Interaction Workflow

User

Input Device

Actions → Signals

System

System transfer function
Signals → System goals

Output Device

Display

Perceptual information

System goals → Display

Human transfer function
Percepts → User goals

User goals → Actions
3D Interaction Techniques

- Choosing the right input and output devices not sufficient for an effective 3D UI
- Interaction techniques: methods to accomplish a task via the interface
  - Hardware components
  - Software components: control-display mappings or transfer functions
  - Metaphors or concepts
- Universal tasks: selection and manipulation, travel, system control

Overview

- Manipulation: a fundamental task in both physical and virtual environments
- 3D manipulation task types
- Classifications of manipulation techniques
- Techniques classified by metaphor:
  - Grasping
  - Pointing
  - Surface
  - Indirect
  - Bimanual
  - Hybrid
3D Manipulation Tasks

- Broad definition: any act of physically handling objects with one or two hands
- Narrower definition: spatial rigid object manipulation (shape preserving)

Canonical Manipulation Tasks

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

Canonical Manipulation Tasks
- Task parameters

<table>
<thead>
<tr>
<th>Task</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selection</td>
<td>Distance and direction to target, target size, density of objects around the target, number of targets to be selected, target occlusion</td>
</tr>
<tr>
<td>Positioning</td>
<td>Distance and direction to initial position, distance and direction to target position, translation distance, required precision of positioning</td>
</tr>
<tr>
<td>Rotation</td>
<td>Distance to target, initial orientation, final orientation, amount of rotation, required precision of rotation</td>
</tr>
</tbody>
</table>

Application-Specific Manipulation Tasks
- Canonical tasks can fail to capture important task properties for real applications
- Ex: positioning a medical probe relative to virtual models of internal organs in a VR medical training application
- Techniques must capture and replicate minute details of such manipulation tasks
3D Manipulation Tasks

Manipulation Techniques and Input Devices

- Number of control dimensions
- Integration of control dimensions
  - Multiple integrated DOFs typically best for 3D manipulation
- Force vs. position control
  - Position control preferred for manipulation
  - Force control more suitable for controlling rates

Device shape
- Generic vs. task-specific
- Device placement/grasp
  - Power grip
  - Precision grip
    - Use fingers
    - Reduce clutching
Classifications for 3D Manipulation

- Isomorphic (realistic) vs. non-isomorphic (magic)
- Task decomposition
- Metaphor

Grasping Metaphors

**Hand-Based Grasping**

- Simple virtual hand
- Go-Go
Grasping Metaphors

**Finger-Based Grasping**
- Rigid-body fingers
- Soft-body fingers
- god fingers

**Enhancements for Grasping Metaphors**
- 3D bubble cursor
- PRI SM
- Hook
- Intent-driven selection
Pointing Metaphors

- Pointing is powerful for selection
  - Remote selection
  - Fewer DOFs to control
  - Less hand movement required
- Pointing is poor for positioning
- Design variables:
  - How pointing direction is defined
  - Type of selection calculation

Vector-Based Pointing Techniques

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

Volume-Based Pointing Techniques

- Flashlight
- Aperture
- Sphere-casting

Enhancements for Pointing Metaphors

- Bendcast
- Depth ray
- Absolute and relative mapping
Surface Metaphors

Surface-Based 2D Interaction Techniques
- Dragging
- Rotating

Surface-based 3D Interaction Techniques
- Pinching
- Void shadows
- Balloon selection
- Corkscrew widget
- Triangle cursor
Indirect Metaphors

Indirect Control-Space Techniques
- Indirect touch
- Virtual interaction surface
- Levels-of-precision cursor
- Virtual pad

Indirect Proxy Techniques
- World in miniature
- Voodoo Dolls
Indirect Metaphors

Indirect Widget Techniques
- 3D widgets
- Virtual sphere
- Arcball

Bimanual Metaphors
- Dominant and non-dominant hands
- Symmetric vs. asymmetric
- Synchronous vs. asynchronous
- Ex: balloon selection is asymmetric (two hands have different functions) and synchronous (two hands operate at the same time)
Bimanual Metaphors

Symmetric Bimanual Techniques
- Spindle
- iSith

Asymmetric Bimanual Techniques
- Spindle + Wheel
- Flexible pointer
Hybrid Metaphors

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

Other Aspects of 3D Manipulation

**Nonisomorphic 3D rotation**
- Amplifying 3D rotations to increase range and decrease clenching
- Slowing down rotation to increase precision
- Absolute vs. relative mappings
  - Absolute mappings can violate *directional compliance*
  - Relative mappings do not preserve *nulling compliance*
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 \(\theta\) 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
  
  \begin{align}
  (1) \quad q_c &= \left( \sin \left( \frac{\theta}{2} \right) \hat{u}_x, \cos \left( \frac{\theta}{2} \right) \right) = e^{\frac{\theta}{2} \hat{u}_x} \\
  (2) \quad q_d &= \left( \sin \left( \frac{k\theta}{2} \hat{u}_x \right), \cos \left( \frac{k\theta}{2} \right) \right) = e^{\frac{k\theta}{2} \hat{u}_x} = q_o^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_c q_o^{-1} )^k q_o, \quad k = CD \text{ gain coefficient}
  \end{align}

Non-Linear 0th Order 3D Rotation

- Consider
  
  \begin{align}
  (3) \quad q_d &= q_c^k \\
  (4) \quad q_d &= (q_c q_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 $\theta_{new} = \theta(1 - \phi)$

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

Other Aspects of 3D Manipulation

**Multiple Object Selection**
- Serial selection mode
- Volume-based selection techniques:
  - e.g., flashlight, aperture, sphere-casting
- Defining selection volumes:
  - e.g., two-corners, lasso on image plane
- Selection-volume widget:
  - e.g., PORT
Other Aspects of 3D Manipulation

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

Design Guidelines
- Use existing manipulation techniques unless a large amount of benefit might be derived from designing a new application-specific technique.
- Use task analysis when choosing a 3D manipulation technique.
- Match the interaction technique to the device.
- Use techniques that can help to reduce clutching.
Design Guidelines

- Nonisomorphic (“magic”) techniques are useful and intuitive.
- Use pointing techniques for selection and grasping techniques for manipulation.
- Consider the use of grasp-sensitive object selection.
- Reduce degrees of freedom when possible.
- Consider the trade-off between technique design and environment design.
- There is no single best manipulation technique.

Case Studies

VR Gaming Case Study

- Bimanual approach:
  - Non-dominant hand defines interaction area (“flashlight”)
  - Dominant hand selects/manipulates in that area (“tool”)
- Playful metaphors, multiple tools
- Key concepts:
  - Progressive refinement selection techniques can help users avoid fatigue by not requiring precise interactions.
  - Basic 3D selection and manipulation techniques can be customized to fit the theme or story of a particular application.
Case Studies

Mobile AR Case Study
- Finger-based selection for infrequent use with single datasets
- Pen-based selection for frequent use or richer datasets
- Key concepts:
  - Size of selectable items: keep the size of your selectable objects or menu items as small as possible, while reflecting the limitations of your input method and the visibility (legibility) of these items.
  - Selection method: depending on the frequency of selection tasks, different input methods could be preferable. Often, there is a direct relationship between input method, selection performance and frequency, and user comfort.

Conclusion
- 3D manipulation is a foundational task in 3D UIs
- Huge design space with many competing considerations
- Consider tradeoffs in your application context carefully
Next Class

- Navigation – Travel
- Readings
  - 3DUI Book – Chapter 7