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**
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

\[ p(\alpha) = h + \alpha \cdot \hat{p} \]

where \( 0 < \alpha < \infty \)

- \( h \) = 3D position of virtual hand
- \( \hat{p} \) = ray attached to \( h \)
Pointing – Two-Handed Pointing

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

\[ p(\alpha) = h_l + \alpha \cdot (h_r - h_l) \]
where \( 0 < \alpha < \infty \)
\( h_l \) = 3D position of left hand
\( h_r \) = 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

\[ p(\alpha) = e + \alpha \cdot (h - e) \]
where \( 0 < \alpha < \infty \)
\( h \) = 3D position of hand
\( e \) = 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

\[ p_v = \alpha \cdot p_r, R_v = R_r \]
\[ p_r, R_r \text{ = position and orientation of real hand} \]
\[ p_v, R_v \text{ = position and orientation of hand in VE} \]
\[ \alpha \text{ = a scaling factor} \]
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

\[ r_v = F(r_v) = \begin{cases} r_v & \text{if } r_v \leq D \\ r_v + \alpha (r_v - D)^2 & \text{otherwise} \end{cases} \]

where \( r_v \) = length of \( \mathbf{R}_v \)
\( r_v \) = length of \( \mathbf{R}_b \)
\( D, \alpha \) 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 $d_h = \text{dist}(h, t)$
- Get object position $o$ and distance $d_o = \text{dist}(o, t)$
HOMER Implementation (cont.)

- Each frame:
  - Copy hand tracker matrix to v. hand matrix (to set orientation)
  - Get physical hand position $h_{curr}$ and distance:
    $d_{h-curr} = dist(h_{curr}, t)$
  - V. hand distance
    $$d_{vh} = d_{h-curr} \times \left( \frac{d_t}{d_h} \right)$$
  - Normalize torso-hand vector
    $$t_{h-curr} = \frac{h_{curr} - t}{\|h_{curr} - t\|}$$
  - V. hand position
    $$v_h = t + d_{vh} \times t_{h-curr}$$

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

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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 \((\mathbf{v}, w)\) where \(\mathbf{v}\) 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 \(\mathbf{u}\) and angle \(\theta\) as
  \[ q = (\sin(\frac{\theta}{2})\mathbf{u}, \cos(\frac{\theta}{2})) = e^{\frac{\theta}{2}\mathbf{u}} \]
Linear 0\textsuperscript{th} Order 3D Rotation

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

  \begin{align*}
  (1) \quad q_c &= (\sin(\frac{\theta}{2})\hat{u}_c, \cos(\frac{\theta}{2})) = e^{\frac{\theta}{2}\hat{u}_c} \\
  (2) \quad q_d &= (\sin(\frac{k\theta}{2})\hat{u}_c, \cos(\frac{k\theta}{2})) = e^{\frac{k\theta}{2}\hat{u}_c} = q_c^k
  \end{align*}

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

  \begin{align*}
  (3) \quad q_q &= q_c^k \\
  (4) \quad q_d &= (q_cq_o^{-1})^k q_o, \quad k = \text{CD gain coefficient}
  \end{align*}

Non-Linear 0\textsuperscript{th} Order 3D Rotation

- Consider

  \begin{align*}
  (3) \quad q_d &= q_c^k \\
  (4) \quad q_d &= (q_cq_o^{-1})^k q_o
  \end{align*}

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

  $\omega = 2\arccos(q_c \cdot q_o)$ 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 $\omega_o$ is the threshold 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 $\theta$ 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 $\theta_{\text{new}} = \theta(1 - \phi)$

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 $LT = a \cdot D_{\text{min}} + b$
- Mapped velocity $v = \frac{\vec{L}_r}{\|\vec{L}_r\|} - LT$
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
  \[ F = \alpha \cdot e^{-\beta |\vec{H} \cdot \vec{v}_{up}|} \]
- Final leaning velocity is
  \[ v_{final} = F \cdot v \]

Next Class

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