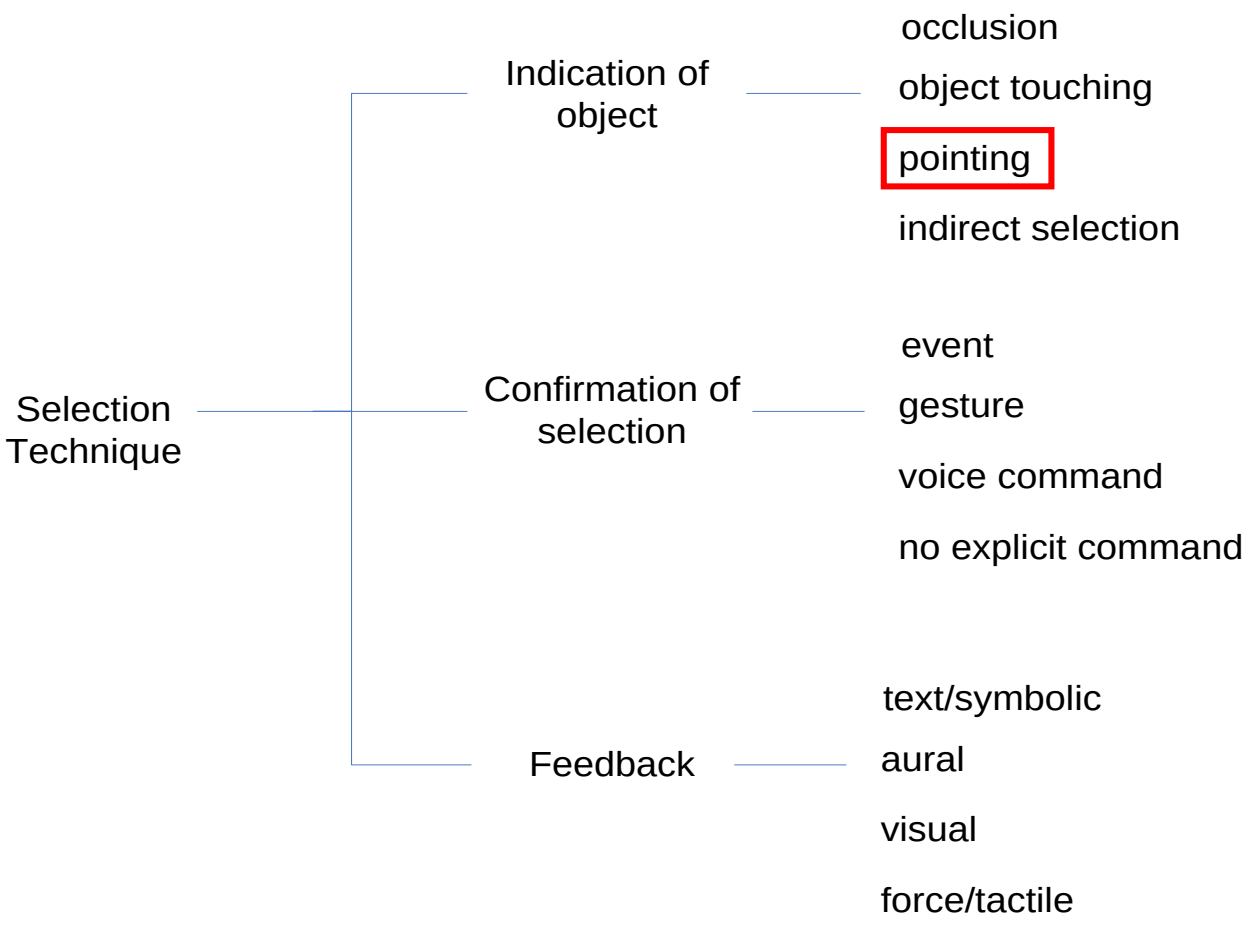
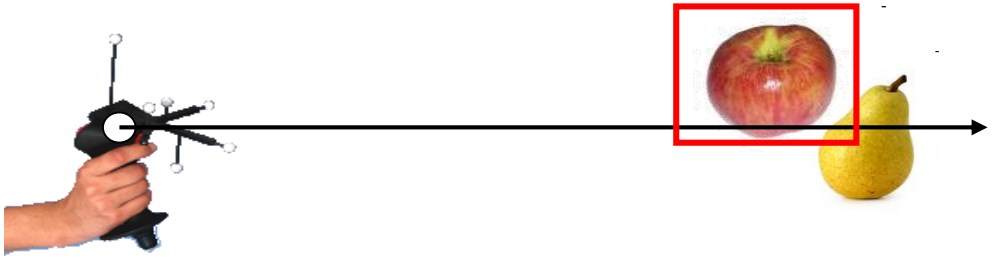
Selection

- Classification by task decomposition



Pointing: Ray-Casting

- Virtual ray from input device



- Choose closest intersected candidate

\+ Easy

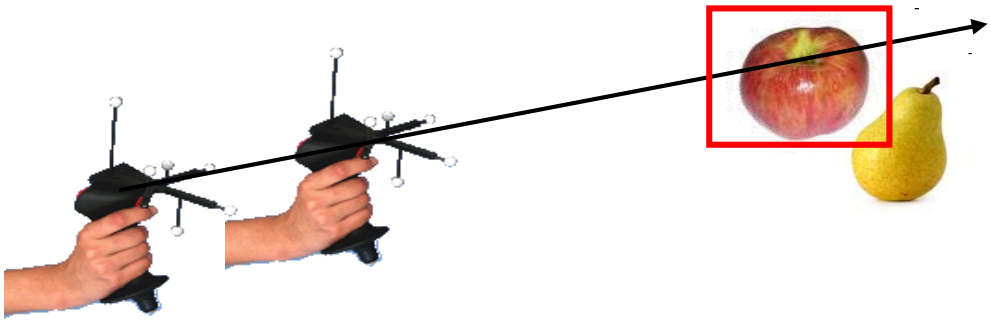
\+ Accurate at close range

– High angular accuracy needed, jitter problematic

– Hard to select small or far-away objects

Pointing: Two-Handed Ray-Casting

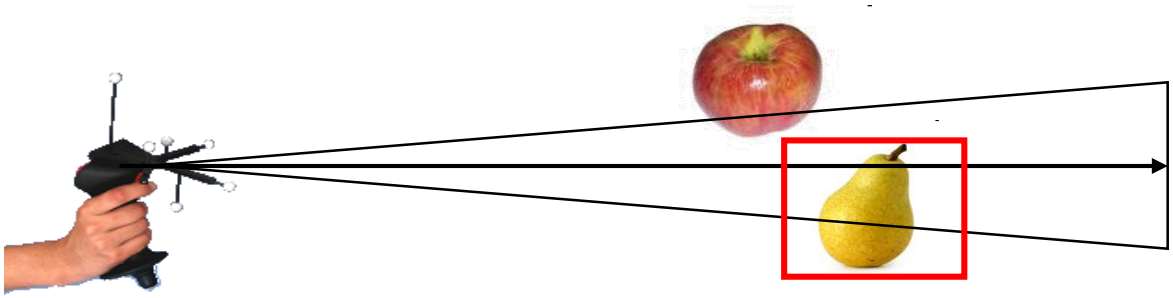
- Use both hands to define the ray



+ More accurate than one-handed
+ Specify pointer length by distance between hands
– Requires two tracked devices
– Cumbersome to use
– Fatigue

Pointing: Flashlight Technique

- Imitate flashlight: „Illuminate object, even if it is not accurately hit.“



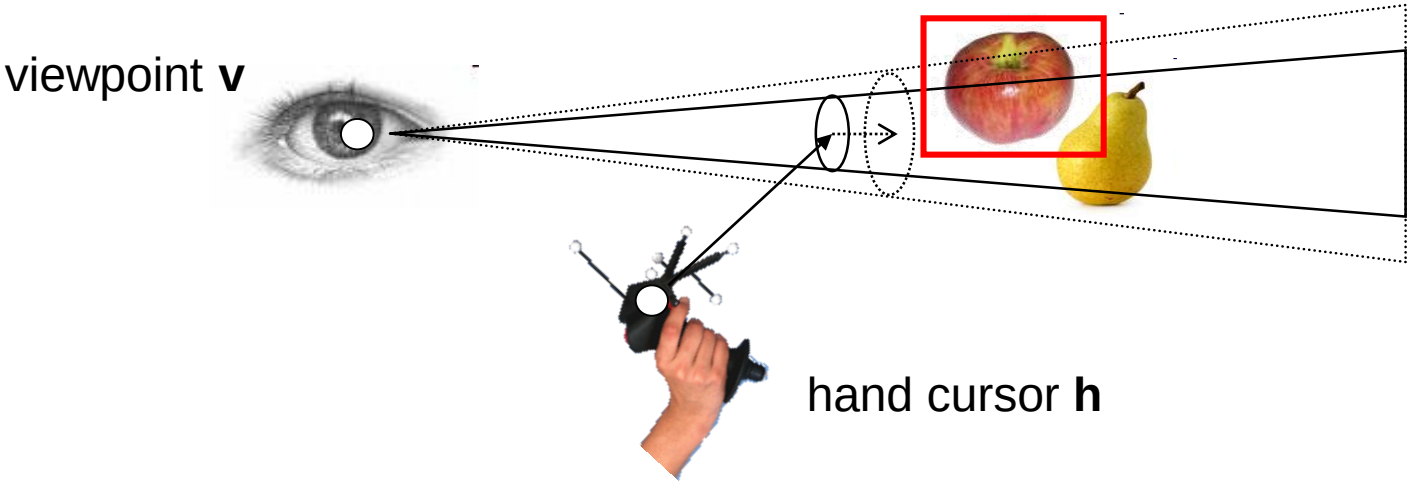
- Indicate the object touched by the selection volume that is
  - closest to the center line
  - or in case of multiple candidates: choose closest to the user

\+ Does not require high precision

– Hard to select small, tightly grouped objects

Pointing: Flashlight Extension – Aperture Technique

- Modifiy cone aperture using h-v



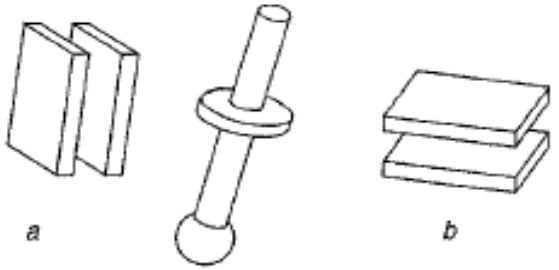
- Include orientation information: choose object whose orientation matches device orientation

\+ More control over selection

– Complicated to use

– Coupling of view and selection

a) Pointer selects rod



b) Pointer selects ring

DeHaan et al., 2005

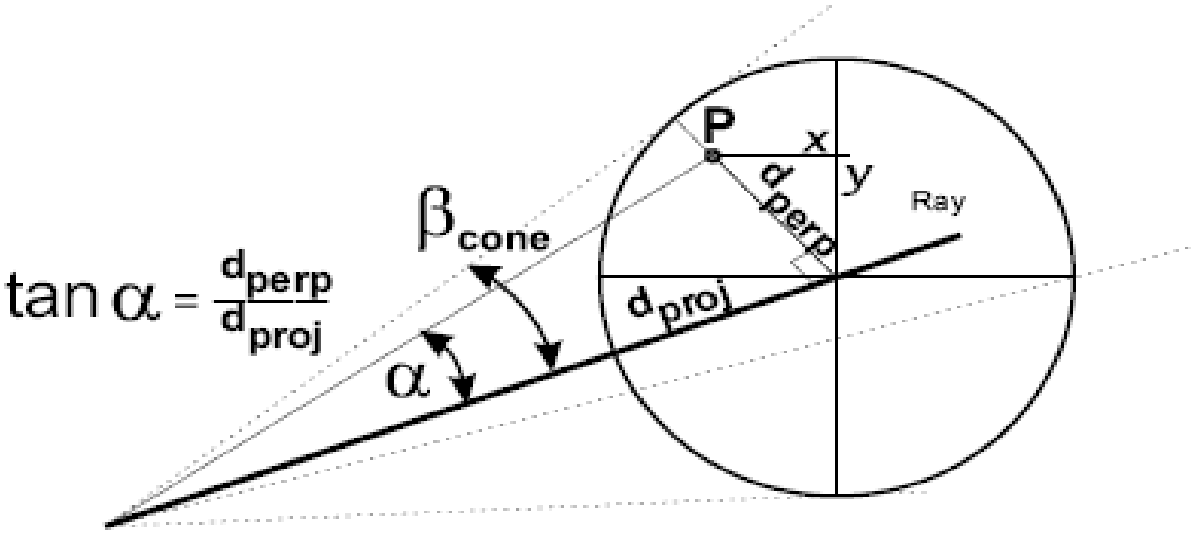
Pointing: IntenSelect

- Uses a ranking based on spatial matching and temporal consistency

- Four steps:
  - Selection volume test
  - Score contribution
  - Score accumulation
  - User feedback

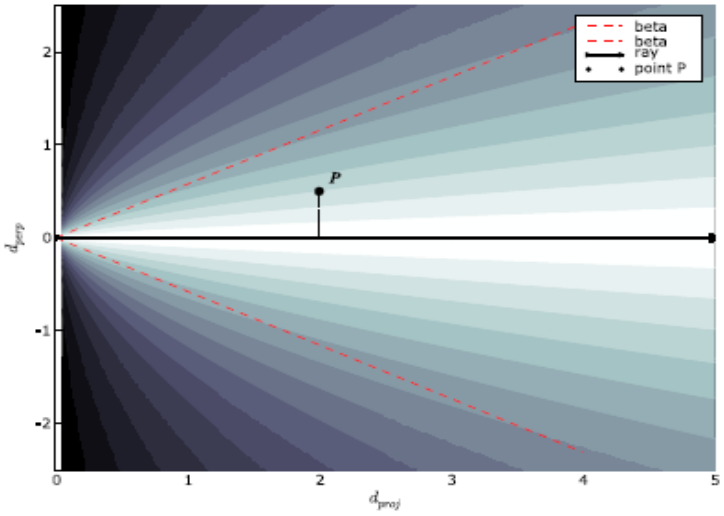
Pointing: IntenSelect

- Selection volume test
  - Like in flashligt technique
  - Test if point is inside of the selection cone
- Score contribution
- Score accumulation
- User feedback

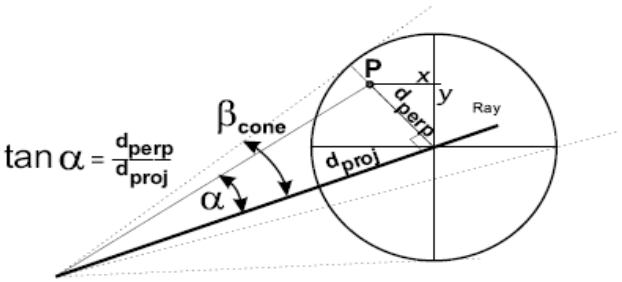


Pointing: IntenSelect

- Selection volume test
- Score contribution
  - Use scoring metric
  - Each object has a score between [0,1]
  - First approach: $s_{contrib} = 1 - \frac{\alpha}{\beta_{cone}}$
  - Second approach: $s_{contrib} = 1 - \frac{\arctan\left(\frac{d_{perp}}{d_{proj}}^{k}\right)}{\beta_{cone}}$
- Score accumulation
- User feedback



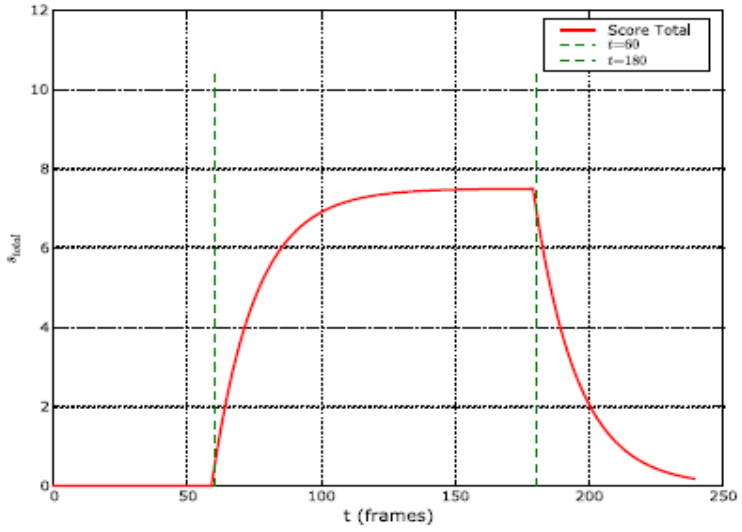
e.g., k=0.8



DeHaan et al., 2005

Pointing: IntenSelect

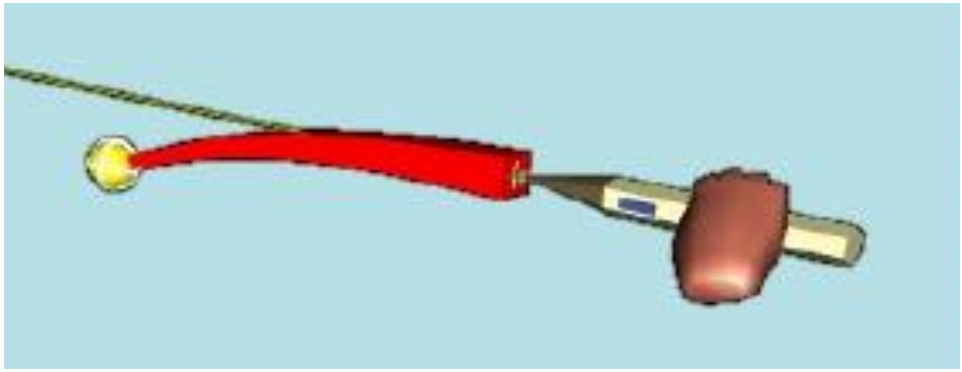
- Selection volume test
- Score contribution
- Score accumulation
  - accumulate over time: $s_{total}(t) = s_{total}(t-1) \cdot c_s + s_{contrib}(t) \cdot c_g$
  - stickiness $c_s \in [0,1]$ „rate of decay“
  - snappiness $c_g \in [0,1]$ „rate of growth“
  - choose object with highest total score
- User feedback



DeHaan et al., 2005

Pointing: IntenSelect

- Selection volume test
- Score contribution
- Score accumulation
- User feedback
  - Bent ray
  - Highlight the selected object



Summary:

\+ Easy to select small or crowded objects

\+ Easy to select moving objects

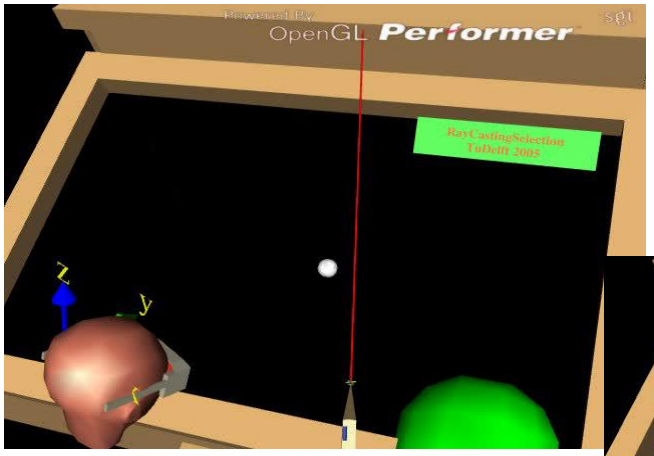
\+ Default scoring or special purpose scoring

– Only works for points/lines or objects they can approximate

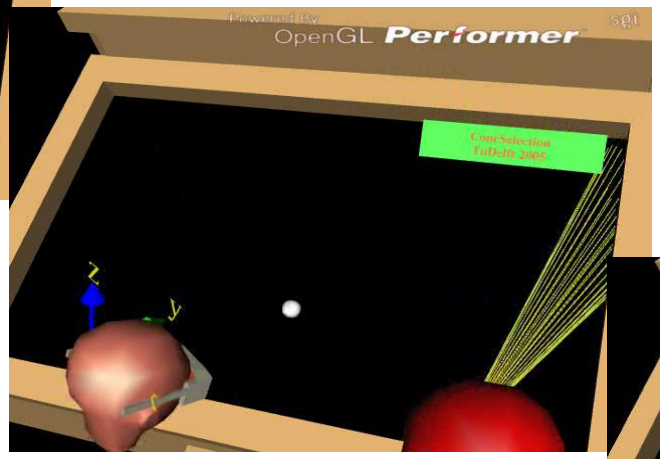
DeHaan et al., 2005

Pointing: Comparison of techniques

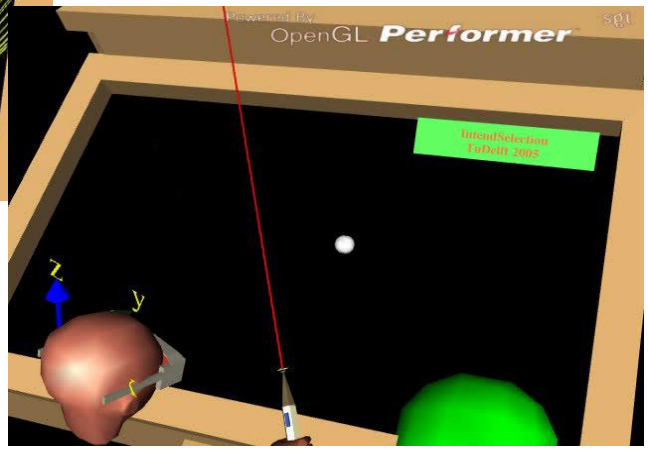
Ray-casting



Flashlight



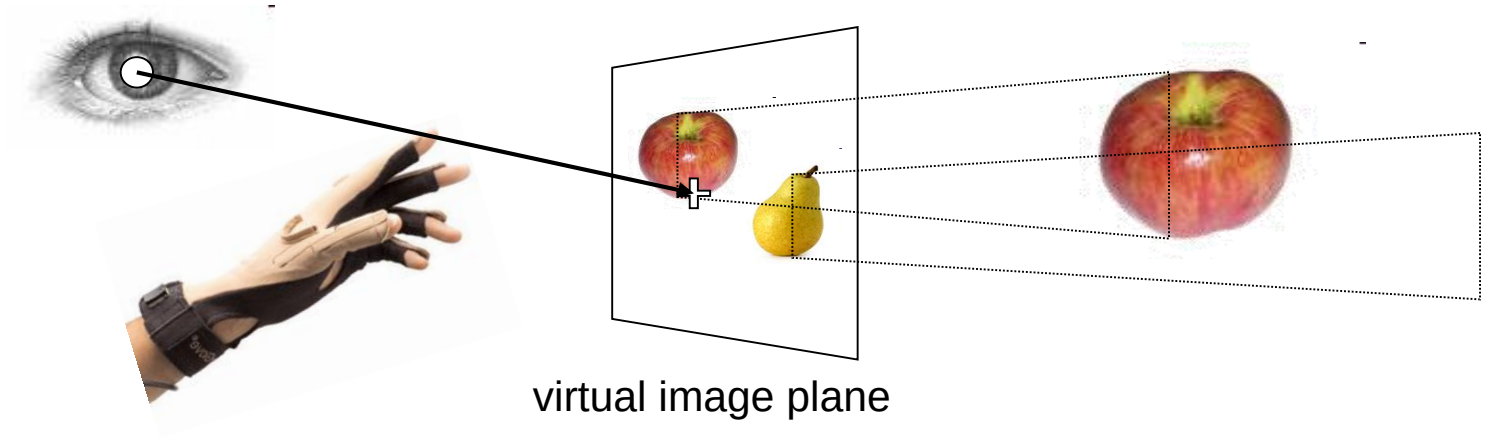
IntenSelect



Pierce et al. 1997

Pointing: Image-Plane Techniques

- Touch and manipulate 2D projection of 3D object



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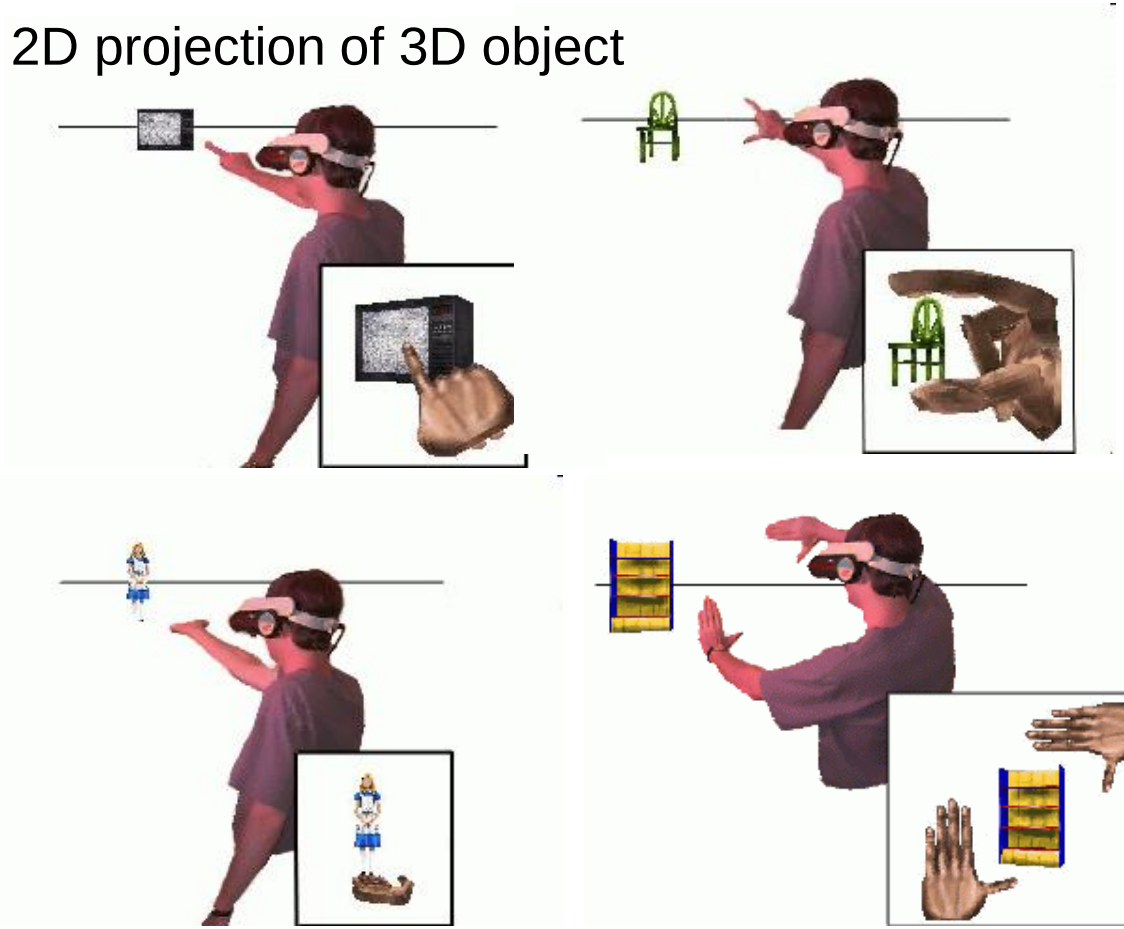


- Sticky finger
- Head crusher
- Lifting palm
- Framing hands

– Cannot modify distance to user

Touching: Virtual Hand Techniques

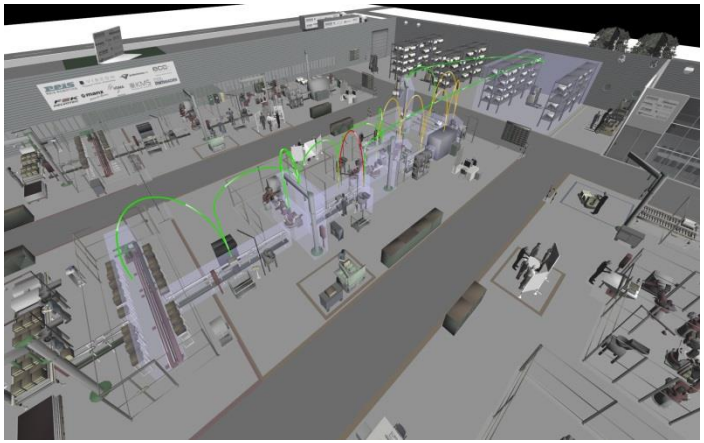
- Uses virtual hand or cursor
- Indication of object: touching

\+ Natural way of object indication

– Only works for objects within reach

Theory and Practice

- The “one and only selection technique” does not exist
- If required, real applications use combinations of different selections techniques
- Example: factory planning application flapAssist
  - IntenSelect works well for points and lines
  - Ray casting works better for large geometries
  - → Proper merging and priorization of both techniques needed



Canonical Manipulation Tasks

- Two specific types of tasks:
  - Selection (or target acquisition)
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  - Manipulation
    - Change 3D position
    - Change 3D orientation

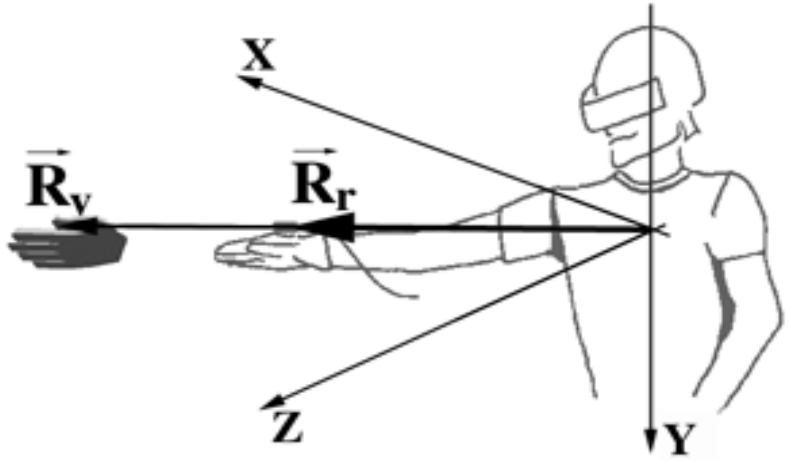
Object Manipulation

- Use simplified or realistic virtual hand („avatar“)
- Direct mapping between real hand and virtual hand
  - Linear position mapping
    $P_v = \alpha \cdot P_r + P_{offset}$
  - Typically direct orientation mapping
    $O_v = O_r$
- „Grasped“ object is attached to virtual hand
  - Transformations (translation, rotation) of virtual hand are directly applied to object

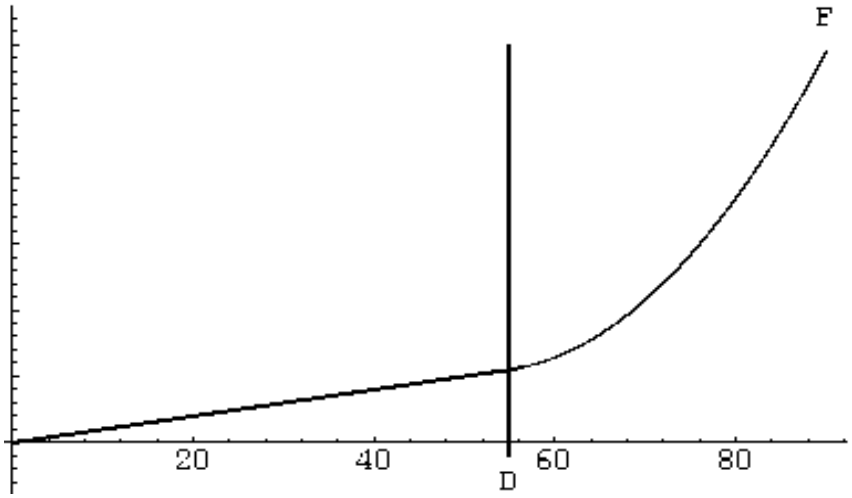
- Limited to reach, travel required to acquire remote objects

Go-Go

- Interactively change length of arm
- Use non-linear mapping function F between real and virtual hand
- Modify virtual arm-length r_v



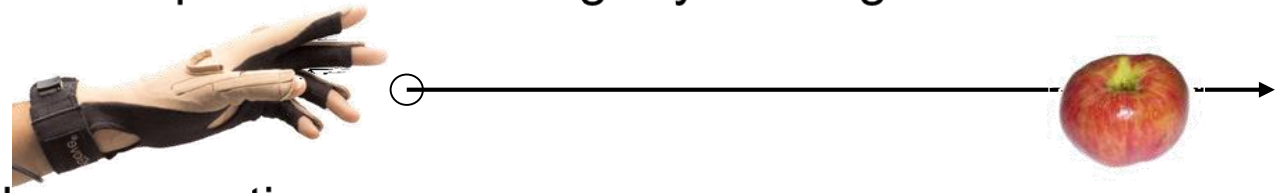
$$r_v = F(r_r) = \begin{cases} r_r \text{ if } r_r \le D \\ r_r + \alpha(r_r - D)^2 \text{ otherwise} \end{cases}$$



+ Seamless near-far transition
- Still finite reach
- Hard to position precisely in far distance

HOMER

- **H**and-centered **o**bject **m**anipulation **e**xtending **r**ay-casting



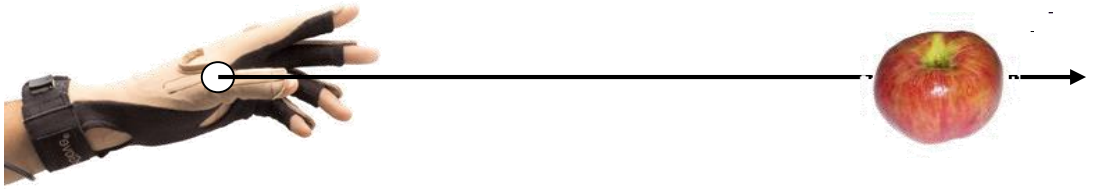
- Hybrid technique
  - Object selection by ray-casting
  - Manipulation by virtual hand

(1) Virtual hand moves towards object
(2) (Remote) object manipulation
(3) Virtual hand moves back to body

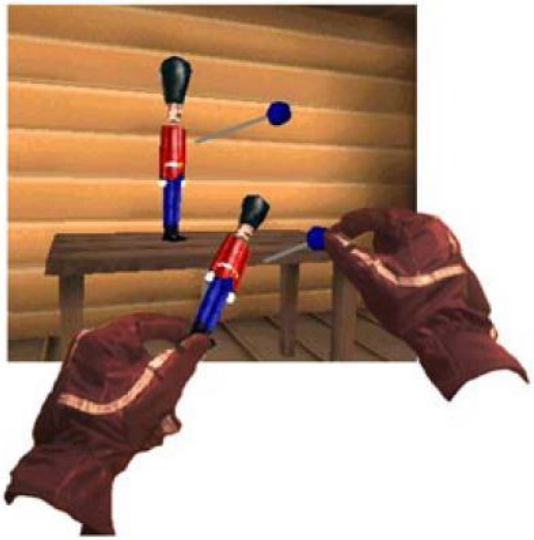
\+ Unlimited range
\- Limited manipulation range

Voodoo Dolls

- Manipulate remote objects by using temporary, miniature, hand-held copy



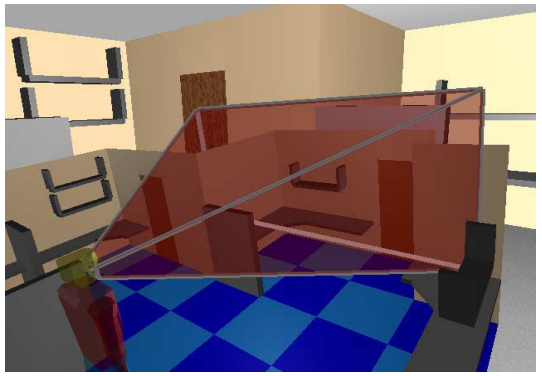
- Non-dominant hand specifies stationary frame-of-reference
- Dominant hand specifies moving frame-of-reference



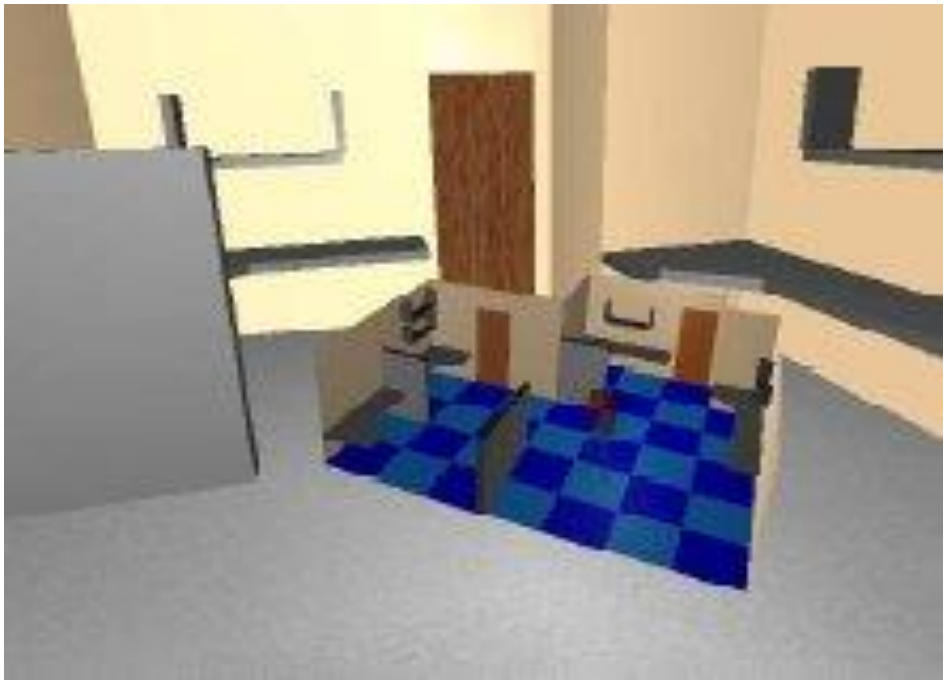
\+ Manipulation independent of distance size or occlusion

\- Requires two 6DoF devices

World-in-Miniature (WIM)



- Miniature is a hand-held copy of the virtual environment
- Manipulations to objects in the WIM are applied to the corresponding objects in the virtual environment

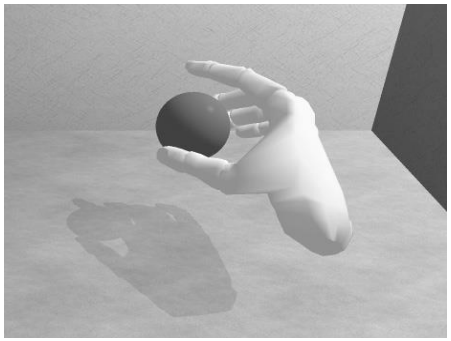
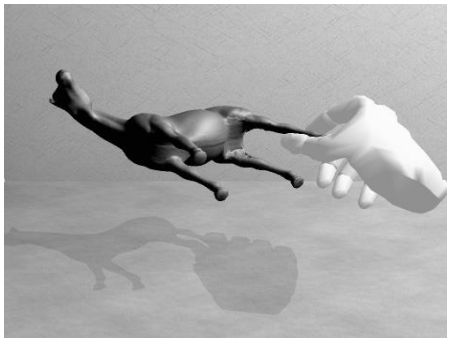
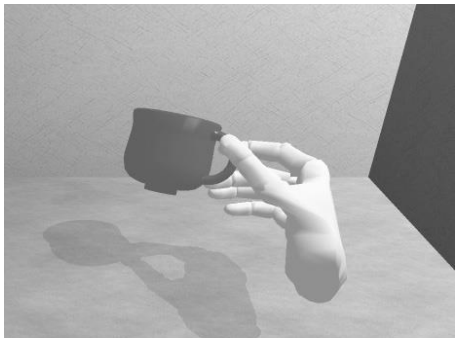
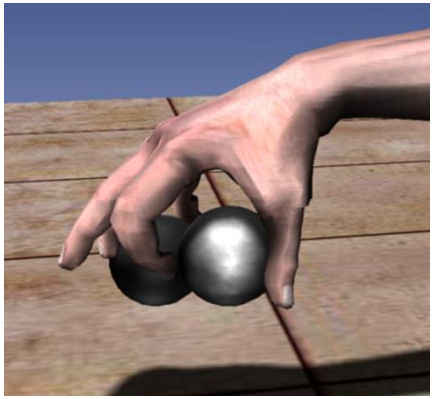
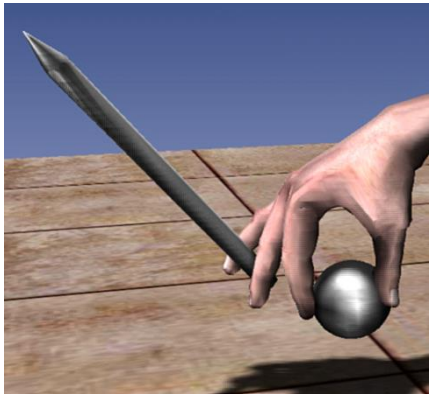


\+ Good overview while manipulation

– Lack of precision due to miniaturization

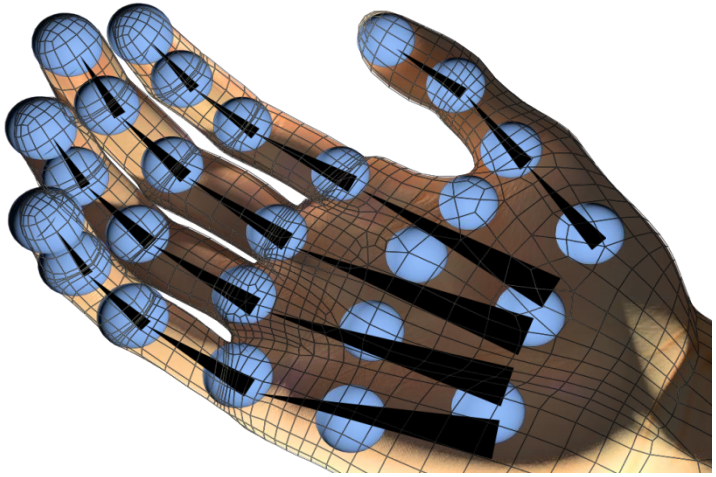
Grasping

- Natural interaction technique
- Exact simulation not trivial
- Tactile/force feedback in real world

Virtual Hand Model

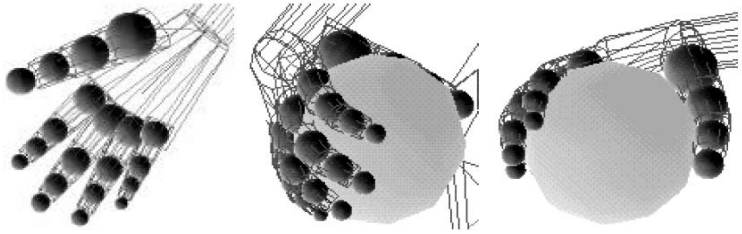
- Geometry-based
  - \+ accurate
  - \- computationally expensive

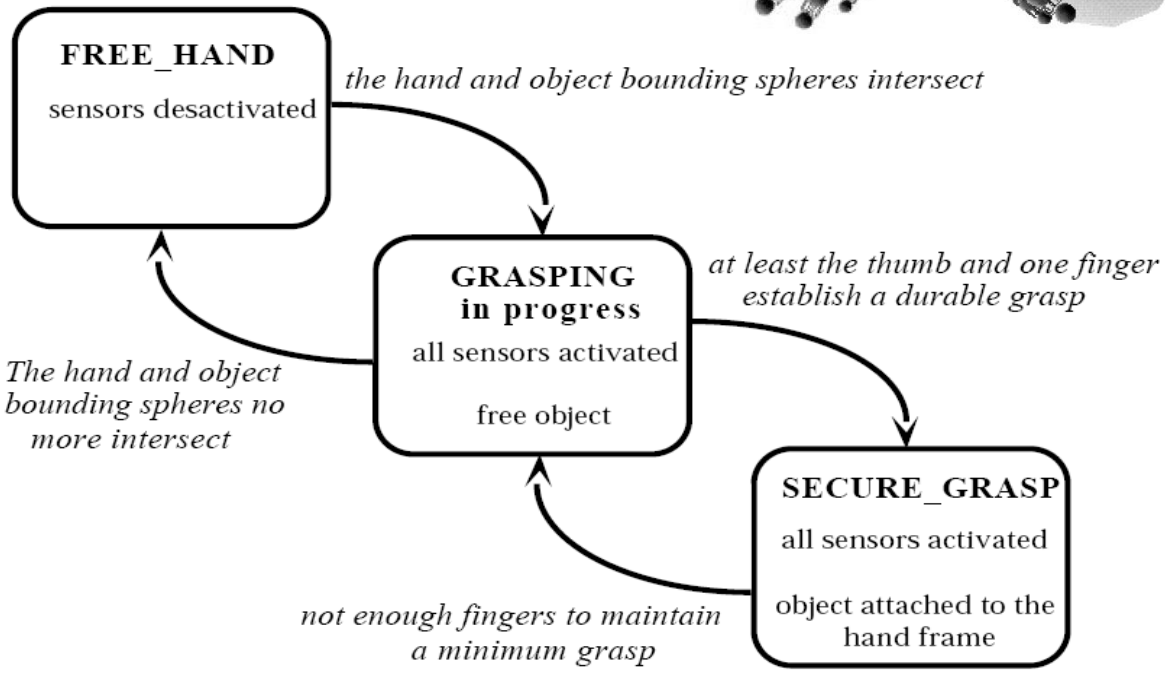


- Simplified sensor model
  - e.g., spheres
  - \+ easy collision detection
  - \- grasping only at contact points

Automata-based Grasp

- Simple state machine
- Object moves with hand



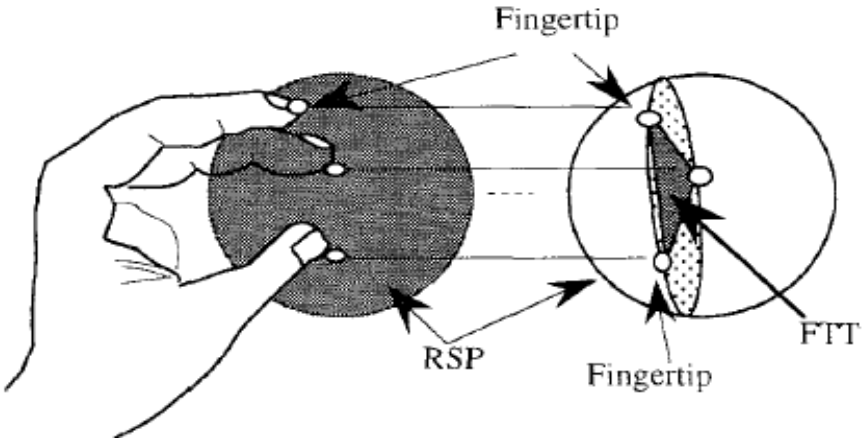


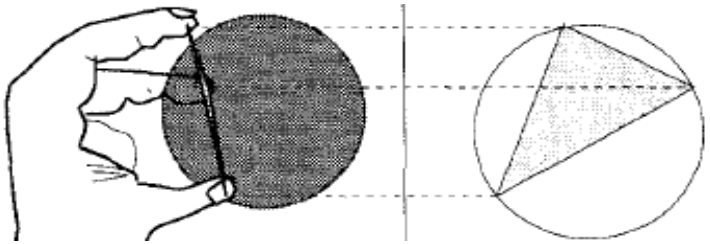
- Not physically based
- No finger manipulation

Representive Spherical Plane Method

- Targets finger manipulation of objects

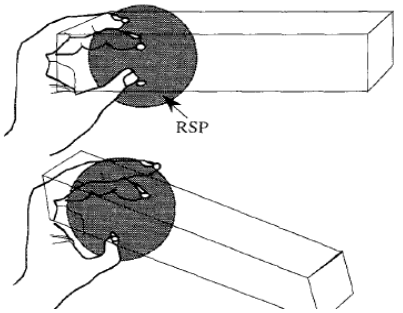
- Basic idea:
  - Object represented by sphere (RSP)
    - e.g., bounding sphere
  - Three fingertips form a triangle (finger tip triangle, FTT)

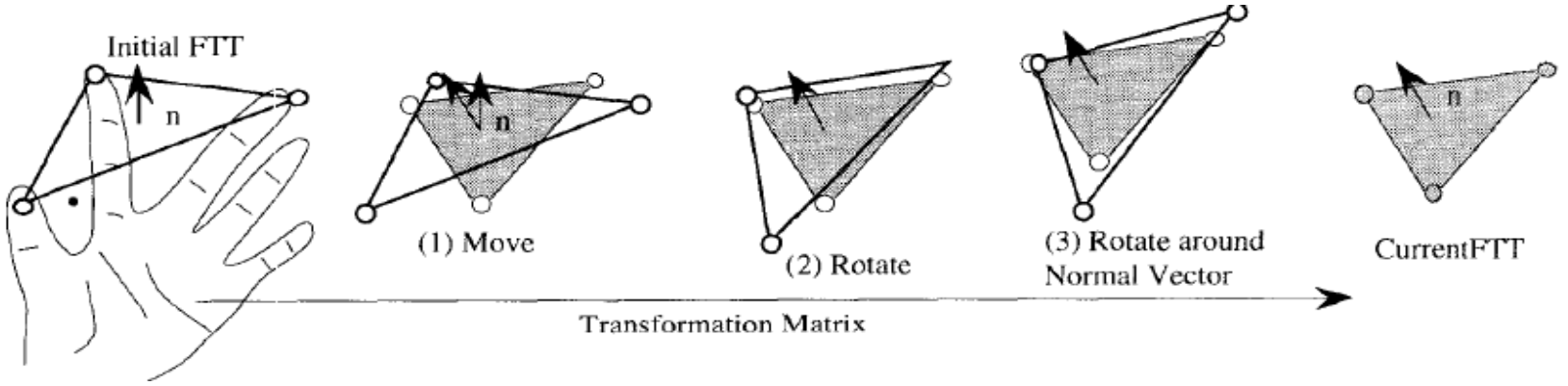




Representive Spherical Plane Method

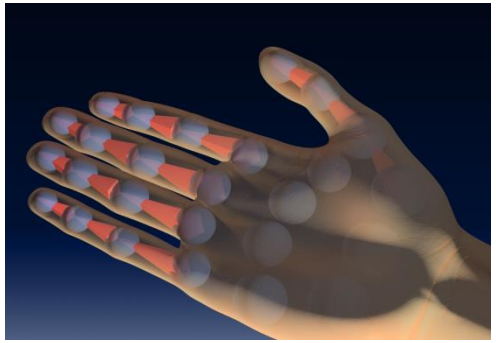
- Movement of fingers on sphere result in new FTT‘
- Analytical transformation from FTT → FTT‘
  1. Move to center of gravity
  2. Match normal vectors by rotation
  3. Rotate around normal until vertices are close
- Apply these transformations(1-3) to object



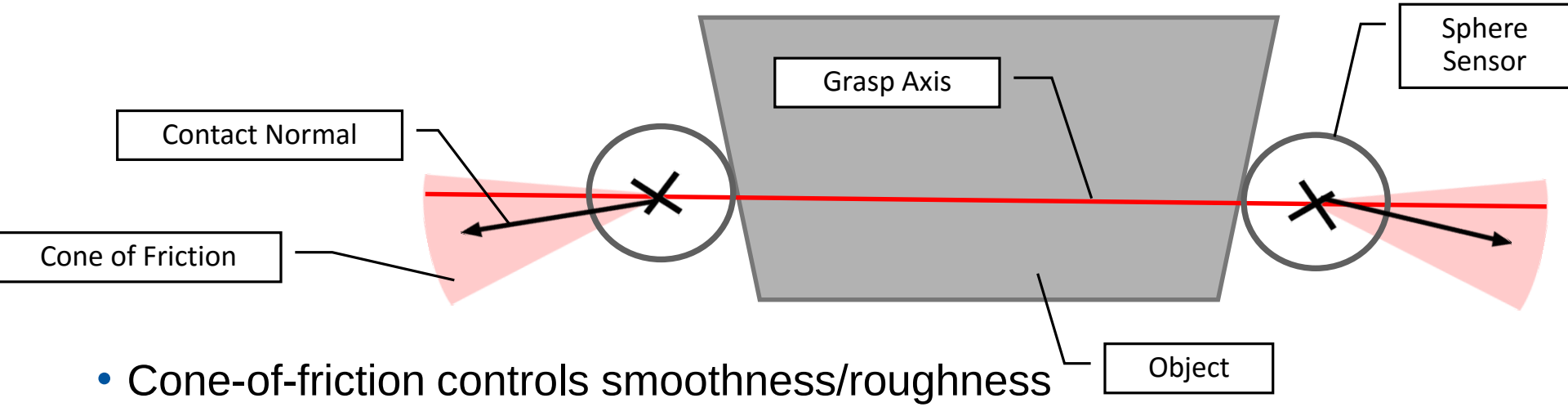


Multi-Contact Grasping

- Multi-Contact Grasping
  - Use pairs of sensors („grasp pair“)



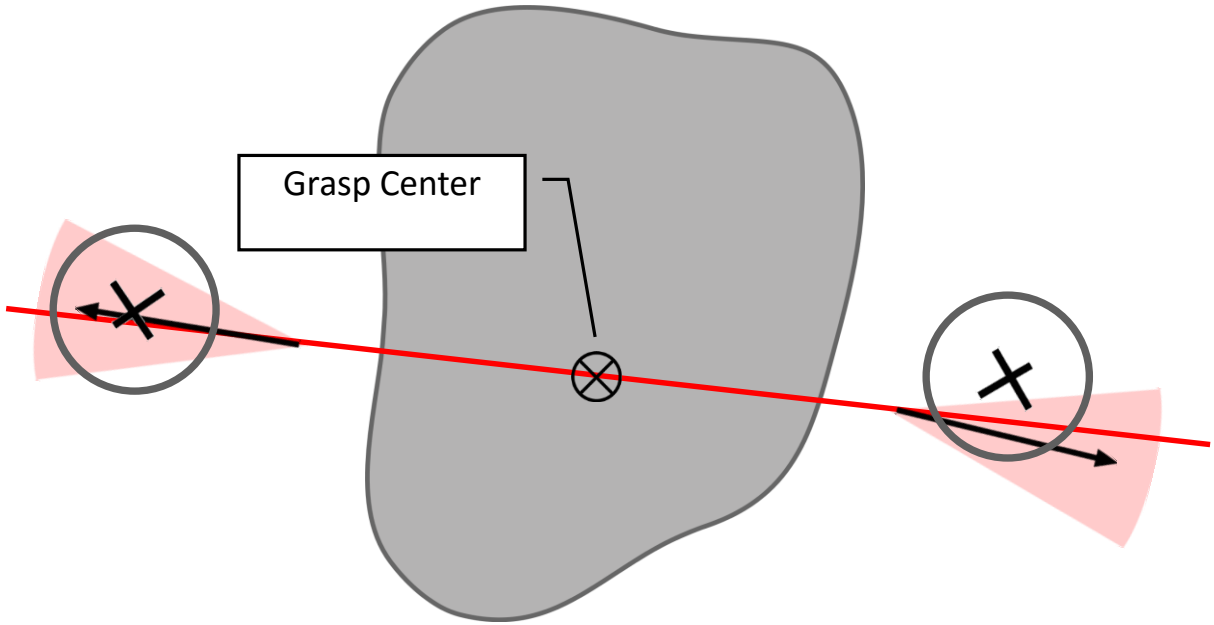
- Use simple grasp condition:
  - Grasp is valid if grasp axis inside cone-of-frictions



- Cone-of-friction controls smoothness/roughness

Grasping

One grasp pair:



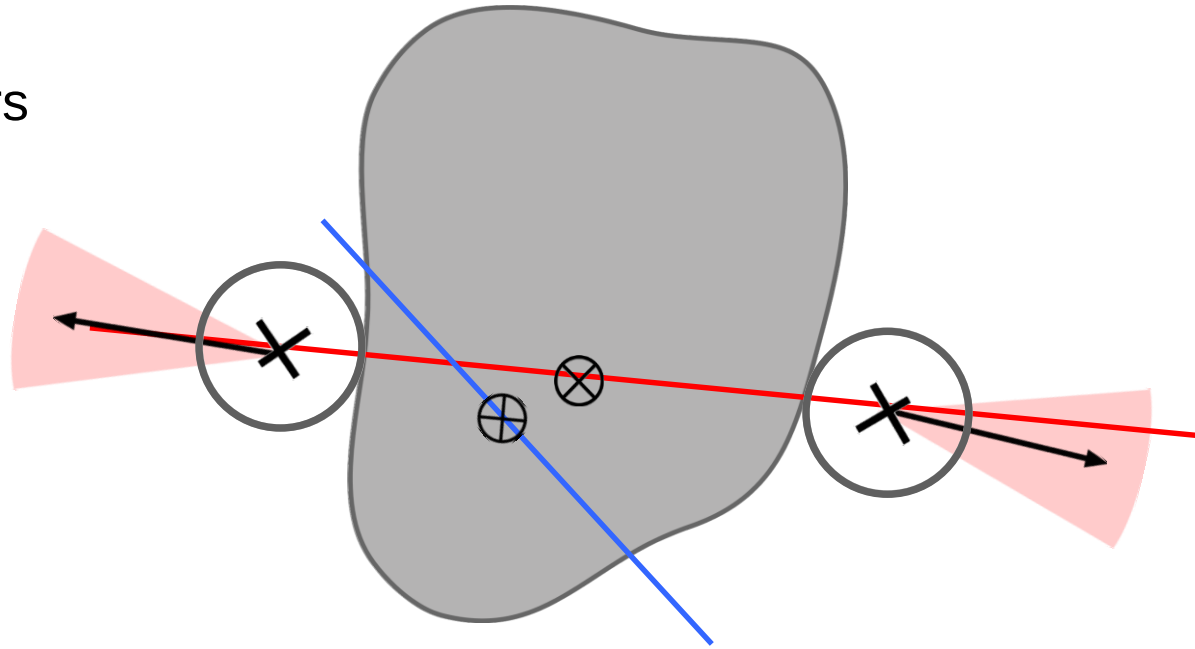
Grasping

One grasp pair:

- Movement of the sensors

Grasp Simulation:

1. **Calculate center translation**
2. **Calculate center rotation**

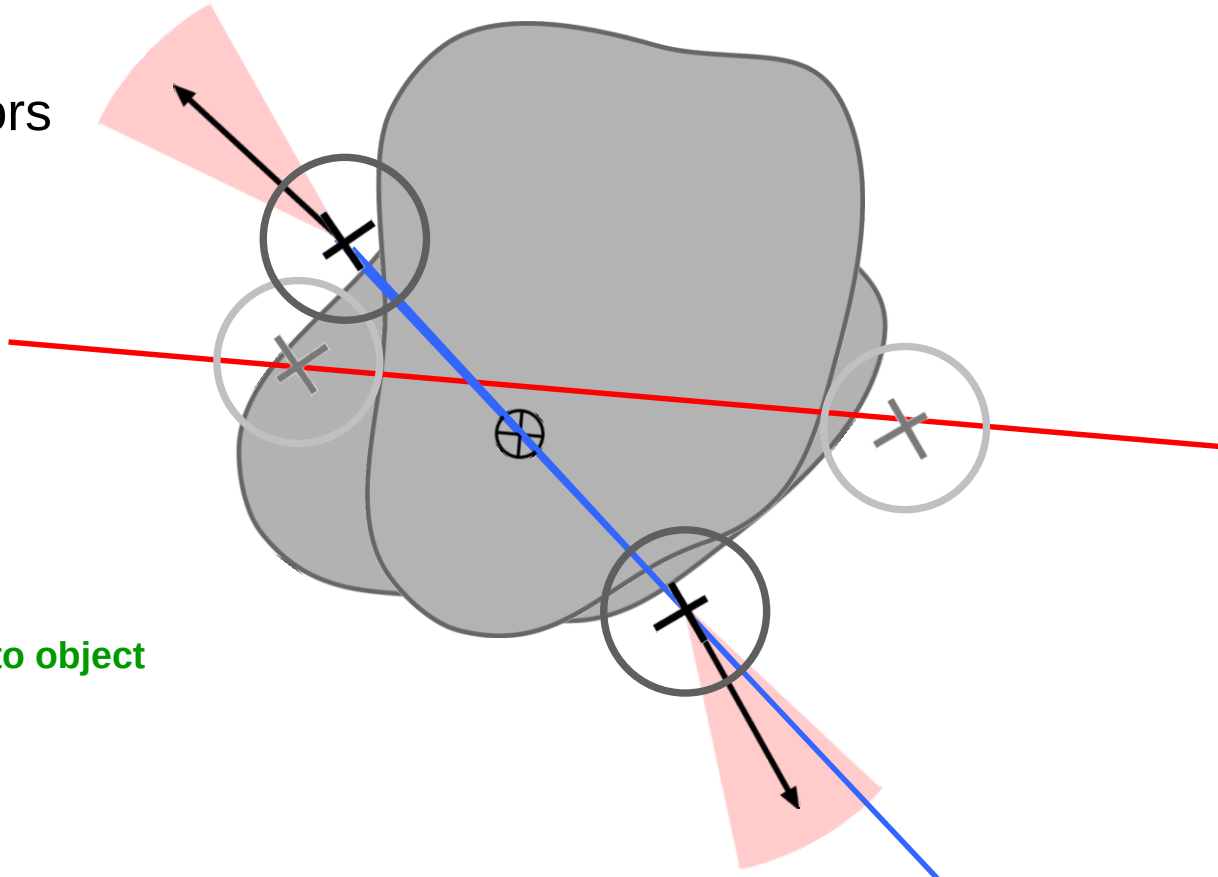


Grasping

One grasp pair:

- Movement of the sensors

Grasp Simulation:



1. **Calculate center translation**
2. **Calculate center rotation**
3. **Try manipulation ...**
4. **Is the result a valid grasp?**

Yes!

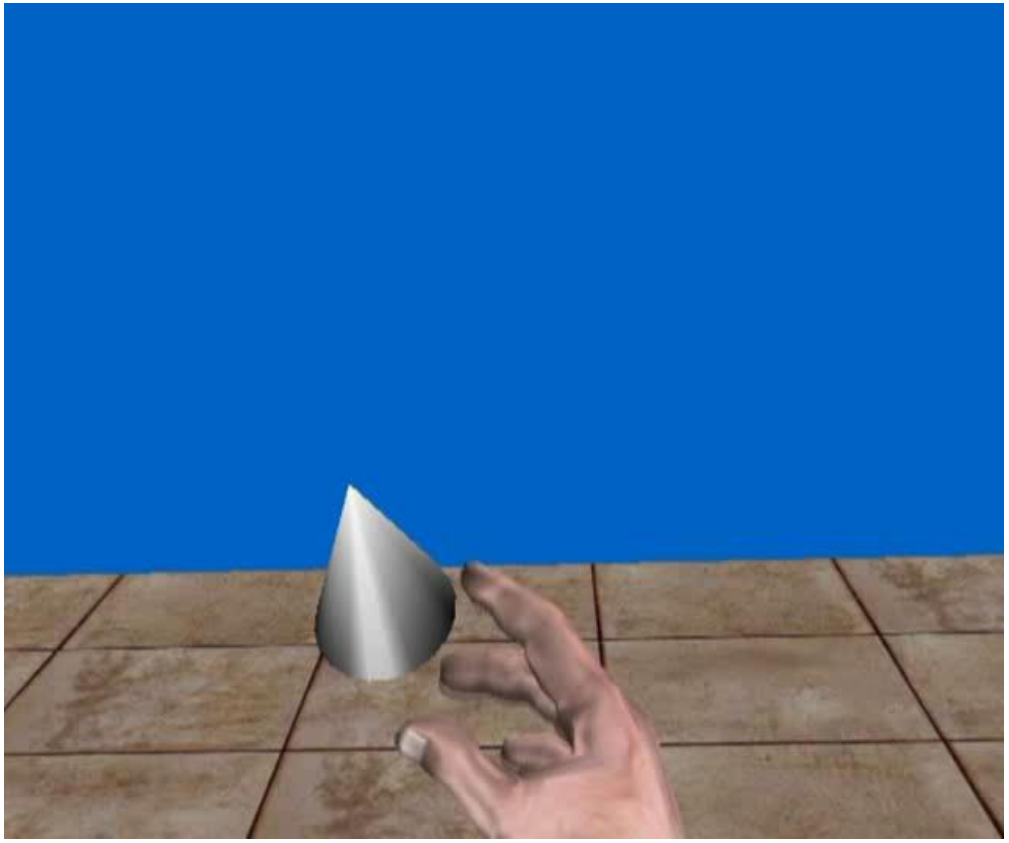
→ **Apply transformation to object**

No!

→ **Release object**

Grasping

- Example
  - Grasp simulation for one grasp pair (multiple pairs not shown here)
  - Movement of the sensors



1. Calculate center translation

2. Calculate center rotation

3. Try manipulation ...

4. Is the result a valid grasp?

Yes!

→ **Apply transformation to object**

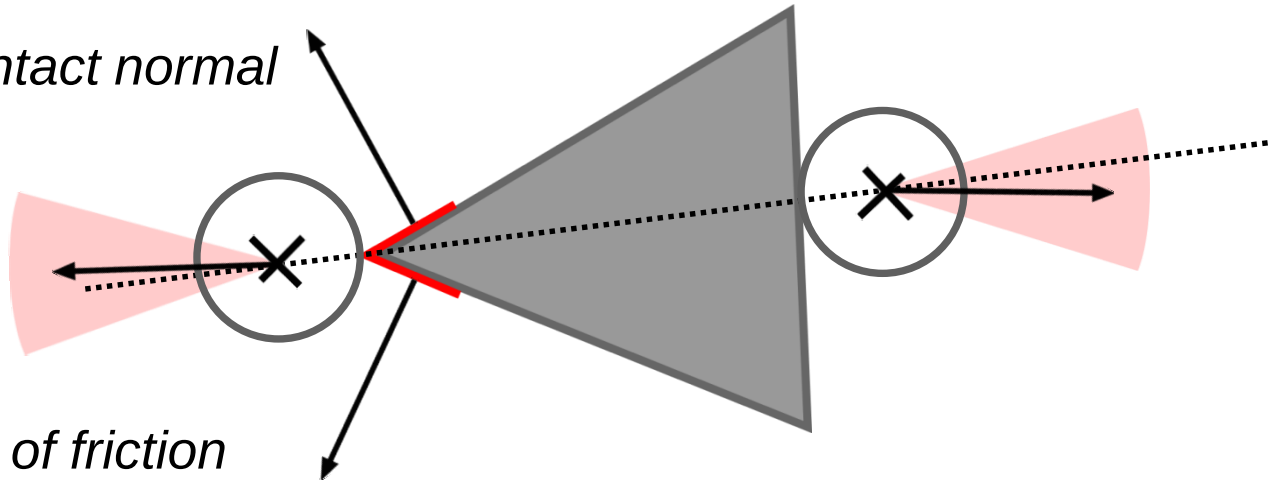
No!

→ **Release object**

Grasping

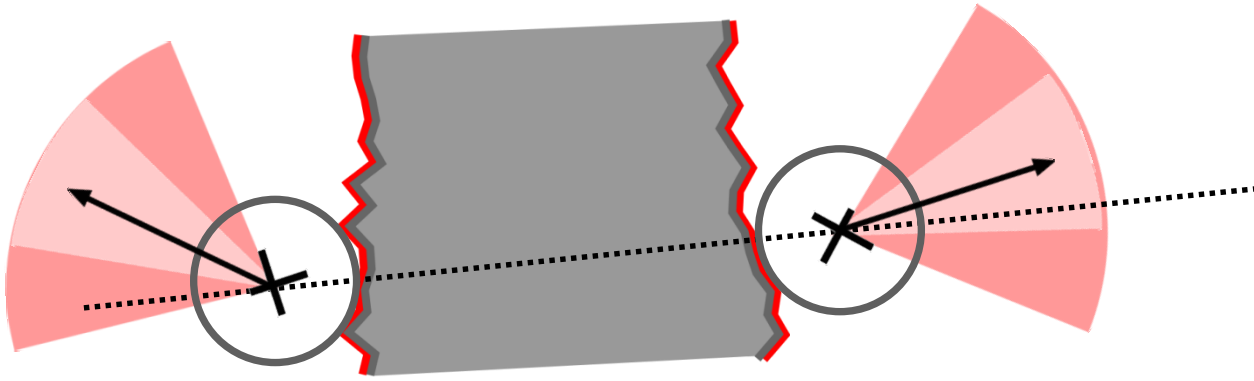
Sharp objects:

→ *Interpolate contact normal*



Rough objects:

→ *Increase cone of friction*



Application-Specific Manipulation Tasks

- ...could be anything

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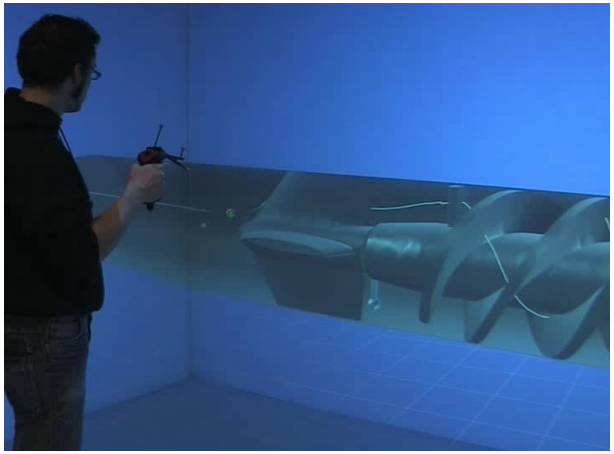

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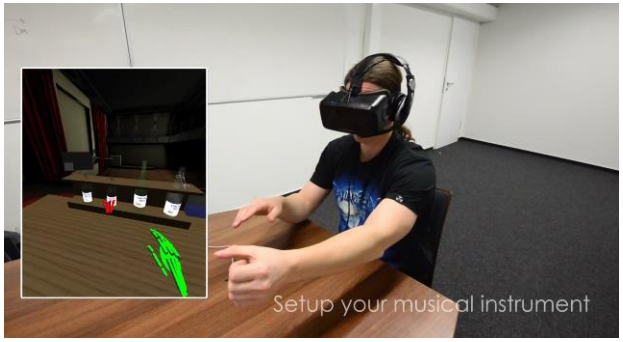

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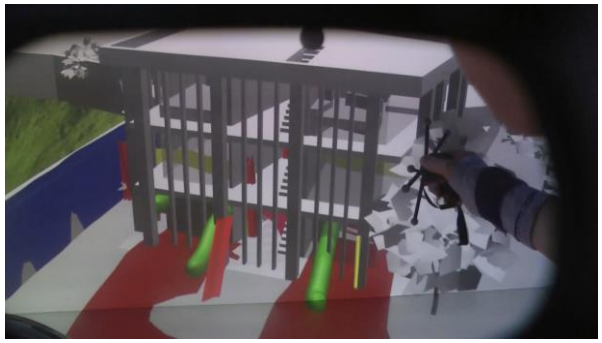

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RWTH Aachen

Outline

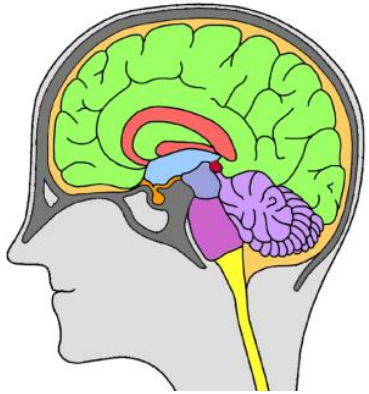
- 3D Interaction Techniques: Definitions and Basics
- Manipulation Tasks
- Navigation
- System Control

Navigation Tasks

- **Navigation**: movement in and around an environment

- Travel
  - Motor component

- Wayfinding
  - Cognitive process
  - Define a path
  - Use and acquire spatial memory



Navigation Tasks

- **Navigation**: movement in and around an environment

- Travel
  - Motor component

- Wayfinding
  - Cognitive process
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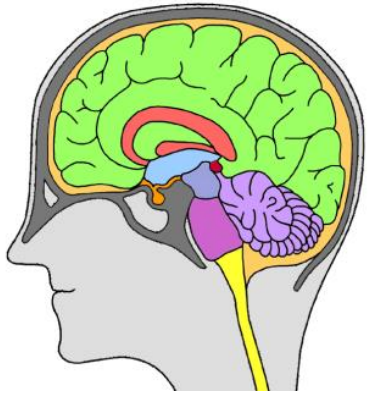
  - Use and acquire spatial memory



Travel Tasks

- Different travel tasks require different techniques

- **Exploration**
  - No explicit goal, unplanned movement, spontaneous target changes
  - Browse through the environment, acquire spatial knowledge
  - Typically at the beginning of an interaction

- **Search**
  - Travel to a specific target location
  - Naïve search: user does not know target position or path there
  - Primed search: user knows target position (e.g., has been there before)

- **Maneuvering**
  - Small, precise movements, local area
  - Ex.: step aside, move around object

Travel Techniques

- By metaphor
  - Physical locomotion
  - Steering
  - Route-planning
  - Target-based

Physical Locomotion – Real Walking

- Real Movement = virtual movement

\+ Natural
  + Correct vestibular and proprioceptive cues (no conflict of senses)
  + Highest possible immersion
  + No devices, no learning
  + Higher cognitive performance

− Spatial limitations
− Technological limitations
− Not applicable to all use cases (e.g., office)

Physical Locomotion – Walking-in-Place

- „Simulate“ walking movement
  - Trackers at feet or legs
  - Track „bobbing“ head
- Move without actually translating the body

\+ Little space requirements

\+ Unlimited range

− Vestibular cues not realistic

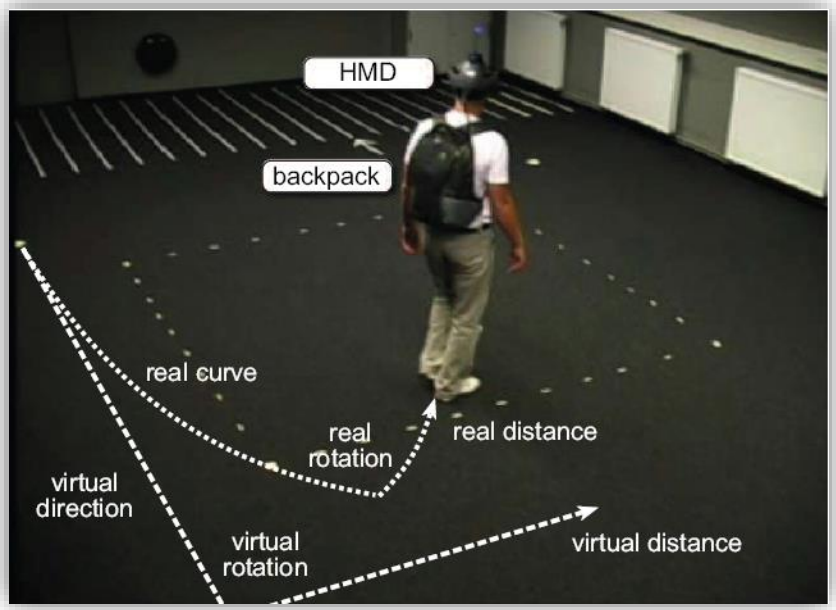
− Reliably detecting the actual start and stop of the motion is tricky

Wendt et al., 2010

Razzaque et al., 2001, Bruder et al., 2008, Steinicke et al., 2009, Suma et al., 2012 etc.

Physical Locomotion – Redirected Walking

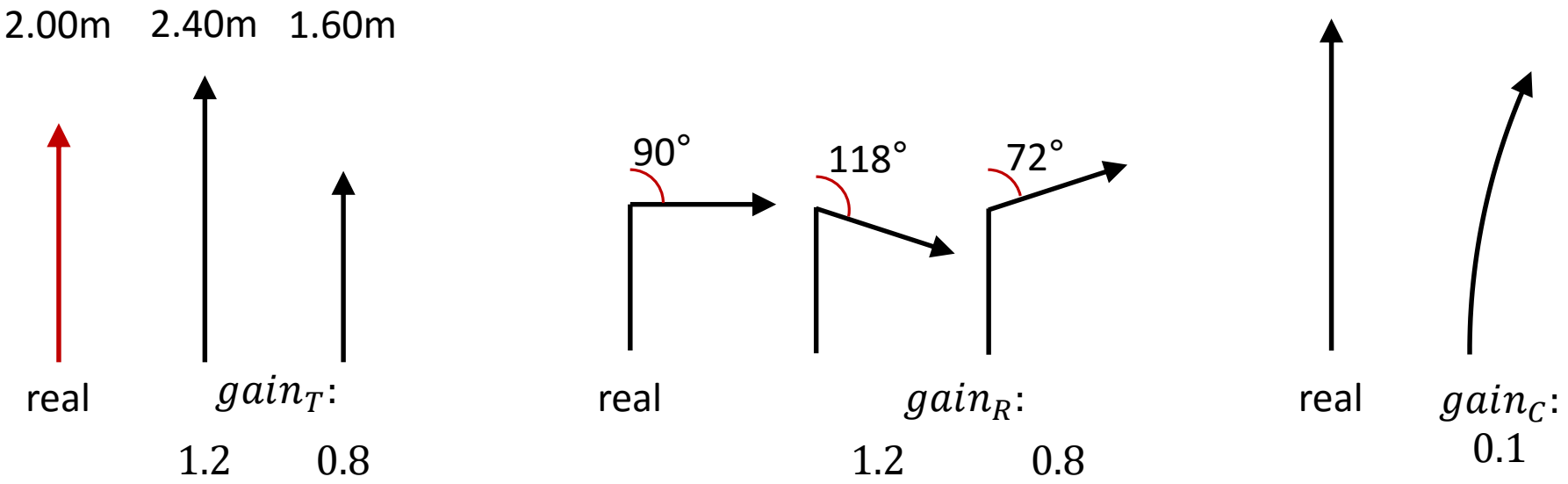
- Imperceptible manipulations to guide user (e.g., away from walls)
- Most common: apply *gains* -> amplify/reduce motion or rotation by factor
- Three basic/common techniques:
  - *Translation* gain
    - multiply (forward) movement
    - User walks faster/slower
  - *Rotation* gain
    - multiply rotation around vertical axis
    - User turns more/less
  - *Curvature* gain
    - Rotate as a function of forward movement
    - User walks in a circle



Steinicke et al., 2009

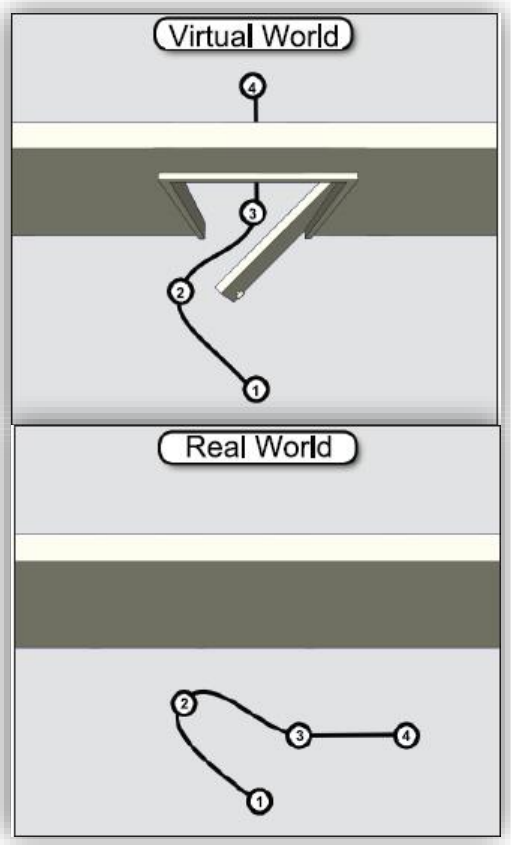
Redirected Walking: Examples

- Translation Gain: $forward_{virtual} = gain_T \cdot forward_{real}$
- Rotation Gain: $rot_{virtual} = gain_R \cdot rot_{real}$
- Curvature Gain: $rot_{virtual} = rot_{real} + gain_C \cdot forward_{real}$



Physical Locomotion – Redirected Walking

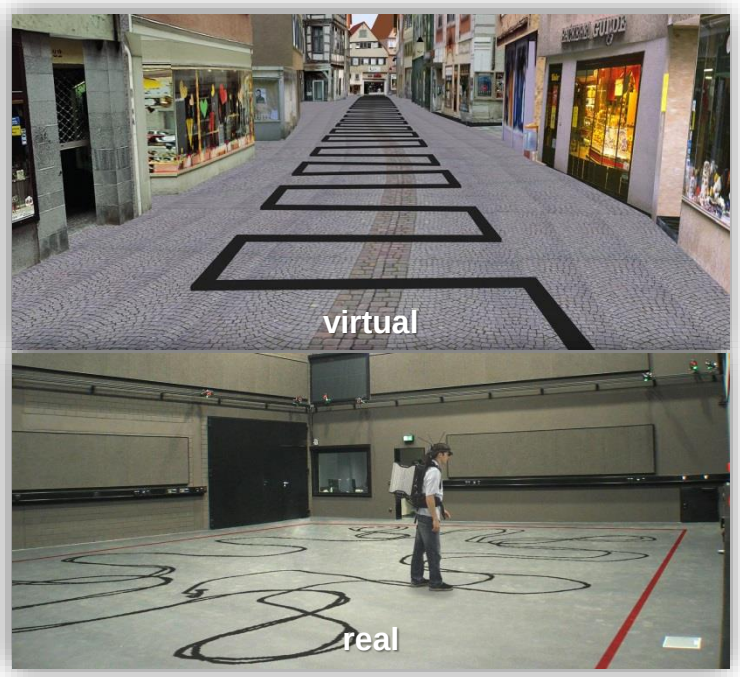
- Modify gains at runtime to guide user (e.g., to the center of the room)

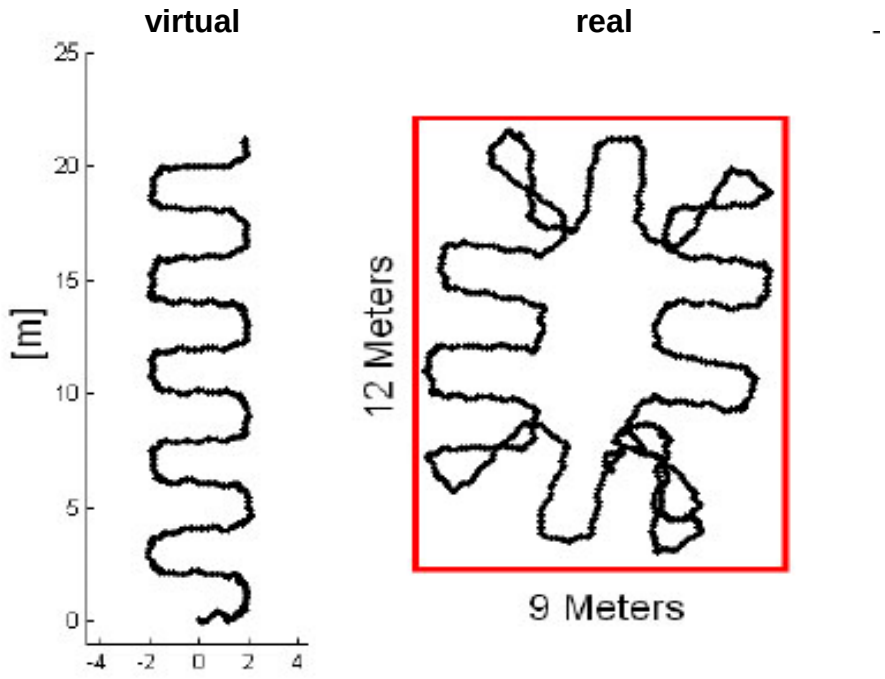


Bruder et al., 2009

Physical Locomotion – Redirected Walking

- Limits for deviation (without most people noticing)
  - Gains between ~0.8 and ~1.2 for translation gain
  - Gains between ~0.7 and ~1.2 for rotation gain
  - $\sim 40m \times 40m$ area for curvature





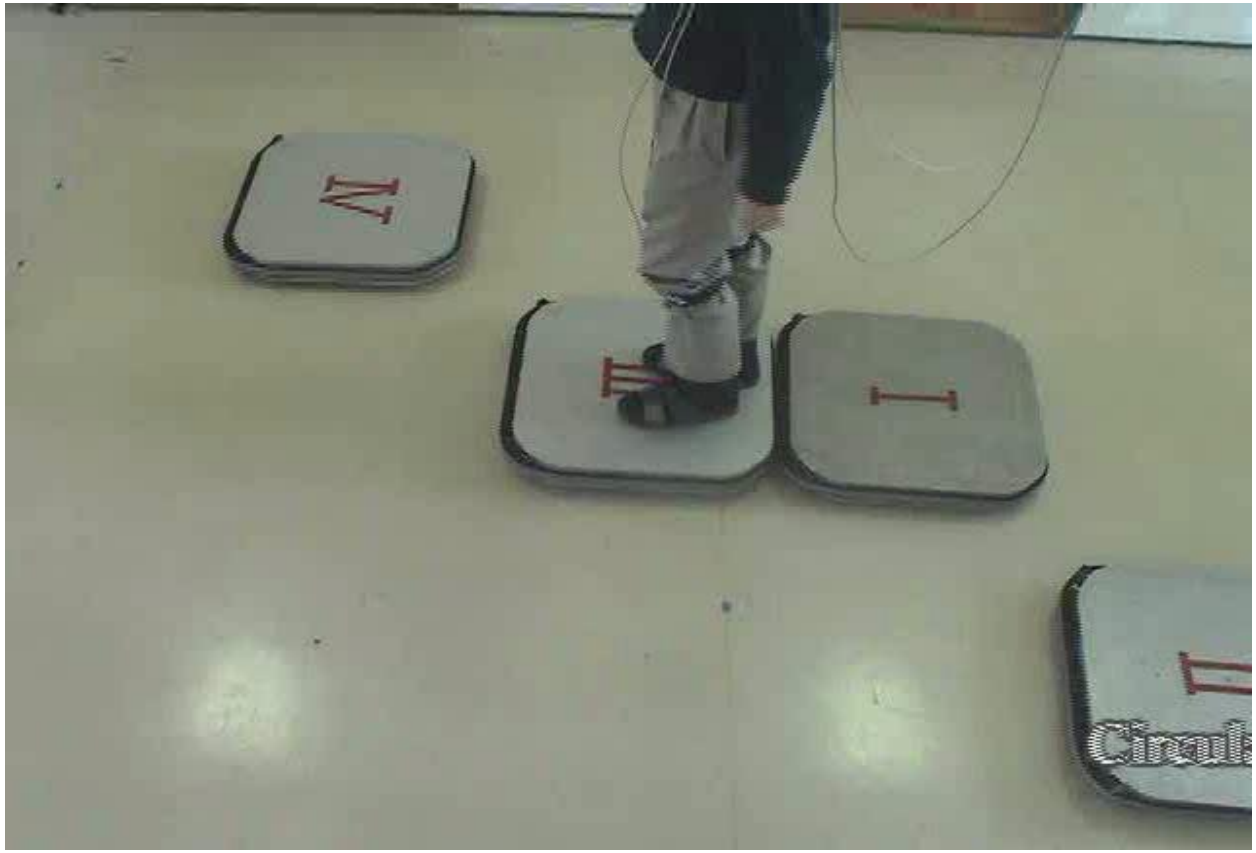
Engel et al., 2008

Physical Locomotion – Walking Devices

GaitMaster2

Iwata et al. 2001

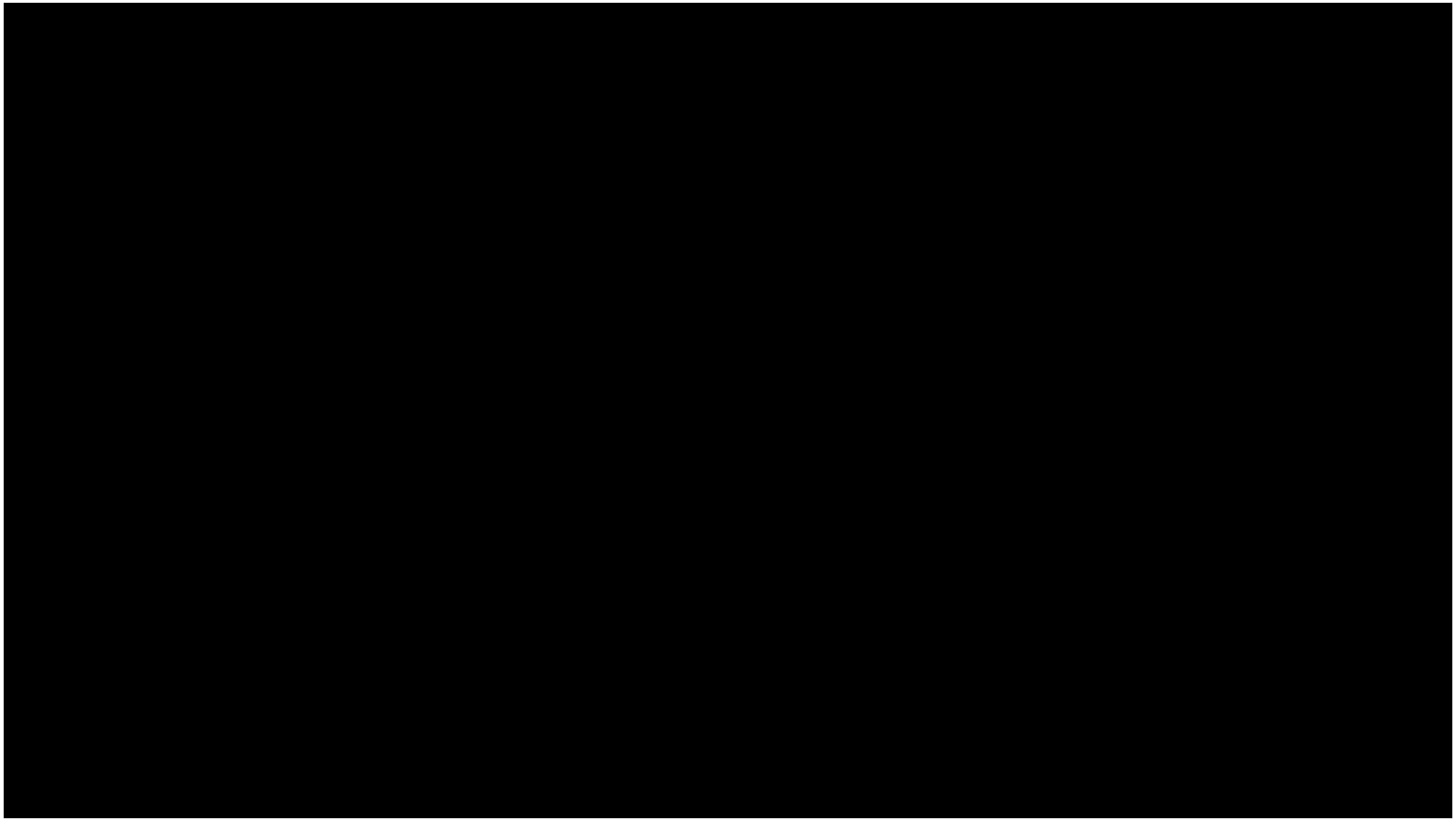
Movable Plates



Iwata et al. 2005

Physical Locomotion – Walking Devices

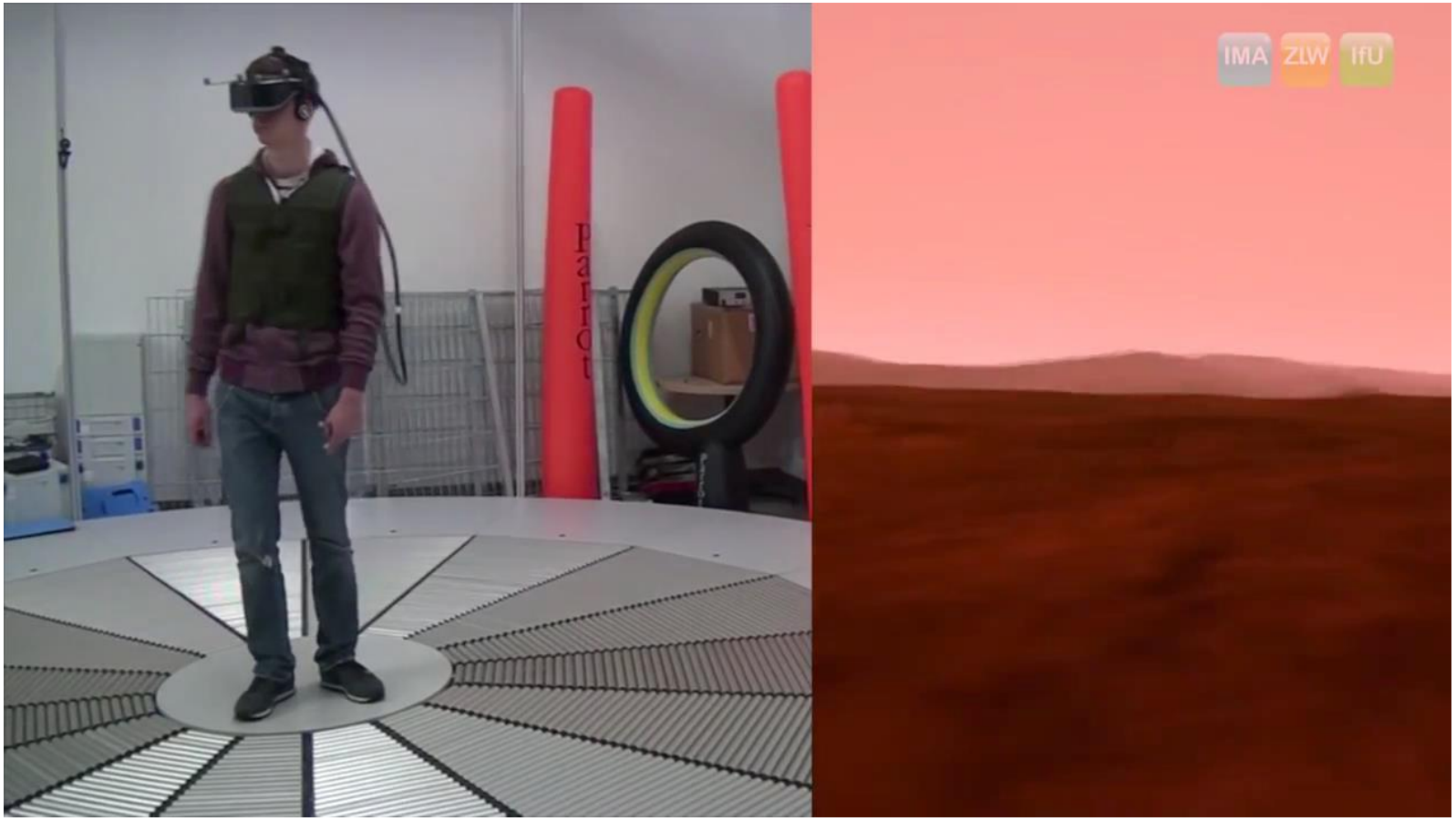
Infinadeck



www.infinadeck.com

Physical Locomotion – Walking Devices

Virtual Theatre



IMA, ZLW & IfU der RWTH Aachen

Physical Locomotion – Walking Devices

Virtuix Omni

http://www.virtuix.com

Travel Techniques

- By metaphor
  - Physical locomotion
  - Steering
  - Route-planning
  - Target-based

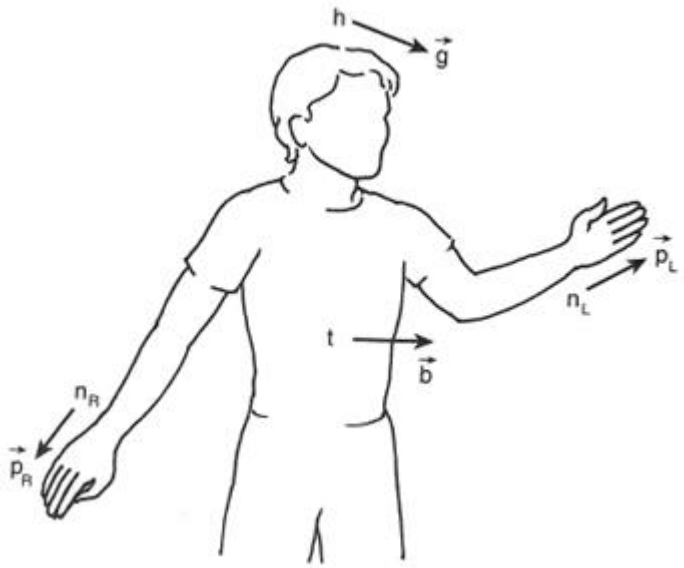
Steering

- Continuous direction control by user
  - Absolute direction („move along [0,0,-1] in world coordinates“)
  - Relative direction („move right“)

- Determine position by speed v and direction d:

$$p_{new} = p_{old} + v \cdot \frac{d}{\|d\|}$$

- Gaze-Directed
- Pointing
- Torso-Directed
- Physical Steering Props



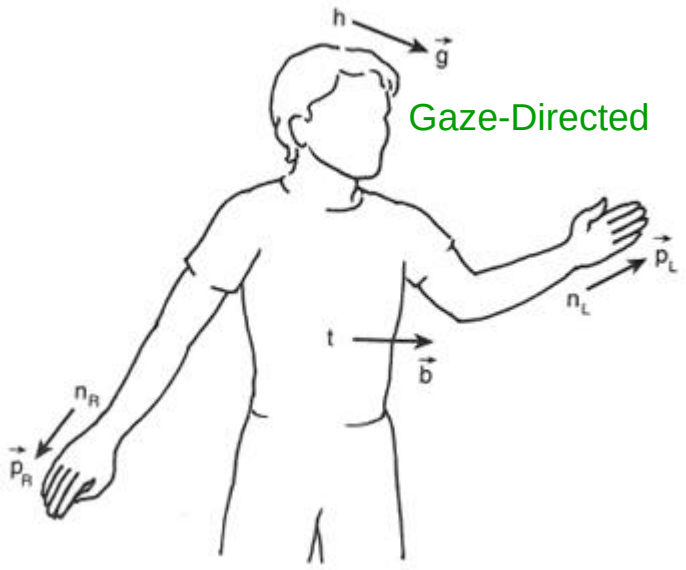
Steering

- Continuous direction control by user
  - Absolute direction („move along [0,0,-1] in world coordinates“)
  - Relative direction („move right“)

- Determine position by speed v and direction d:

$$p_{new} = p_{old} + v \cdot \frac{d}{\|d\|}$$

- Gaze-Directed
  - Couples gaze and movement
- Pointing
- Torso-Directed
- Physical Steering Props



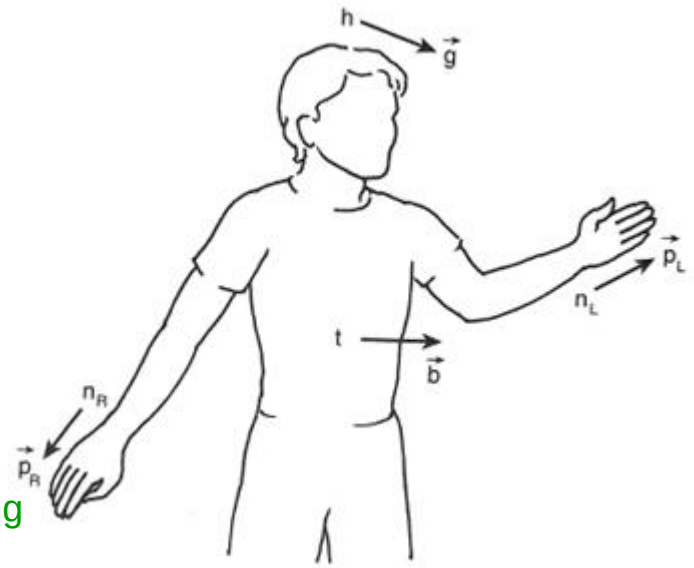
Steering

- Continuous direction control by user
  - Absolute direction („move along [0,0,-1] in world coordinates“)
  - Relative direction („move right“)

- Determine position by speed v and direction d:

$$p_{new} = p_{old} + v \cdot \frac{d}{\|d\|}$$

- Gaze-Directed
- Pointing
  - \+ Look around while moving
- Torso-Directed
- Physical Steering Props



Pointing

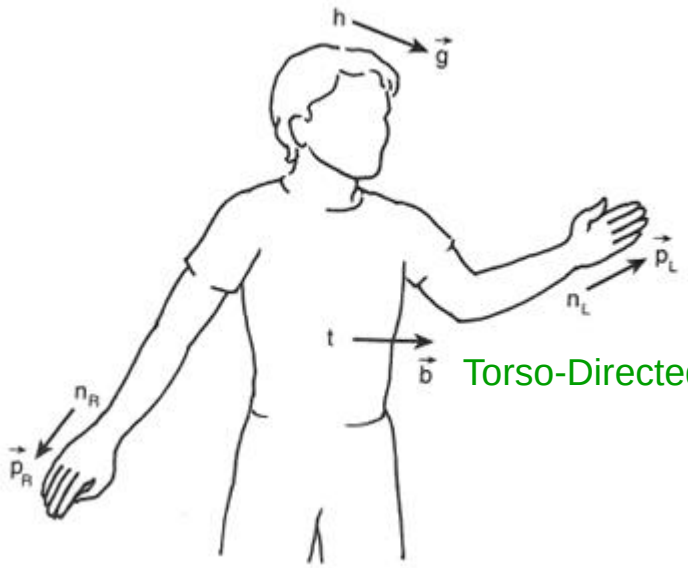
Steering

- Continuous direction control by user
  - Absolute direction („move along [0,0,-1] in world coordinates“)
  - Relative direction („move right“)

- Determine position by speed v and direction d:

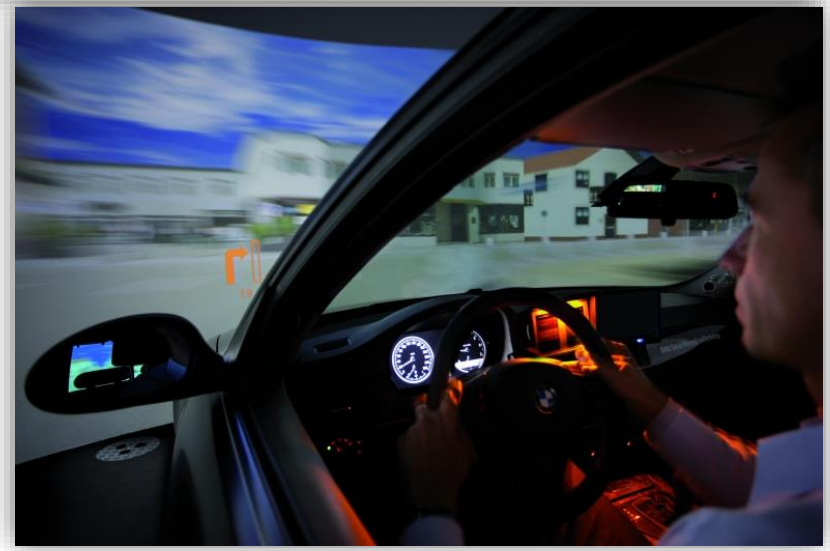
$$p_{new} = p_{old} + v \cdot \frac{d}{\|d\|}$$

- Gaze-Directed
- Pointing
- Torso-Directed
  - \+ More natural than pointing
  - \- Only horizontal directions
- Physical Steering Props



Torso-Directed

Steering

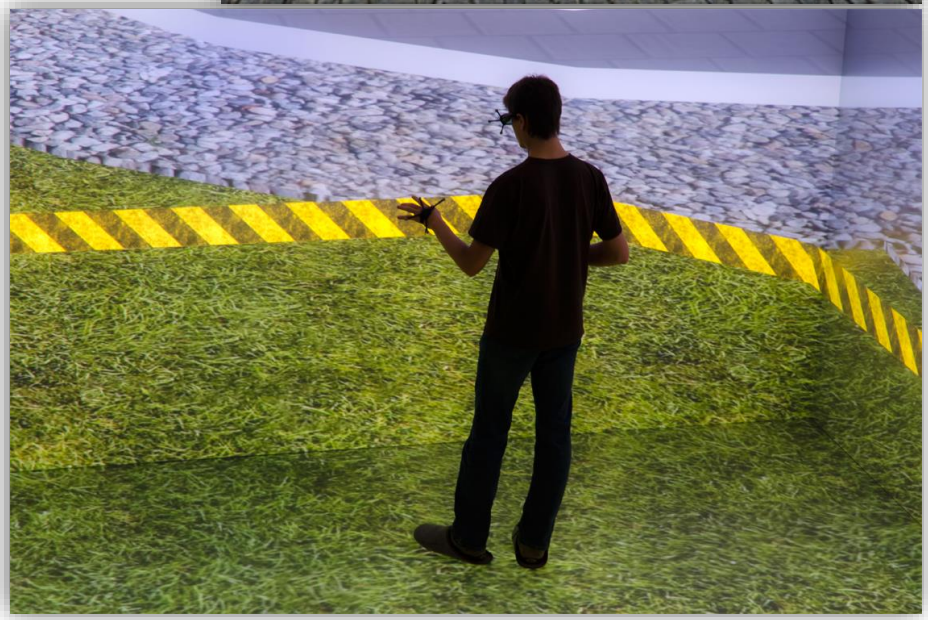


BMW

- Physical Steering Props
  - \+ Specialized for vehicle type
  - \+ „Physical feedback“
  - \- Unrealistic expectations
  - \- Not generally applicable

Steering – Magic Barrier Tape

- User walks within CAVE/tracking limits
- When reaching walls, tape appears
- Push against tape for movement
- When changing direction, turn around and walk again

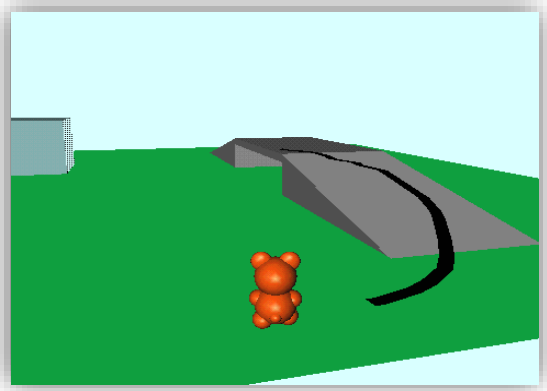


Travel Techniques

- By metaphor
  - Physical locomotion
  - Steering
  - Route-planning
  - Target-based

Route-Planning

- Two step process
  - User plans route
    - Draw a route
    - Mark points along path
    - Automatic collision-free path generation
  - System carries out the plan
    - User is automatically transported along route
    - User maintains some degree of control („river analogy“)



Igarashi et al. 1998

+ Usually enables review, refinement or editing of path
+ Focus on other tasks while traveling
+ Allows for predefined routes
- Requires exocentric view
- Low degree of control while traveling

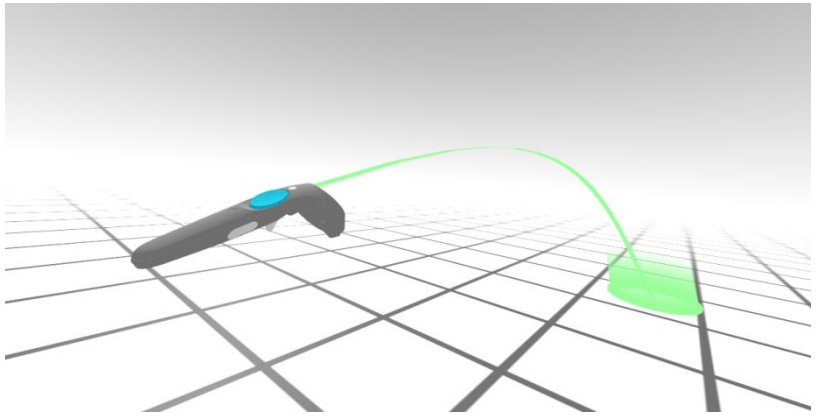
Travel Techniques

- By metaphor
  - Physical locomotion
  - Steering
  - Route-planning
  - Target-based

Target-Based

- Move to specific position

- Teleportation
  - \+ No additional cyber sickness
  - – Decreases spatial orientation



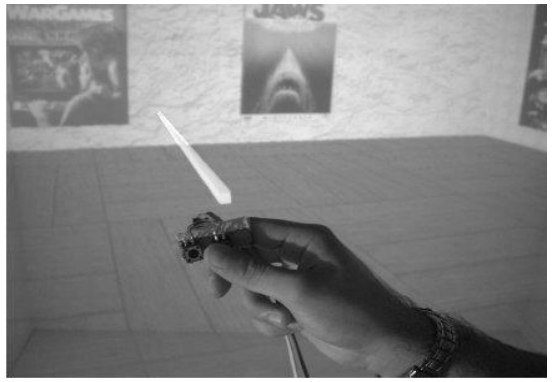
[aframe.io/blog/teleport-component]

- Continuous movement to target
  - \+ Maintains spatial orientation
  - – Potentially increases cyber sickness

  - – Linear movement (speed remains constant)
  - – Sinusoidal/polynomial (slow-in, slow-out)
  - – Exponential speed, based on distance
  - – …

ZoomBack

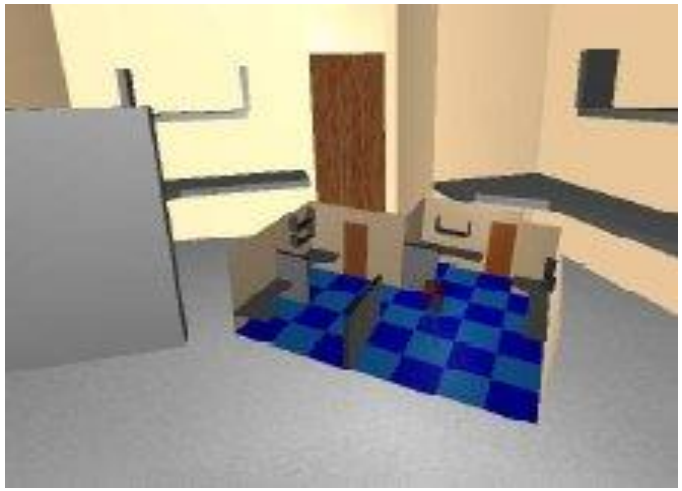
- Requires two-state button: light and firm pressure
- Select target object
- Actions:
  - Light press: user translates to target
  - Release light press: user returns to original position
  - Firm press: user remains at target

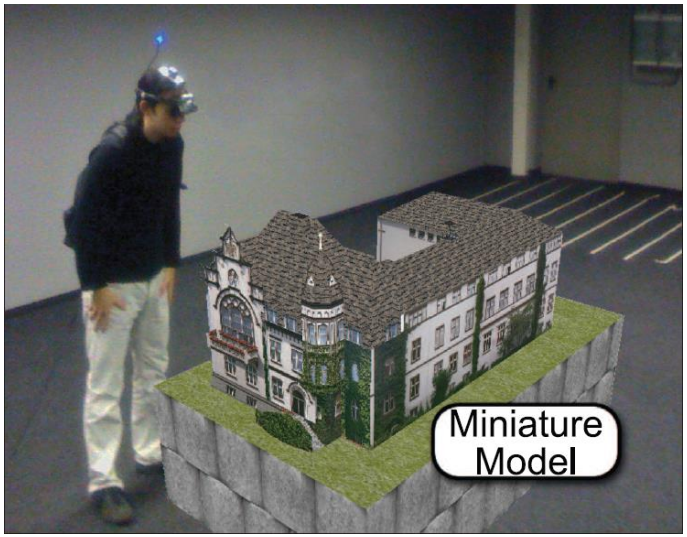


Stoakley et al. 1995, Trueba et al. 2009, Bruder et al. 2008, etc.

Travel Techniques: Target-Based
World-in-Miniature (WIM)

- Miniature is a copy of the virtual environment
- Select the point or drag an avatar to specify target position
- Usually animate travel, e.g., zoom into the WIM as the new environment





Travel using portals

- Portals connect two distant points
- Users can walk through portals to travel
- Work for view as well
- User chooses target portal position
  - By direct pointing
  - Using WIM
- Start portal is placed automatically
- Goals
  - Travel by real walking
  - Reorientation of the user
  - Travel over any distance in constant time

Design Guidelines for Travel Techniques

- Match the travel technique
  - …to the application
  - …to display and input devices
  - …to other interaction techniques in the application

- Consider both natural and „magic“ techniques
  - Use physical locomotion for increased naturalness
  - Use appropriate „magic“ techniques if immersion is not required

- Use transitional motions to increase spatial knowledge

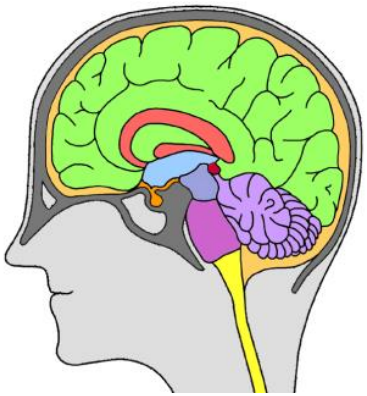
- Provide multiple (simple) travel techniques for complex applications
  - e.g., steering (exploration) + target-based (goal-oriented travel)

Navigation Tasks

- **Navigation**: movement in and around an environment

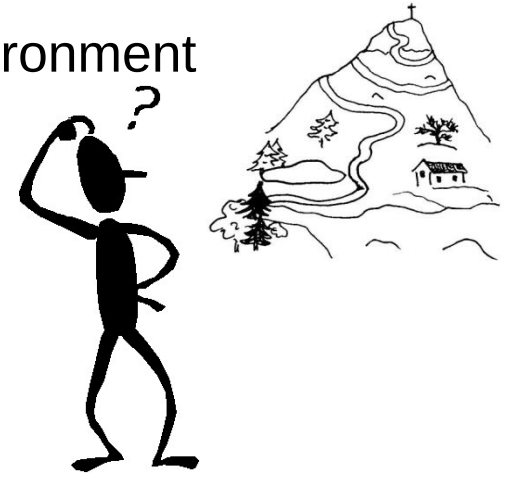
- Travel
  - Motor component

- Wayfinding
  - Cognitive process
  - Define a path
  - Use and acquire spatial memory

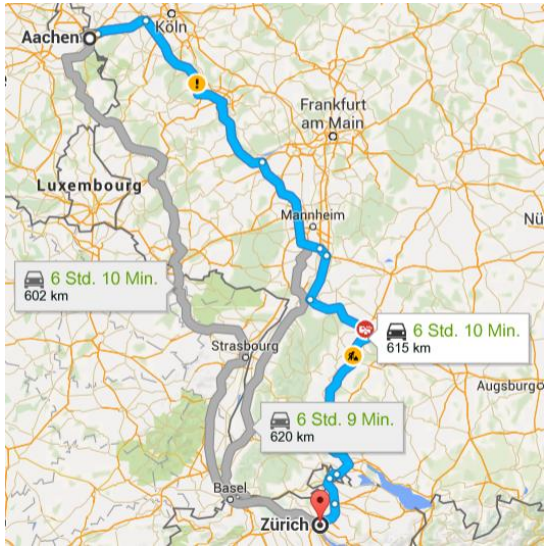


Wayfinding

- Cognitive process of defining a path through an environment



- Usage and acquisition of spatial knowledge
- Reference frames:
  - Egocentric (first-person) information
  - Exocentric (third-person) information
- During motion, we match egocentric information to the exocentric cognitive map

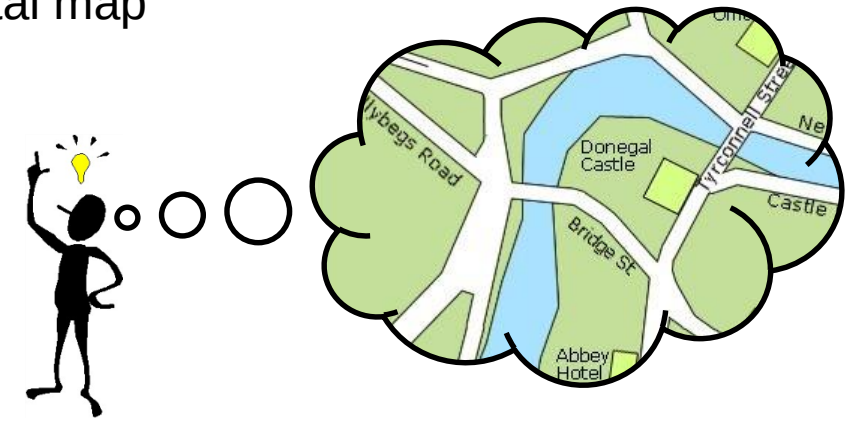


Types of Spatial Knowledge

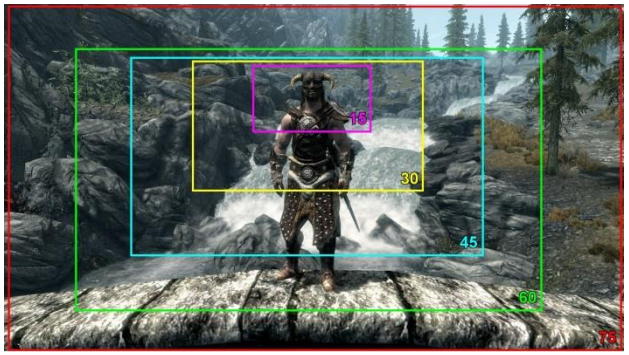
- Landmark knowledge
  - Visually prominent spots

- Procedural knowledge
  - Sequence of actions to reach target

- Survey knowledge
  - Object locations, distances, orientations
  - Mental map



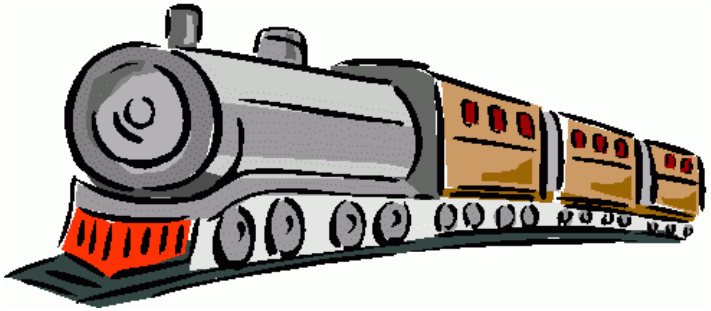
Wayfinding cues



- Large field of view

- Self-motion cues
  - Optical flow (also in peripheral vision → large FOV)
  - Vestibular cues (walking improves spatial orientation)

- Audio (environmental sounds)



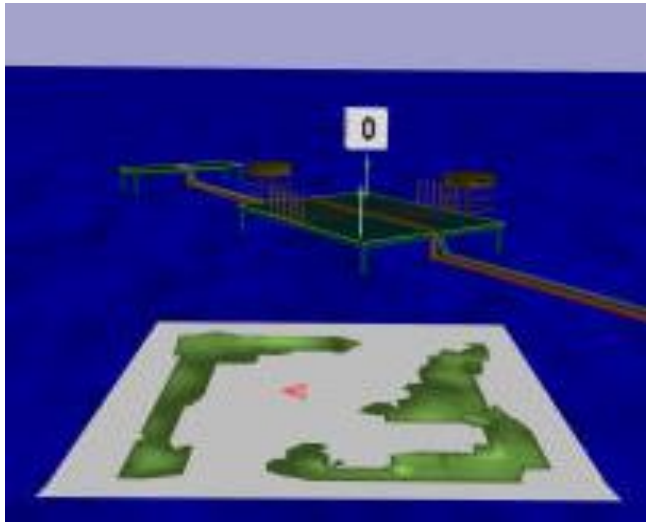
Wayfinding Aids

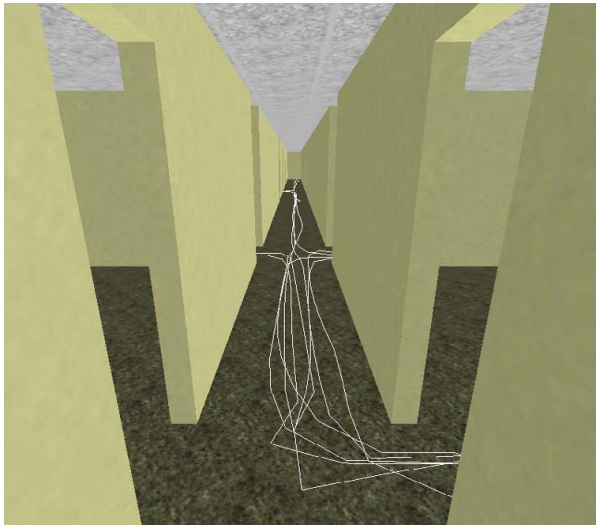
- Environment design
  - Legibility
    - Parts with distinct character
    - Simple spatial organization
  - Real-world design
    - Natural: horizon, atmospheric color, fog
    - Realistic lighting (shadows, direction)
    - Architectural: bright and open spaces attract people
    - Color and texture to group or highlight
- Artificial Cues

Wayfinding Aids

- Environment design

- Artificial Cues
  - Maps
  - Compasses
  - Signs
  - Artificial landmarks
  - Trails
  - Audio cues





Outline

- 3D Interaction Techniques: Definitions and Basics
- Manipulation Tasks
- Navigation
- System Control

Definition

„System control is the user task in which a command is issued to

1. request the system to perform a particular function,
2. change the mode of interaction, or
3. change the system state“

(Bowman et al. 2004)

- Well established system control techniques is 2D UIs
  (WIMP: Windows, Icons, Menus, and Pointers)
- Those can hardly be directly adapted to 3D UIs

→ New techniques must be developed

Classification

Different classes of system control techniques exist in 3DUIs:

- Graphical Menus
- Voice Command
- Gestural Command
- Tool

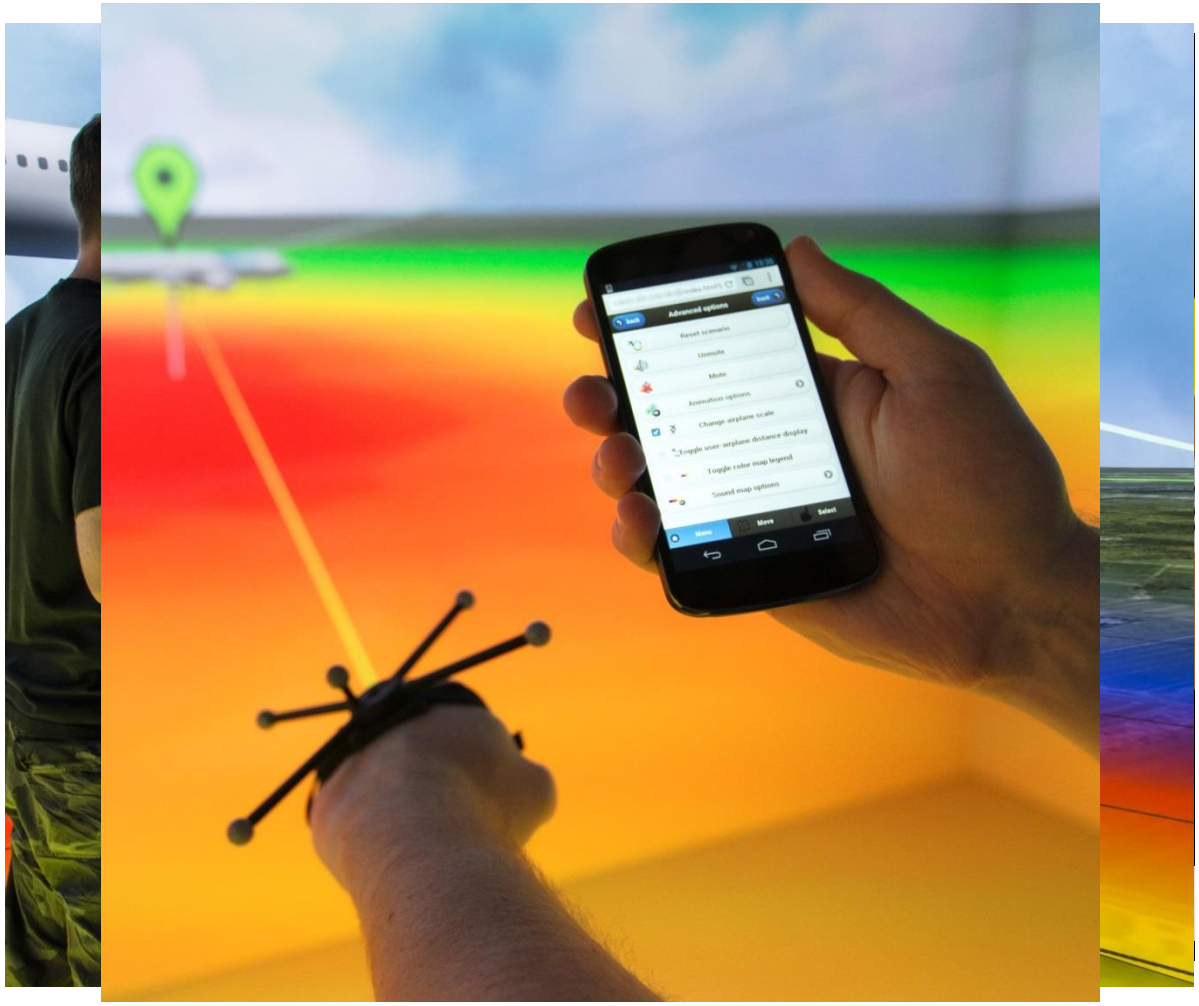
Classification

Different classes of system control techniques exist in 3D UIs:

- Graphical Menus
- Voice Command
- Gestural Command
- Tool

Graphical Menus

- Adapted 2D Menus
- 1-DoF Menus
- TULIP Menus
- 3D Widgets
  - Command and Control Cube
  - Extended Pie Menus
- Mobile Devices



Classification

Different classes of system control techniques exist in 3D UIs:

- Graphical Menus
- Voice Command
- Gestural Command
- Tool

Overall Summary