3D User Interface Techniques for Selection and Manipulation

Lecture #8: Selection and Manipulation

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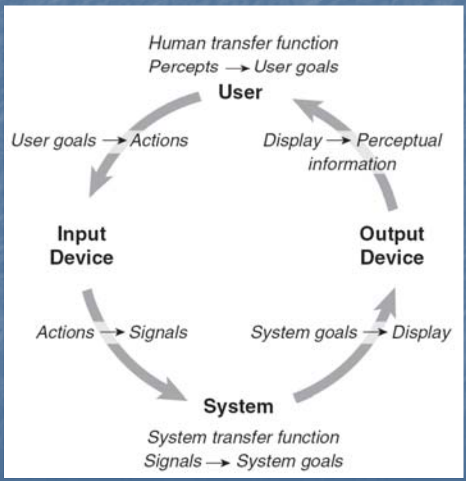
Interaction Workflow



Universal 3D Interaction Tasks

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

Why Selection and Manipulation?

- Major method of interaction with physical environments
- Major method of interaction with virtual environments
- Affects the quality of entire 3D interface
- Design of 3D manipulation techniques is difficult

Lecture Outline

- What is 3D selection and manipulation?
- Relationship between IT and input device
- Manipulation technique classification
- Techniques
  - selection
  - manipulation
  - hybrid
- Isomorphism vs. Non-isomorphism

Selection & Manipulation

- Selection: specifying one or more objects from a set
- Manipulation: modifying object properties
  (position, orientation, scale, shape, color, texture, behavior, etc.)

Goals of Selection

- Indicate action on object
- Query object
- Make object active
- Travel to object location
- Set up manipulation

Selection Performance

- Variables affecting user performance
  - object distance from user
  - object size
  - density of objects in area
  - occluders

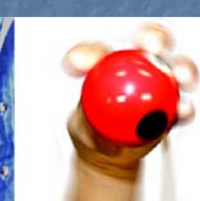
Canonical Parameters

- Selection
  - distance and direction to target
  - target size
  - density of objects around the target
  - number of targets to be selected
  - target occlusion.
- Positioning
  - distance/direction to initial position
  - distance/direction to target position
  - translation distance
  - required precision of positioning
- Rotation
  - distance to target
  - initial orientation
  - final orientation
  - amount of rotation

3D Interaction Techniques and the Input Device

- Number of control dimensions
- Control Integration
- Force vs. Position control
- Device placement
- Form Factor

Attached to Hand



Rolled with fingers

Technique Classification by Metaphor

- VE manipulation techniques
  - Exocentric metaphor
    - World-In-Miniature
    - Scaled-world grab
  - Egocentric metaphor
    - Virtual Hand metaphor
      - "Classical" virtual hand
      - Go-Go
      - Indirect, stretch Go-Go
    - Virtual Pointer metaphor
      - Ray-casting
      - Aperture
      - Flashlight
      - Image plane

Technique Classification by Components

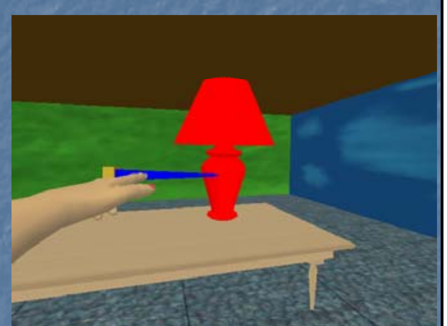
- Manipulation
  - Object Attachment
    - attach to hand
    - attach to gaze
    - hand moves to object
    - object moves to hand
    - user/object scaling
  - Object Position
    - no control
    - 1-to-N hand to object motion
    - maintain body-hand relation
    - other hand mappings
    - indirect control
  - Object Orientation
    - no control
    - 1-to-N hand to object rotation
    - other hand mappings
    - indirect control
  - Feedback
    - graphical
    - force/tactile
    - audio

3D Selection and Manipulation Techniques

- Pointing
  - ray-casting
  - two-handed pointing
  - flashlight & aperture
  - image plane
- Direct manipulation
  - simple virtual hand
  - Go-Go
  - WIM
- Hybrids
  - Homer
  - Scaled-World Grab
  - Voodoo Dolls

Pointing – Ray-Casting

- User points at objects with virtual ray
- Ray defines and visualizes pointing direction



$$\mathbf{p}(\alpha) = \mathbf{h} + \alpha \cdot \vec{\mathbf{p}}$$

where $0 < \alpha < \infty$

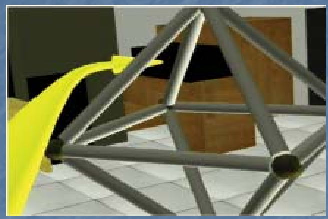
$\mathbf{h}$ = 3D position of virtual hand

$\vec{\mathbf{p}}$ = ray attached to $\mathbf{h}$

Pointing – Two-Handed Pointing

- Ray casting with 2 hands
- More control
  - distance between hands controls length
  - twisting curves pointer

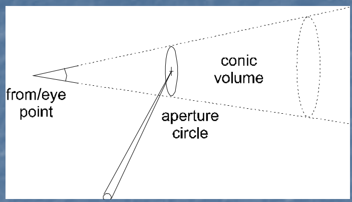
$$\mathbf{p}(\alpha) = \mathbf{h_l} + \alpha \cdot (\mathbf{h_r} - \mathbf{h_l})$$
where $0 < \alpha < \infty$
$\mathbf{h_l}$ = 3D position of left hand
$\mathbf{h_r}$ = 3D position of right hand

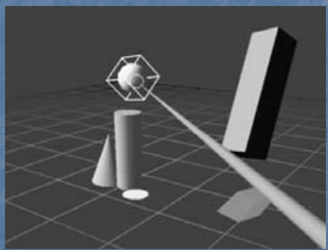


Pointing – Flashlight and Aperture

- Flashlight – soft selection technique
  - does not need precision
  - conic volume constant
- Aperture – extension to Flashlight
  - adjustable volume

$$\mathbf{p}(\alpha) = \mathbf{e} + \alpha \cdot (\mathbf{h} - \mathbf{e})$$
where $0 < \alpha < \infty$
$\mathbf{h}$ = 3D position of hand
$\mathbf{e}$ = 3D coordinates of viewport





Pointing – Image Plane Family

- Requires only 2 DOF
  - selection based on 2D projections
  - virtual image plane in front of user

Framing

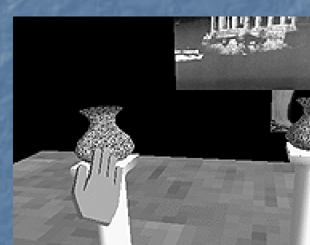
Lifting Palms

Head-Crusher

Sticky Finger

Direct Manipulation – Virtual Hand

- Select and manipulate directly with hands
- Hand represented as 3D cursor
- Intersection between cursor and object indicates selection



$\mathbf{p}_v = \alpha \cdot \mathbf{p}_r, \mathbf{R}_v = \mathbf{R}_r$

$\mathbf{p}_r, \mathbf{R}_r$ = position and orientation of real hand

$\mathbf{p}_v, \mathbf{R}_v$ = position and orientation of hand in VE

α = a scaling factor

Direction Manipulation – Go-Go

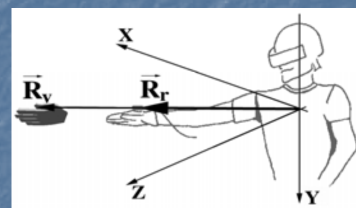
- Arm-extension technique
- Like simple v. hand, touch objects to select them
- Non-linear mapping between physical and virtual hand position
- Local and distant regions

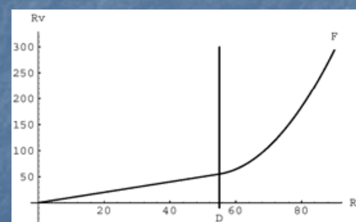
$$r_v = F(r_r) = \begin{cases} r_r & \text{if } r_r \le D \\ r_r + \alpha (r_r - D)^2 & \text{otherwise} \end{cases}$$

where r_r = length of $\vec{\mathbf{R}}_r$

r_v = length of $\vec{\mathbf{R}}_v$

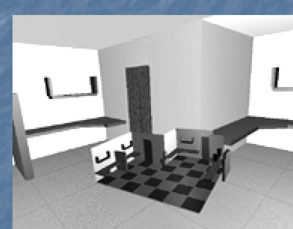
D, α are constants



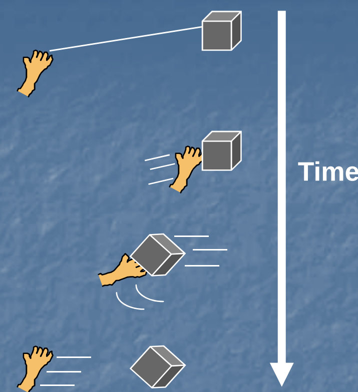


Direct Manipulation – WIM

- “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

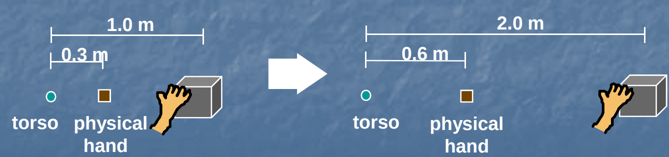


Hybrids – HOMER



Hand-Centered
Object
Manipulation
Extending
Ray-Casting

- Select: ray-casting
- Manipulate: hand



HOMER Implementation

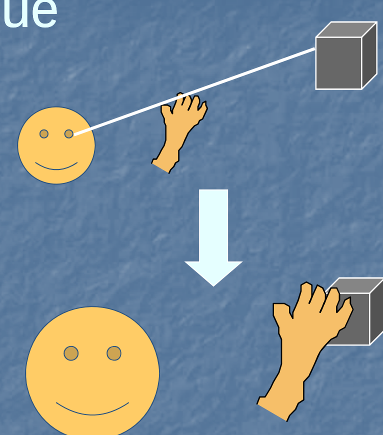
- Requires torso position *t*
- Upon selection, detach virtual hand from tracker, move v. hand to object position in world CS, and attach object to v. hand (w/out moving object)
- Get physical hand position *h* and distance $d_h = dist(h, t)$
- Get object position *o* and distance $d_o = dist(o, t)$

HOMER Implementation (cont.)

- 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 $vh = t + d_{vh} * (th_{curr})$

Hybrids – Scaled-World Grab Technique

- Often used w/ occlusion
- At selection, scale user up (or world down) so that v. hand is actually touching selected object
- User doesn't notice a change in the image until he moves

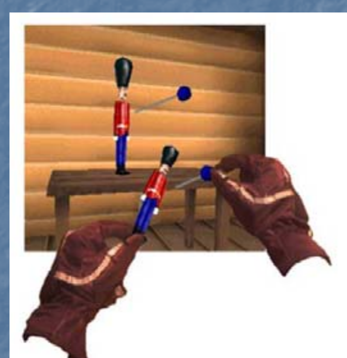


Scaled-World Grab Implementation

- 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

Hybrids – Voodoo Dolls

- Two handed technique
- Builds upon image plane and WIM techniques
- Creates copies of objects (dolls) for manipulation
- Non-dominant hand – stationary frame of reference
- Dominant hand – defines position and orientation



Isomorphic vs. Non-Isomorphic Philosophies

- Human-Machine interaction
  - input device
  - display device
  - transfer function (control to display mapping)
- Isomorphic – one-to-one mapping
- Non-isomorphic – scaled linear/non-linear mapping

Non-Isomorphic 3D Spatial Rotation

- Important advantages
  - manual control constrained by human anatomy
  - more effective use of limited tracking range (i.e vision-based tracking)
  - additional tools for fine tuning interaction techniques
- Questions
  - faster?
  - more accurate?

Rotational Space

- Rotations in 3D space are a little tricky
  - do not follow laws of Euclidian geometry
- Space of rotations is not a vector space
- Represented as a closed and curved surface
  - 4D sphere or manifold
- Quaternions provide a tool for describing this surface

Quaternions

- Four-dimensional vector (***v***, *w*) where ***v*** is a 3D vector and *w* is a real number
- A quaternion of unit length can be used to represent a single rotation about a unit axis $\hat{u}$

  and angle θ as

$$q = (\sin(\frac{\theta}{2}\hat{u}), \cos(\frac{\theta}{2})) = e^{\frac{\theta}{2}\hat{u}}$$

Linear 0th Order 3D Rotation

- Let q_c be the orientation of the input device and q_d be the displayed orientation then

$$(1) \quad q_c = (\sin(\frac{\theta_c}{2}\hat{u}_c), \cos(\frac{\theta_c}{2})) = e^{\frac{\theta_c}{2}\hat{u}_c}$$

$$(2) \quad q_d = (\sin(\frac{k\theta_c}{2}\hat{u}_c), \cos(\frac{k\theta_c}{2})) = e^{\frac{k\theta_c}{2}\hat{u}_c} = q_c^k$$

- Final equations w.r.t. identity or reference orientation q_o are

$$(3) \quad q_q = q_c^k \qquad (4) \quad q_d = (q_c q_o^{-1})^k q_o, \; k = \text{CD gain coefficient}$$

Non-Linear 0th Order 3D Rotation

- Consider

$$(3) \quad q_d = q_c^k \qquad (4) \quad q_d = (q_c q_o^{-1})^k q_o$$

- Let *k be* a non-linear function as in

$$\omega = 2\arccos(q_c \cdot q_o) \;\text{ or }\; \omega = 2\arccos(w)$$

$$k = F(\omega) = \begin{cases} 1 & \text{if } \omega < \omega_o \\ f(\omega) = 1 + c(\omega - \omega_o)^2 & \text{otherwise} \end{cases}$$

where c is a coefficient and ω_o is the theshold angle

Design Considerations

- Absolute mapping – taken on *i-th* cycle of the simulation loop

$$q_{d_i} = q_{c_i}^k$$

- Relative mapping – taken between the *i-th* and *i-1th* cycle of the simulation loop

$$q_{d_i} = (q_{c_i} q_{c_{i-1}}^{-1})^k q_{d_{i-1}}$$

Absolute Non-Isomorphic Mapping

- Generally do not preserve directional compliance
- Strictly preserves nulling compliance

Relative Non-Isomorphic Mapping

- Always maintain directional compliance
- Do not generally preserve nulling compliance

Amplified Non-Linear Rotation for VE Navigation (1)

- Users expect the virtual world to exist in any direction
  - 3-walled Cave does not allow this
  - adapt expected UI to work in restricted environment
- Amplified rotation allows users to see a full 360 degrees in a 3-walled display
- A number of approaches were tested
  - important to take cybersickness into account

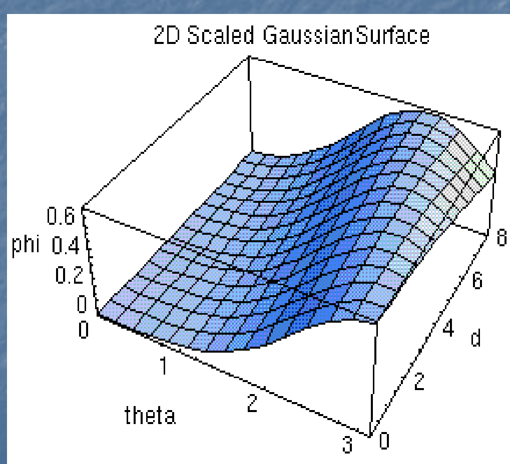
Amplified Non-Linear Rotation for VE Navigation (2)

- Apply a non-linear mapping function to the user's waist orientation θ and his or her distance d from the back of the Cave
- Calculate the rotation factor using a scaled 2D Gaussian function

$$\phi = f(\theta, d) = \frac{1}{\sqrt{2\pi}\sigma_1} e^{-\frac{(|\theta| - \pi(1 - d/L))^2}{2\sigma_2^2}}$$

- The new viewing angle is $\theta_{new} = \theta(1 - \phi)$

Amplified Non-Linear Rotation for VE Navigation (3)



$\sigma_1 = 0.57$

$\sigma_2 = 0.85$

$L = 30$

$\mu = \pi$

Non-Linear Translation for VE Navigation (1)

- Users lean about the waist to move small to medium distances
  - users can lean and look in different directions
- Users can also lean to translate a floor-based interactive world in miniature (WIM)
  - Step WIM must be active
  - user's gaze must be 25 degrees below horizontal

Non-Linear Translation for VE Navigation (2)

- Leaning vector $\vec{L}_R$ is the projection of the vector between the waist and the head onto the floor
  - gives direction and raw magnitude components
- Navigation speed is dependent on the user's physical location
  - Leaning sensitivity increases close to a boundary
- Linear function - $L_T = a \cdot D_{\min} + b$
- Mapped velocity - $v = \left\| \vec{L}_R \right\| - L_T$

Non-Linear Translation for VE Navigation (3)

- Navigation speed is also dependent on the user's head orientation with respect to the vertical axis
  - especially useful when translating the floor-based WIM
- Mapping is done with a scaled exponential function

$$F = \alpha \cdot e^{-\beta \left| \vec{H} \cdot \vec{V}_{up} \right|}$$

- Final leaning velocity is $v_{final} = F \cdot v$

Next Class

- Navigation – Travel
- Readings
  - 3DUI Book – Chapter 5