3D Interaction in Mixed Realities
Computer Science Department - IME/USP

Travel

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based on the notes from Prof. Feiner

Readings

Previously:

“Selection and Manipulation” - Chapter 7

Today:

“Travel” - Chapter 8

Book: “3D User Interfaces - Theory and Practice”,

by LaViola, Kruijff, McMahan, Bowman, and Poupyrev

Fundamental 3D Interaction tasks

Selection and Manipulation

selection, positioning, rotation, and scaling

Travel

moving in and around an environment

motor component of navigation

Wayfinding

cognitive component of navigation

Uses of Navigation

Navigating the web via a browser

Navigating a complex document via word proc

Navigating through several layers of info in a spreadsheet

Navigating the virtual world of a computer game

How to navigate in 3D?

Navigation in 3D

- Movement in an environment
- Two complementary components

  Travel

  - Motor component: Actions involved in getting from one place to another, typically translating/rotating the camera

  Wayfinding

  - Cognitive component: Thinking, planning, and decision making that lead to motion through understanding the environment

- Travel and wayfinding can interact

  Can be combined together

  Techniques used for one can affect the other

Navigational Tasks

- Exploration (also cited as basic visualization task)
  - Undirected “browsing” to get the “big picture” and develop an understanding of the environment
  - Need freedom to deviate from path
  - Should impose minimal cognitive load to allow user to concentrate on understanding the environment
- Search (also cited as basic visualization task)
  - Directed travel to a specific goal/location
    - Naïve search: user doesn’t know path/position in advance
    - Primed search: user has advance knowledge of path/position
  - May benefit from system guiding the user to the destination

Navigational Tasks

- Maneuvering
  - Small precise movements to position/orient the user better to inspect or manipulate
  - Key issue is ease and precision of control

Travel Task Parameters

- For physical and virtual worlds
- Distance to travel
  - Tracking technology and range of physical movement (e.g., size of tracked environment)
    - May constrain how user can move, making it impossible to do a 1:1 mapping of real to virtual
  - Fatigue/time constraints
    - May suggest not using direct isomorphic approaches for greater distances

Travel Task Parameters

- Curvature/turns in path
  - More complexity makes isomorphic body motion more difficult/tiring
- Target visibility
  - Affects applicability of gaze-directed techniques
- DOF of movement
  - Constraints (e.g., surface travel over a landscape)
    - Make it possible to limit DOF of user control, but,...
    - May sacrifice understanding of environment in return for ease of control

Travel Task Parameters

- Accuracy/freedom of movement in space and time
  - If less accuracy/freedom is required, then techniques that use scaled-down models may work well

- Relation to other tasks
  - Is travel the primary task or a secondary task?

Travel Techniques

Active x Passive techniques

- Active
  - User controls movement directly
  - Especially useful in active exploration
- Passive
  - System controls movement
    - “Guided tour”
  - Allows user to concentrate on other tasks
  - May be restricted by design or technology.
    - E.g., user may control only orientation within a remotely controlled vehicle
- Route planning
  - User plans route in advance, and system executes it

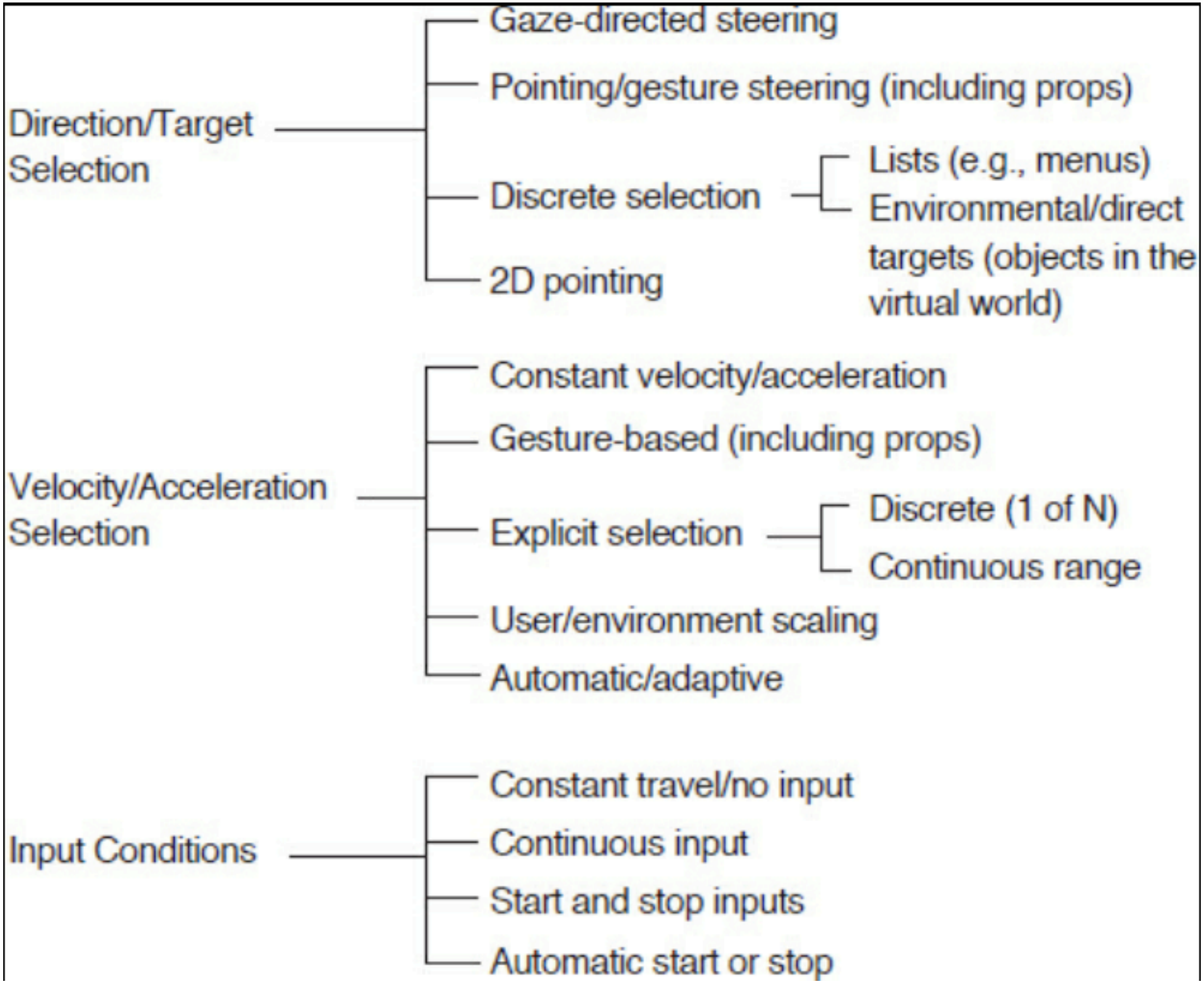
Physical x Virtual techniques

- Physical
  - User body physically translates/rotates to translate/rotate viewpoint
    - E.g., through 6DOF head/body tracking
- Virtual
  - User's body remains stationary while device moves viewpoint virtually
    - E.g., through joystick or pointing
- Hybrid
  - Based on distance
    - Physical travel for short distances, virtual travel for long distances
  - Based on type of DOF
    - Physical orientation (for naturalness), virtual translation (to save time/effort)
- Physical x Virtual is orthogonal to Active x Passive, so they can define a 2x2 design space.

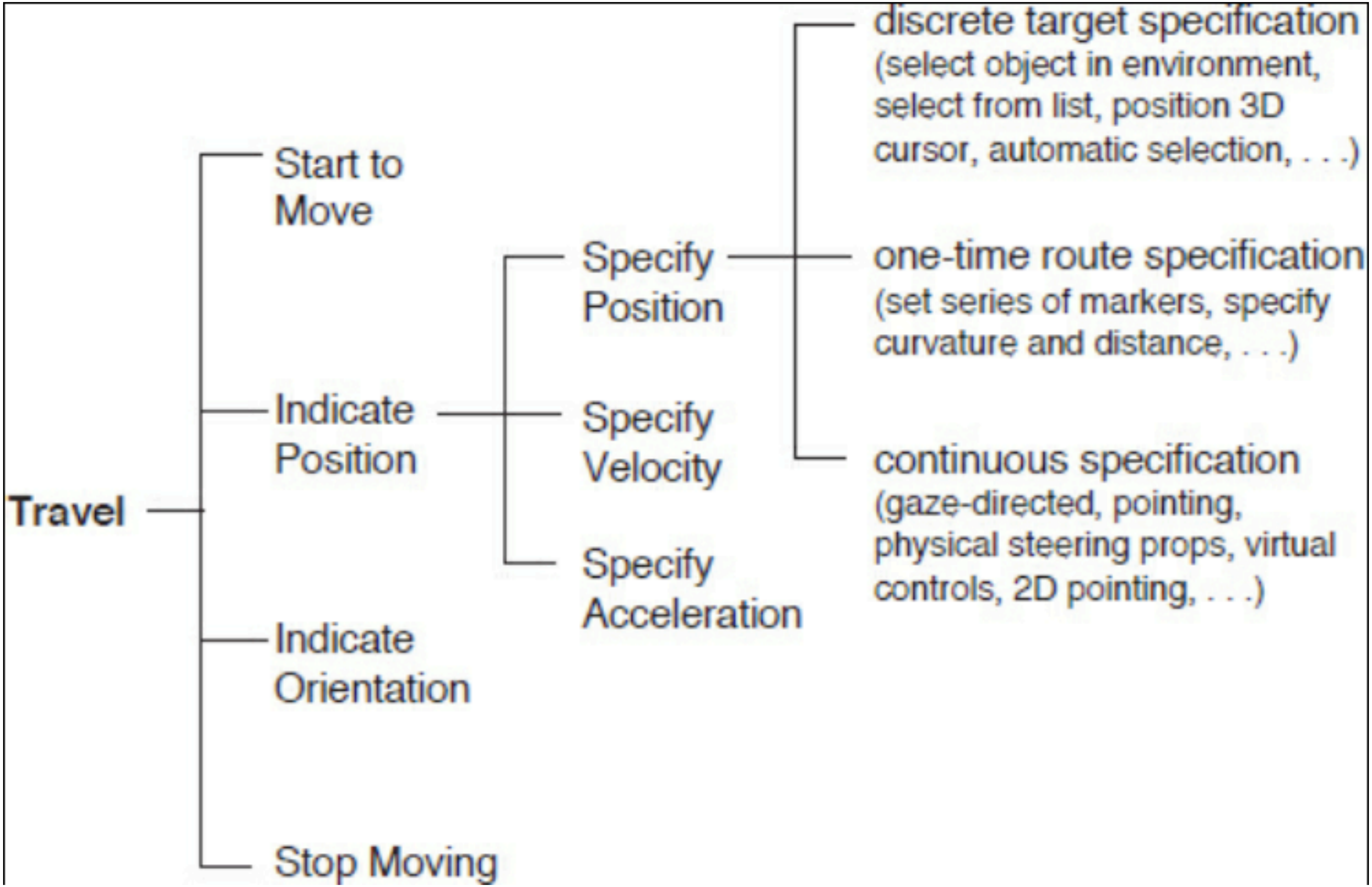
Classification using Task Decomposition (subtasks of travel)

Bowman et al., 1999

- Direction / target selection
  - Control of how / where to move
- Velocity / acceleration selection
  - Control of how fast to move
- Input Conditions
  - Control of how travel is
    - Initiated
    - Sustained
    - Terminated



Taxonomy of travel techniques focusing on subtasks



Taxonomy of travel techniques focusing on level of user control

Classification
By Interaction Metaphor

- Walking
- Steering
- Route planning
- Target selection
- Manual manipulation
- Scaling
- etc

Walking Metaphors

Real Walking

- Isomorphic
- Provides vestibular cues
- Needs physical space (not necessarily 1:1, as we'll see later)
- Must track entire VE
  - Tracker weight, cables, environmental obstacles
- Outdoor, as well as indoor
- Fatigue

Scaled Walking

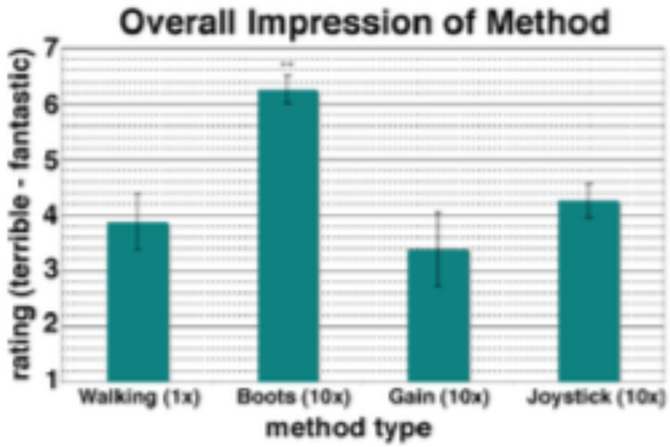
- Naive approach scales in all dimensions
  - Exaggerates up/down and side-to-side motions
- Seven League Boots (V. Interrante, B. Ries, L. Anderson, 3DUI 07)

Scale only motion in intended direction of travel

- Ignore motion orthogonal to ground plane
- Define as dynamic weighted combination of current gaze direction (actually head orientation) and previous travel direction (biased toward gaze direction when recent magnitude of displacement is small

Need trigger to enable/disable

- E.g., button press
- Or automate by easing in/out as user speeds up/slows down
  - Could induce sensation of lag
  - Could affect perception of distance traveled



Walking in Place

- Users move their feet “in place” to simulate walking
- Physical exertion, but unlimited travel
- Limited vestibular/motion cues
  - Increased sense of presence relative to virtual travel, but less than real walking
- For apps which focus on efficiency and performance, a steering technique if often more appropriate

Walking Simulators

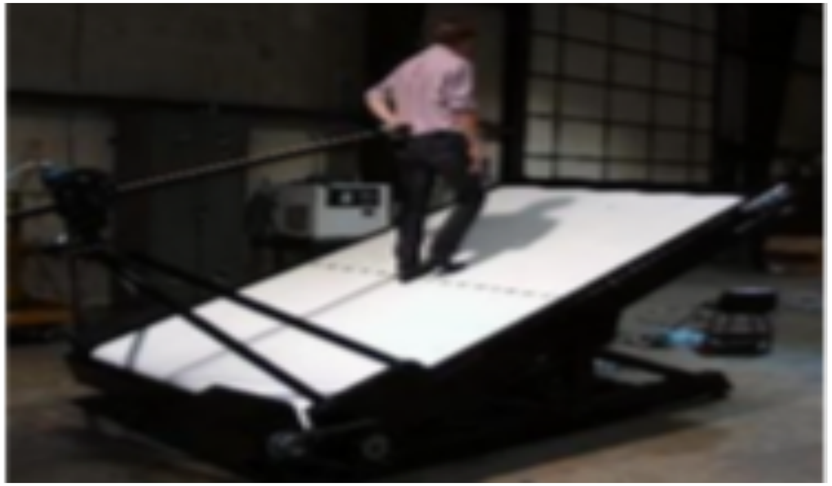
- Consumer products (to be)
  - Virtuix Omni (http://www.virtuix.com)
    - Concave low-friction surface with radial grooves, special shoes, IMU tracking Virtuix Omni (commercial version only now)
  - Cyberith Virtualizer (http://www.cyberith.com)
    - Instrumented flat low-friction surface, ring/belt, and pillars

Virtuix Omni

Cyberith Virtualizer

Walking Simulators

- Conventional treadmill (F. Brooks, UNC, 1986)
  - No natural way to change direction
- Track user's head/feet and rotate entire treadmill (yaw / pitch)
- Sarcos Treadport
  - Control treadmill speed and pitch
  - Track user and exert additional forces (push and pull)

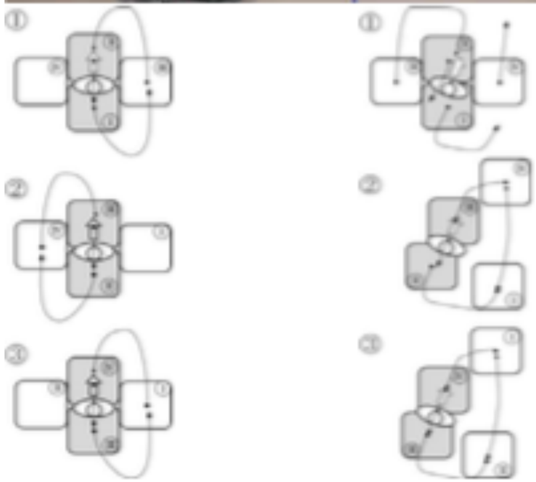


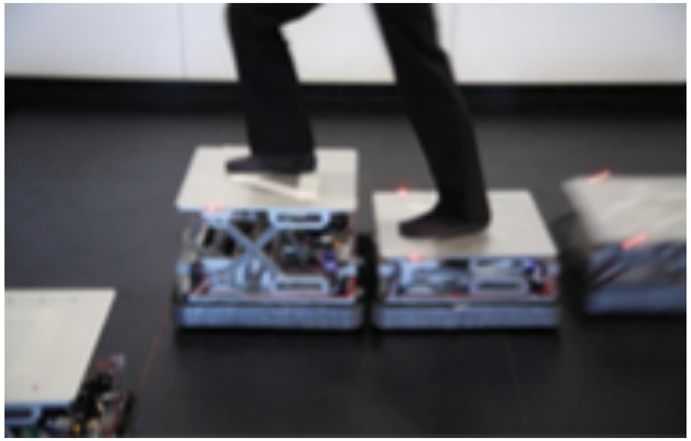
www.cs.utah.edu/research/areas/ve/LocomotionDisplay.html

www.youtube.com/watch?v=ZkAg_YYxHjM

Walking Simulators

- CirculaFloor (H. Iwata et al., U. Tsukuba, 2004)
  - Four tracked moving tiles automatically reconfigure to meet feet of (slow) tracked user
  - Different configurations correspond to tracked user direction

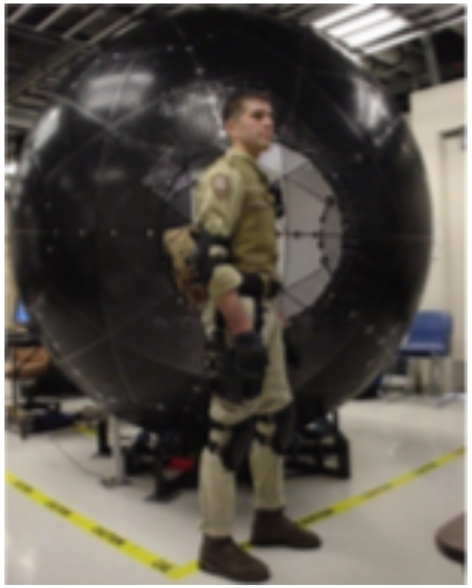




http://intron.kz.tsukuba.ac.jp/CirculaFloor/CirculaFloor_j.htm

Walking Simulators

- VirtuSphere (www.virtusphere.com)
  - User walks inside large (8.5 ft. diam.) modular plastic sphere
  - Base platform uses rollers to support and track rotation (and prevent translation)
  - Display and trackers worn by user must be self-contained or wireless



www.virtualsphere.com

Steering Metaphors

Most common virtual travel technique

Steering

- User specifies relative or absolute direction of motion
  - Flying by finger pointing
    - W. Robinett, 1986 (see W. Robinett and R. Holloway, Implementation of Flying, Scaling, and Grabbing in Virtual Worlds, Proc. Symp. on Interactive 3D Graphics, 1992, 189–192)

Steering: Gaze-Directed

- Move along direction of “gaze” [eye or head]

- Immersive: Use head tracker or eye tracker

- Desktop: Move along vector from eye to center of window (center line of frustum)

- Can also support motion perp. to gaze

- Easy to understand

- Hard to move precisely // to ground

  But can constrain to lie on ground

- Uncomfortable to look straight up/down

- Can only look ahead when traveling!

  $s' = s + w\, g / |g|$, where s and s' are old and new position, w is a scale factor, and g is the gaze direction.

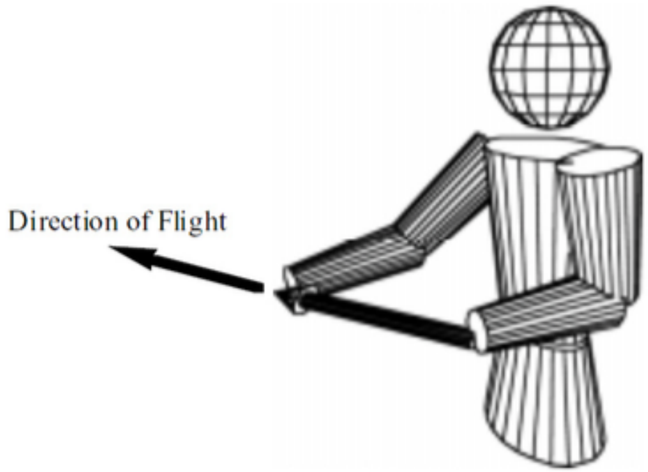
http://www.eyegaze.com/4-eye-tracking-technology-applications-you-may-not-know/

Steering
Pointing-Directed

- Move along direction of pointing
- Immersive
  - Use hand / finger tracker
  - Can sense direction proprioceptively
- Desktop
  - Use cursor keys if mouse already for “eye” control
  - Use keyboard modifier to determine what mouse controls
- s' = s + w p / |p|, where s and s' are old
- and new position, w is a scale factor,
- and p is the hand pointing direction.

Steering
Two-Handed Pointing-Directed

- Use vector between two hands
  - Direction -> direction
  - Magnitude -> velocity



M. Mine, F. Brooks, C. Sequin, *SIGGRAPH 97*

$s' = s + w\,t\,(h_d - h_{nd}) / (|h_d - h_{nd}|)$

where s and s' are old and new position, w is a scale factor, t is the scale factor determined by distance between hands, h_d and h_{nd} are dominant and nondominant hand positions.

Steering Torso Directed

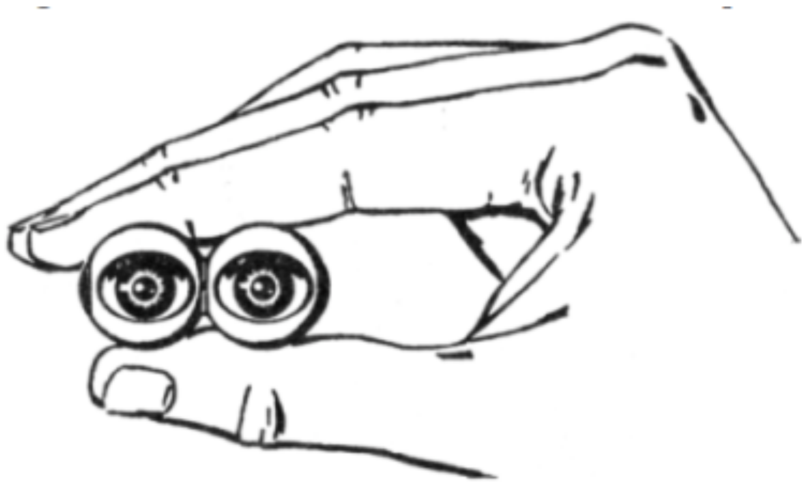
- Use belt worn orientation tracker -> direction
- Decouples gaze/travel directions, so user can look anywhere while traveling
- Hands-free
- Hard to steer up/down with torso

s' = s + w b / |b|, where s and s' are old and new positions, w is a scale factor, b is the body (torso) direction.

Steering
Camera in hand (aka eyeball in hand)

- User holds 6DOF tracker in hand
- Tracker position/orientation -> camera position/orientation
- Takes advantage of proprioception
- Can position hand-held camera (controller) in scaled physical model

c = T t, where c is the camera position, t is the tracker position, and T is the transformation (typically scale)



http://www.gutenberg.org/files/22814/22814-h/22814-h.htm

Wanda (www.ascension-tech.com)

Steering
Physical Props

- Use controls for vehicle of choice
  - car, ship, plane, ..
- Can feel real (or not)
- Performance of system may not match expectations

http://gaming.logitech.com/en-us/microsite/driving-force-racing-simulation

Selection-based travel metaphors

Route Planning

- Idea

- User specifies a path

    – can review/edit

- System moves the user along the path

- User exerts control prior to travel
- Can attend to other tasks while "traveling"

Route Planning
T. Igarashi, 98

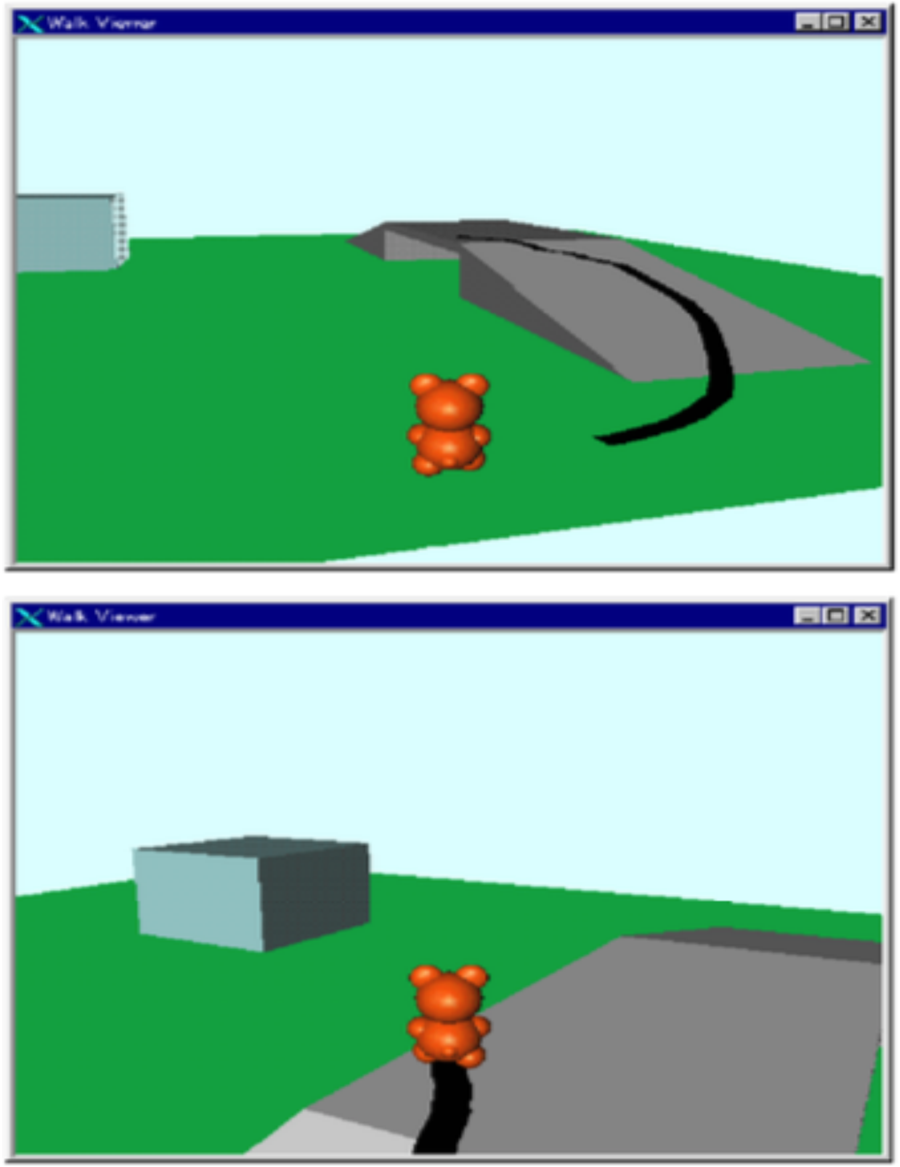
- User draws stroke on view of 3D world
- System projects stroke onto walking surface to create path
- Note: Constrained height
- User's orientation is upright and tangent to stroke
- User can draw new stroke to modify path

- Long stroke -> full path

- Short stroke at goal -> goal position and orientation

- Short stroke at user's foot -> Change orientation

- Takes into account scene structure Obstacle avoidance, slope climbing



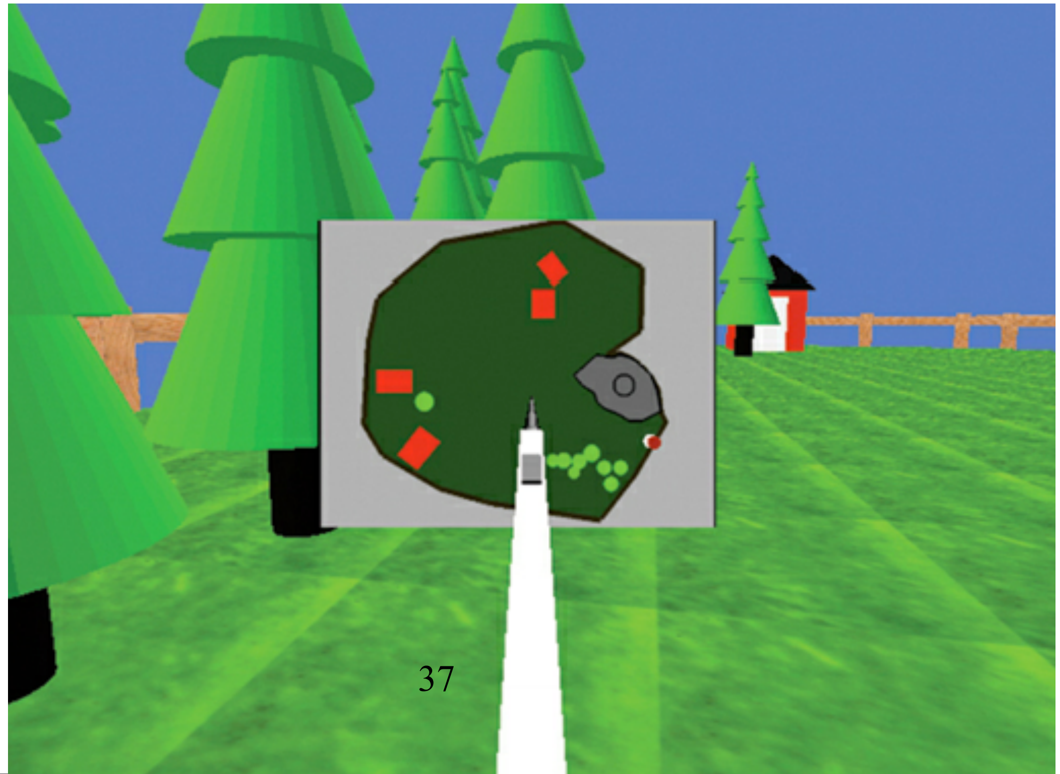
http://www-ui.is.s.u-tokyo.ac.jp/~takeo/research/navi/navi.html

Target Selection

- User specifies target destination
- Dual target: user specifies two targets to define from - to positions to travel.

- System moves user to target

Interpolation avoids confusion of discontinuous "teleportation"



Target Selection

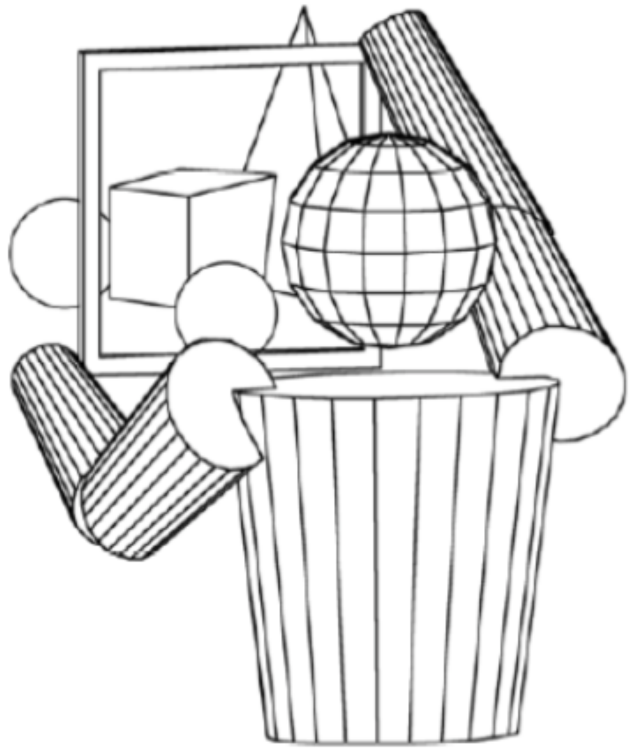
Head Butt "Zoom"

Mine, Brooks, Sequin, 97

- User image-plane selects object of interest
- System leaves frame in air
- User butts head into frame to move forward, pulls head out to return to original position

User can quickly switch between two viewpoints hands-free

User can step forward to move to new view for an extended time, back to return

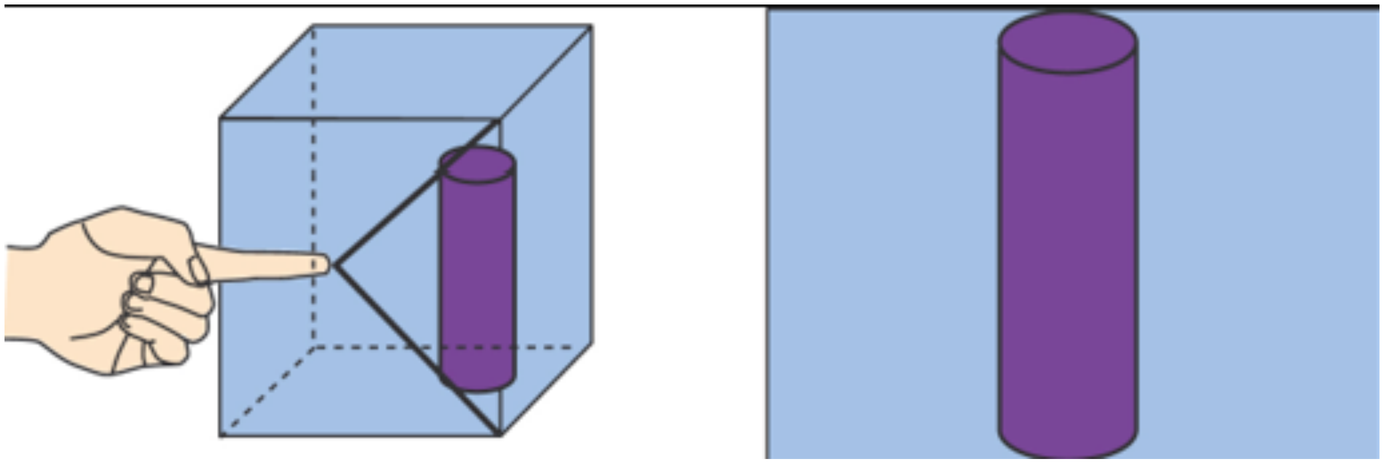


Mine, Brooks, & Sequin, 1997

Manipulation-based travel metaphors

User manipulates viewpoint
as if manipulating an object

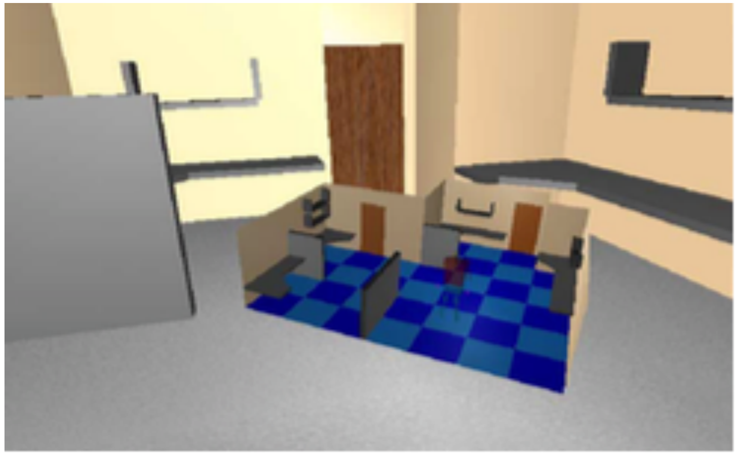
Camera Manipulation

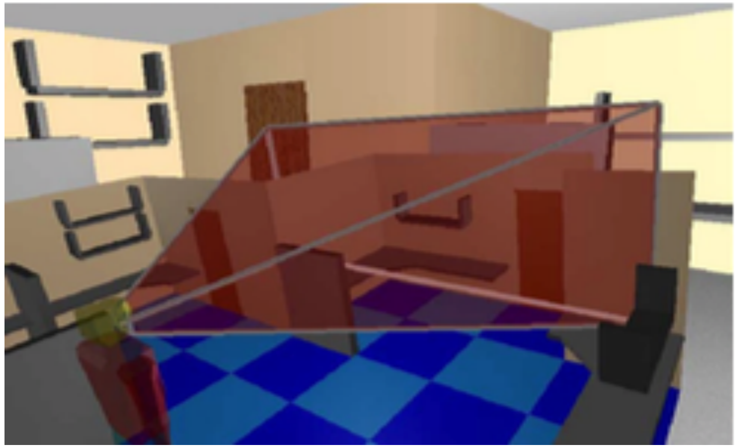


A tracker is held in the hand, and the absolute position and orientation of that tracker in a defined workspace specifies the position and orientation of the camera from which the 3D scene is drawn.

Avatar Manipulation

- User places avatar in WIM at desired target position/orientation
- System flies the user into WIM, which becomes world
  - Originally tried approach of interpolating user in world
  - Users found it disorienting
  - Hypothesis: User is “cognitively vested” in avatar, so avoid shifting focus to world by making user “become” avatar





Fixed-Object Manipulation

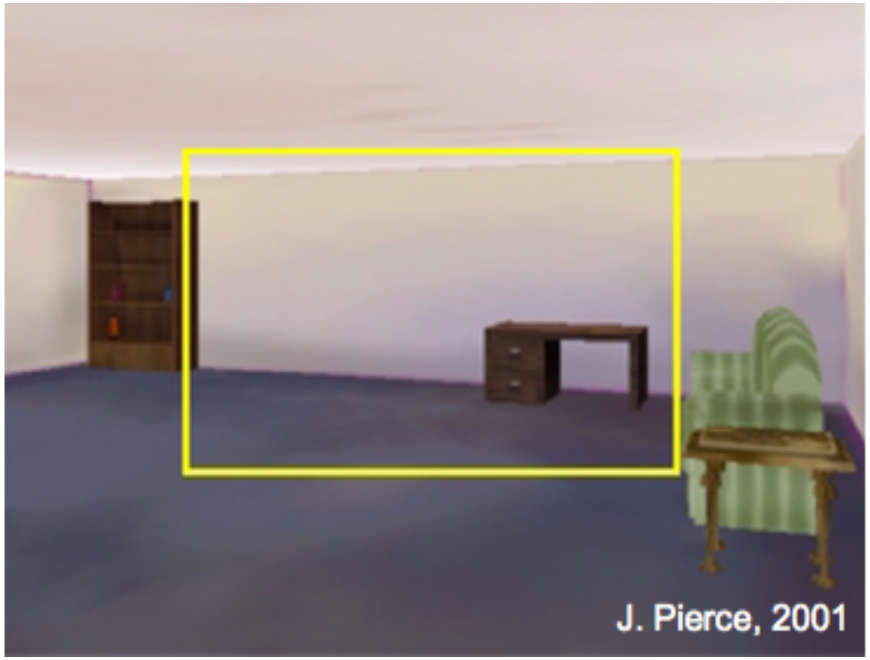
- User selects object, acts as if manipulating it, but viewpoint is changed instead (e.g., differentiate based on button pressed)
  - Image-plane select object, move hand(s) closer to eye to move to object (Pierce et al. 1997)
  - Scaled-world grab object, move self relative to object (Mine, Brooks, Sequin 1997)

World Manipulation Grabbing the Air

- If user selection action (grabbing) doesn't select a movable object, then select the entire world
- Translate world origin (but ignore rotation to avoid confusion)

$w' = w + (n'_d - n_d)$, where w and w' are old and new world positions, and n_d and n'_d are old and new dominant hand positions

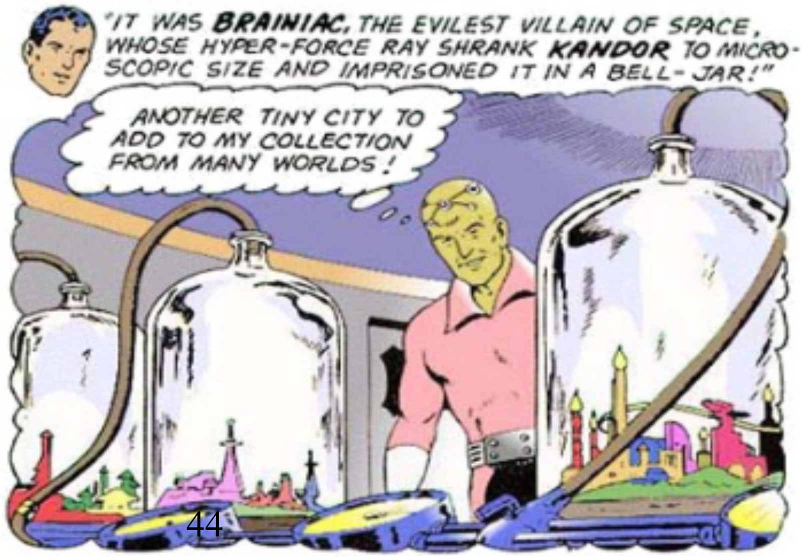
- Use two hands as if pulling a rope (Mapes & Moshell, 1995)
- Can be tiring



Variation: Image-plane select with hands outside of yellow outline during trigger -> grabs air for travel. (Based on the observation that users positioned hands away from center of image plane when grabbing air.
J. Pierce, 2001

Dual point world manipulation

- Scale down world (Scale up user)
- Move
- Scale up world (Scale down user)
  - E.g., S. Bryson & C. Levit, IEEE Visualization 91; J. Butterworth et al., 92
- Use virtual body to help user understand scale
- Scaling
  - affects precision
  - May cause cybersickness in egocentric environment



Other aspects of travel techniques

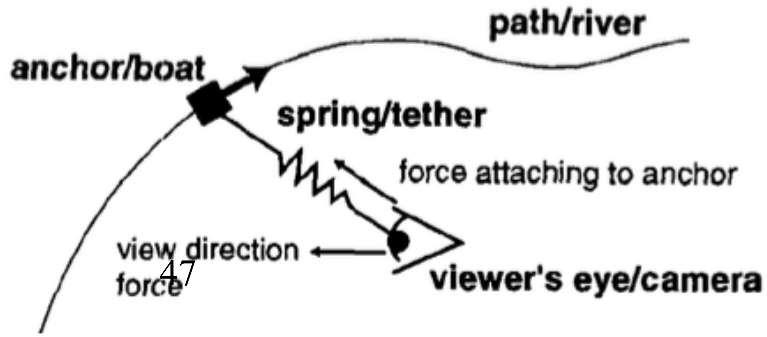
Controlling Viewing Orientation

- Head tracking
  - Natural
  - Improves spatial understanding
- Orbital viewing (J. Chung, i3D 92)
  - Select position p and distance r
  - Head rotations are mapped to move viewpoint about surface of sphere with center p and radius r, looking at p

    Look left, right, up, down to see object's right, left, bottom, top, respectively
- Good for inspection of one object at p, but...
- Can be confusing with more objects in environment
  - Can cause cybersickness

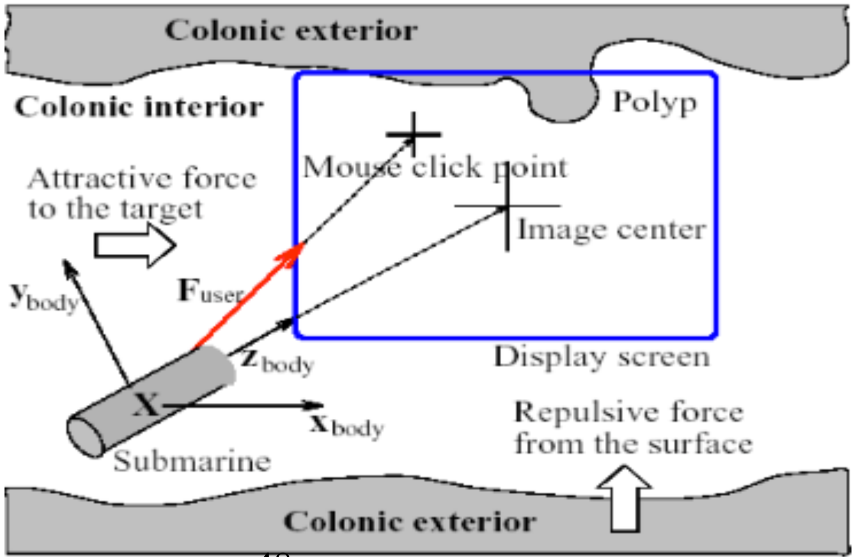
Semi-automated travel

- User is provided only partial control
- "River Analogy" (T. Galyean, 1995)
- Boat is carried down the river by the current, but the user can influence its movement with the rudder
- Anchor (boat) follows path (river)
  - User attached to anchor by spring
  - View direction exerts force on user (pulling user toward items of interest)
  - Variables
    - Anchor speed
    - Rate to reach new speed from old View thrust amount
    - Spring constant
    - Damping constant



Steering
Semi-automated

- User may determine speed of travel only or rough deviations from system-determined path
  - Disney Aladdin's Magic Carpet Ride
- User can explicitly modify constraints on path
  - Interactive navigation of colon (L. Hong et al., SIGGRAPH 1997)



L. Hong et al., SIGGRAPH 97

3D voxel rep of colon Distance to target Distance to wall

Redirected Walking

Back to the walking metaphor
with a twist

Due to physical limitations

How can we redirect the user when/while walking (make turns)?

stop-and-go

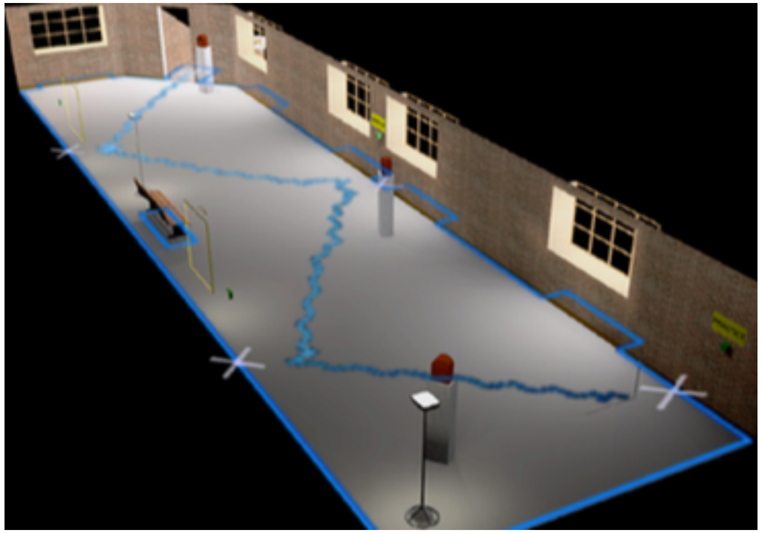
Controlling Viewing Orientation

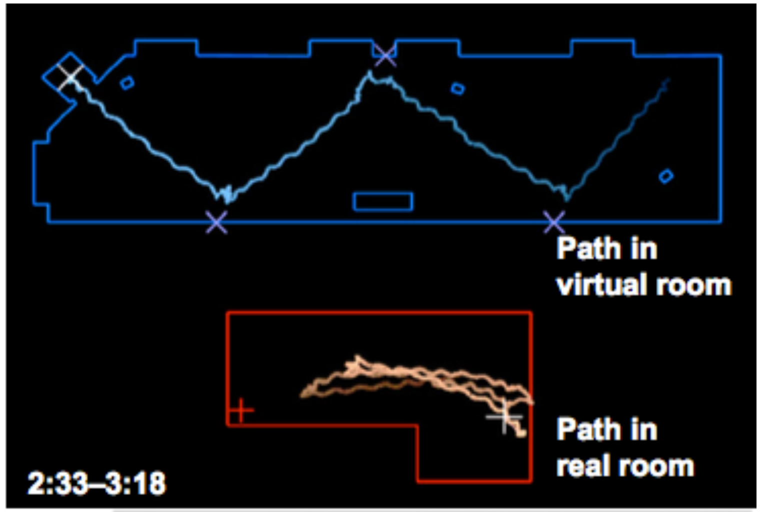
- Redirected walking with distractors
  - Distract user attention while distorting the mapping of real orientation to virtual orientation
  - E.g., virtual butterfly flutters in front of the user while walking in a virtual outdoor environment

T. Peck, M. Whitton, and H. Fuchs, IEEE VR 2008

Controlling Viewing Orientation

- Nonisomorphic rotation
- - Modify treatment of user orientation while walking
- - Redirected Walking (S. Razzaque)
  - Provide user with experience of walking in a much larger environment
  - m° real rotation -> ~ 1⁄2 m°virtual rotation
  - Inject most of distortion while changing physical orientation, add the rest while walking
- Redirected Walking in Place (S. Razzaque)
  - Avoid having user look at missing CAVE rear wall to maintain presence
  - Gradually “adjust” world orientation while user walks in place





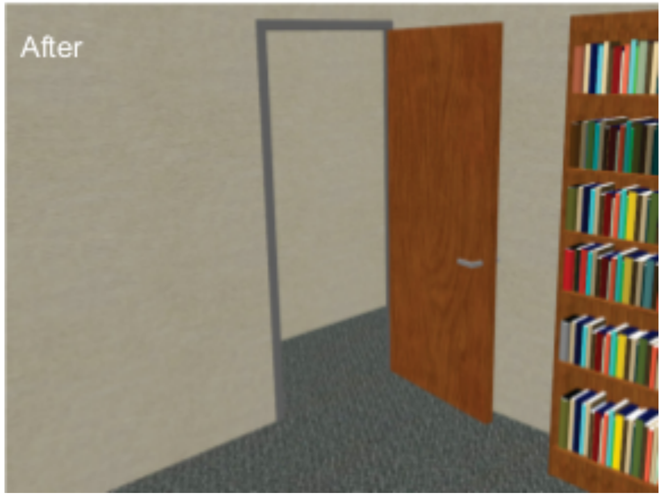
S. Razzaque, Z. Kohn, and M. Whitton, Eurographics 2001

Redirection by Change Blindness

E. Suma et al. VR 2011

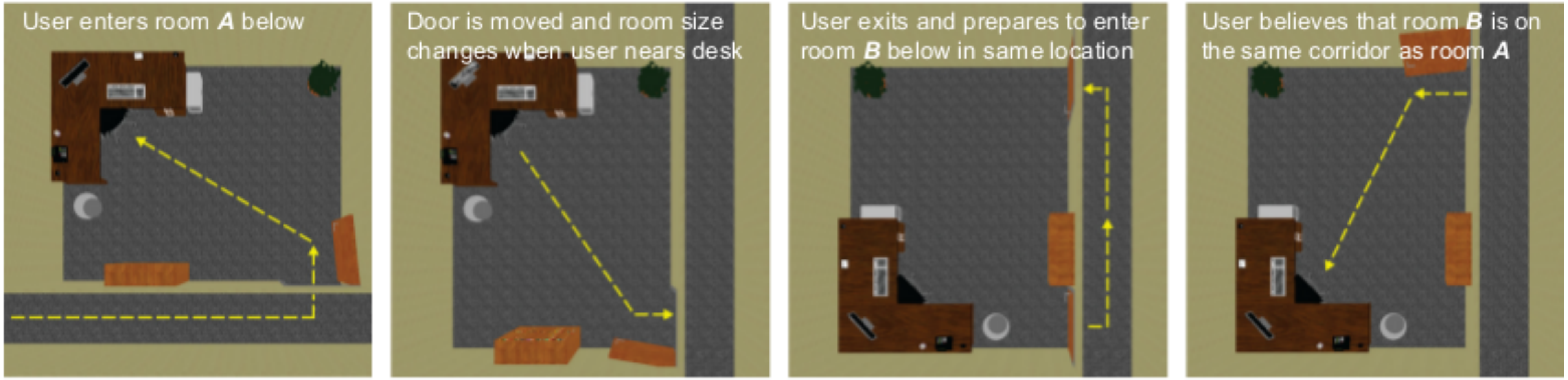
- Change Blindness
  - Failure to notice a large visual change when attention is distracted from the change
  - For general information and examples, see http://www2.psych.ubc.ca/~rensink/flicker
- Change location of virtual door while the user isn't looking
- With right environment design, trick user into thinking they're navigating a larger environment with a different layout

Above: What user would see if they looked behind after entering room
Below: What user sees after performing task before leaving room

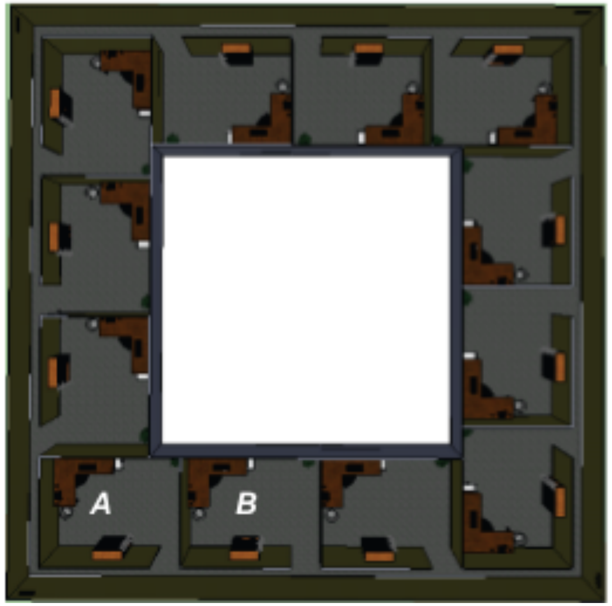


Redirection by Change Blindness

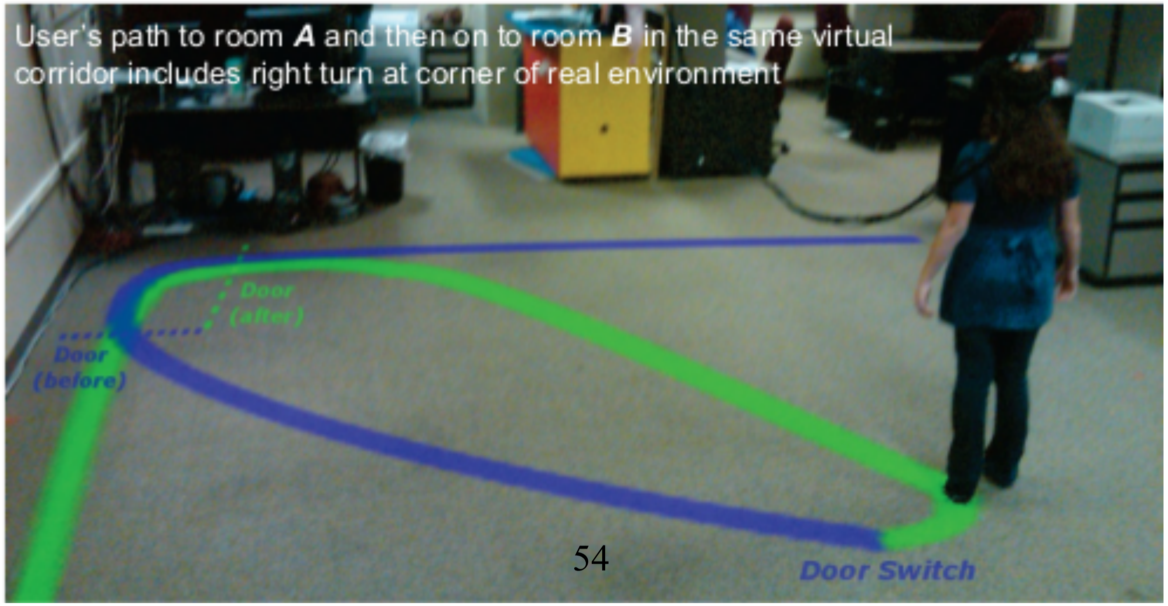
E. Suma et al. VR 2011



Virtual environment



Real environment



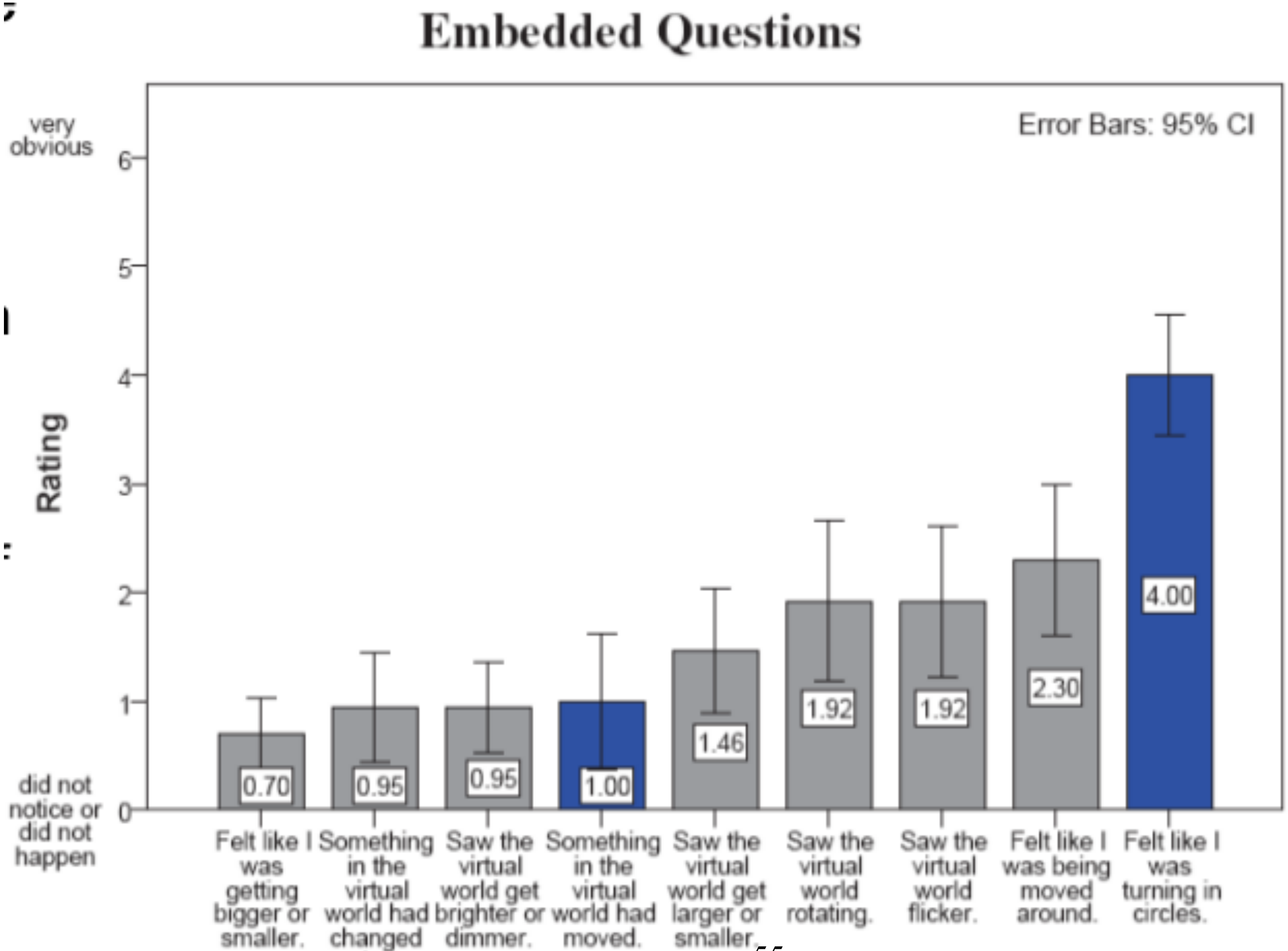
Redirection by Change Blindness

E. Suma et al. VR 2011

- Questionnaire

- Mean outcome questions (blue) embedded in decoy questions

- Only one participant of 77 in two studies definitively noticed a scene change



Redirection for Hand Helds

O. Oda & S. Feiner, ISMAR 2009

- Knock down other player's dominoes by shooting balls from screen

- AR Domino knockdown
    - Two players FPS

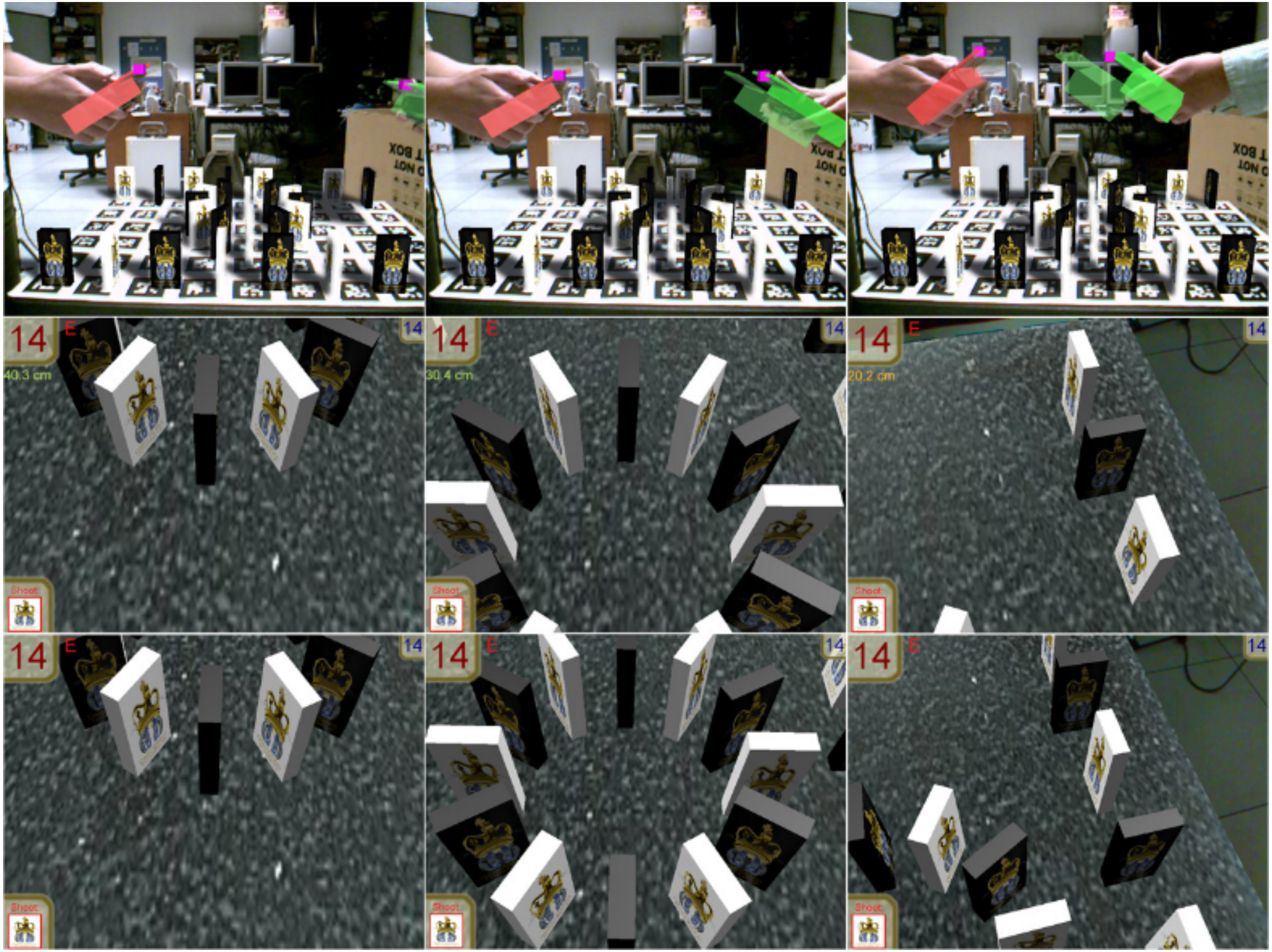
Redirection for Hand Helds

O. Oda & S. Feiner, ISMAR 2009

- How to avoid unwanted physical collisions?
- Redirect motion
  - Shifts virtual location of tracked device ahead of physical location as one player moves toward another player
  - Shifts back as first player retreats

Inspired by redirected walking

[S. Razzaque et al. 2001]

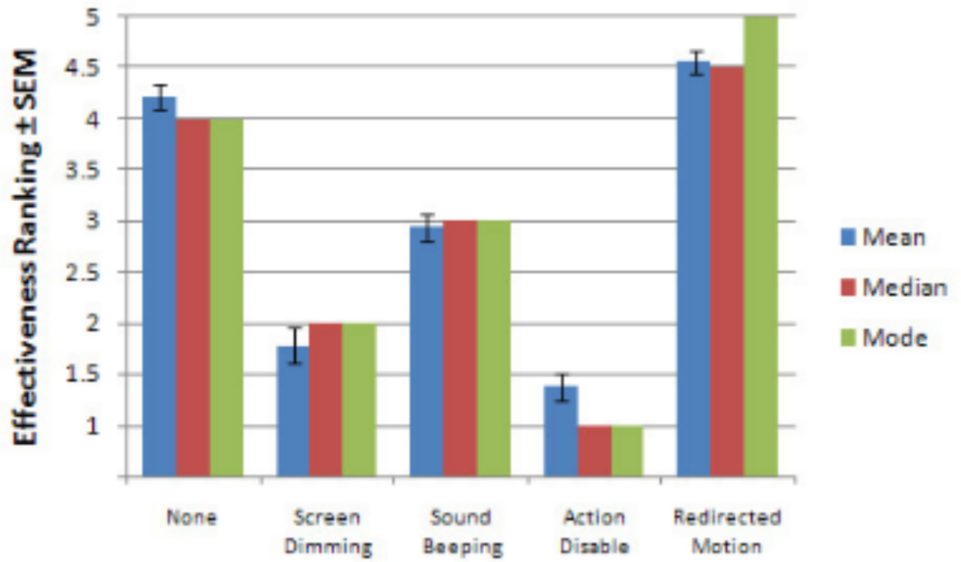


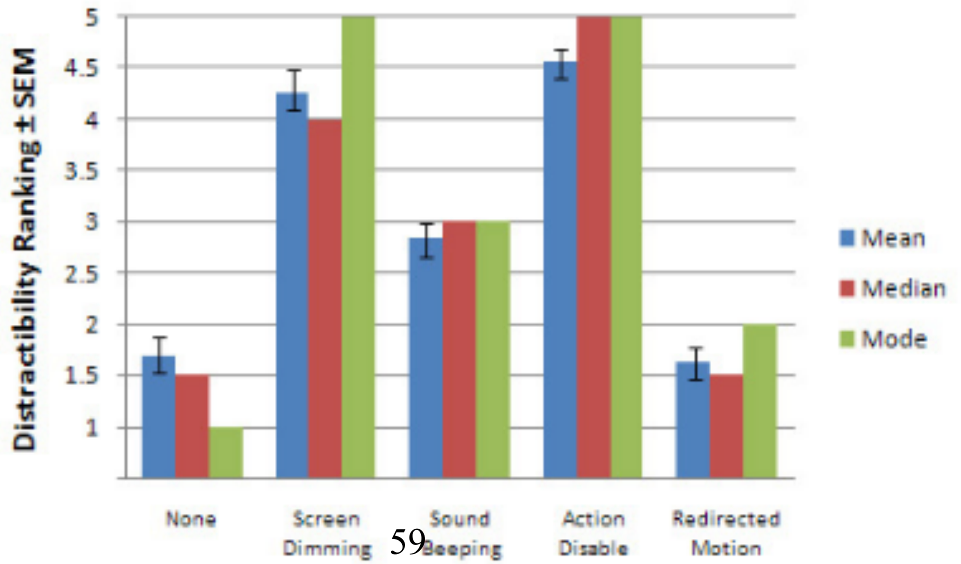
Top: Green moves towards the red player, Mid: Green view redirected, Bottom: Green view without redirection

Redirection for Hand Helds

O. Oda & S. Feiner, ISMAR 2009

- User study
  - Compared 9 pairs of participants playing with/without redirected motion, and other techniques
  - Redirected motion
    - Kept users farther apart
    - Was undetectable when used with parameters set in pilot study





Design Guidelines

Match the travel technique to the application

- no set of 3D interaction techniques is perfect for all applications

Consider both natural and magic techniques

- Nonisomorphic “magic" travel techniques may prove mach more efficient and usable.
  - example compare:
    - “military app” x “choose furniture app"

Myths

There is one optimal travel technique for virtual environments

A “natural" technique will always be better than another technique

Desktop 3D, workbench, and CAVE applications should use the same travel techniques as head-mounted based MX apps.

Design Guidelines

Use an appropriate combination of travel technique, display device, and input devices.

- the travel technique cannot be chosen separately from the hardware used in the system.

Choose travel technique that can be easily integrated with other interaction techniques in the application

- the travel technique cannot be isolated from the rest of the 3D interface.

Design Guidelines

Provide multiple travel techniques to support different travel tasks in the same application

- multiple simple maybe better than one complex

Make simple travel tasks easier by using target-based techniques for goal-oriented and steering techniques for exploration and search

- if the user's goal for travel is not complex, then the travel technique should not be complex either.

Design Guidelines

- Use a physical locomotion technique if user exertion or naturalism is required.
  - walking (or redirected walking) require large tracked areas and devices with serious usability issues. Nonetheless, for some apps…
- The most common travel tasks should require a minimum amount of effort from the user
  - the default navigation mode or controls should focus on the most common tasks.

Design Guidelines

Prefer high-speed transitional motions, not instant teleportation, if overall environment context is important.

- a smooth path from-to another location increases the user's spatial knowledge and keep her oriented to the environment.

Train users in sophisticated strategies to help them acquire survey knowledge

If a map is used, provide a "you-are-here" marker.