3D User Interface Techniques for Selection and Manipulation

Lecture #9: Selection and Manipulation

Spring 2019

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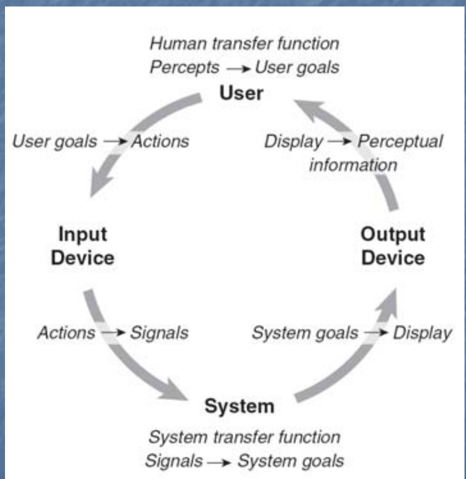
Interaction Workflow



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)

3D Manipulation Tasks

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

Task	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 and direction to initial position, distance and direction to target position, translation distance, required precision of positioning
Rotation	Distance to target, initial orientation, final orientation, amount of rotation, required precision of rotation

3D Manipulation Tasks

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

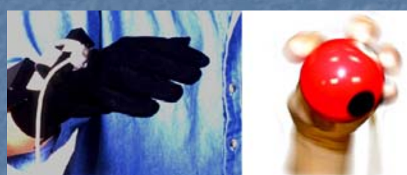
Manipulation Techniques and Input Devices

- 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

3D Manipulation Tasks

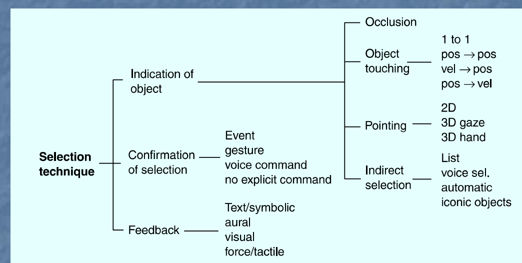
Manipulation Techniques and Input Devices

- Device shape
  - Generic vs. task-specific
- Device placement/grasp
  - Power grip
  - Precision grip
    - Use fingers
    - Reduce clutching



Classifications for 3D Manipulation

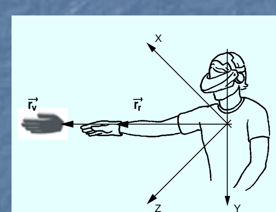
- Isomorphic (realistic) vs. non-isomorphic (magic)
- Task decomposition
- Metaphor

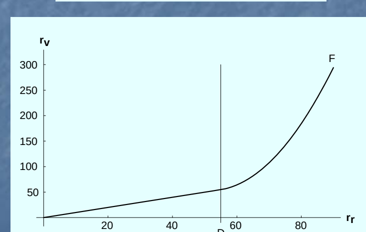


Grasping Metaphors

Hand-Based Grasping

- Simple virtual hand
- Go-Go

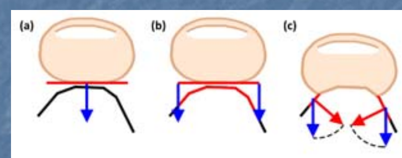




Grasping Metaphors

Finger-Based Grasping

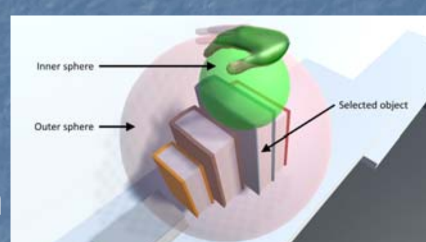
- Rigid-body fingers
- Soft-body fingers
- god fingers



Grasping Metaphors

Enhancements for Grasping Metaphors

- 3D bubble cursor
- PRISM
- Hook
- Intent-driven selection



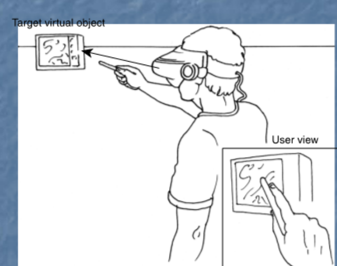
Pointing Metaphors

- 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

Pointing Metaphors

Vector-Based Pointing Techniques

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



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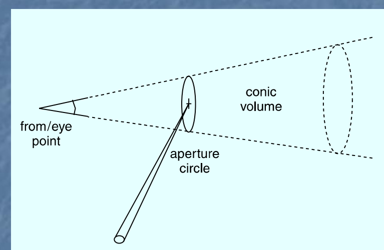
Pointing Metaphors

Volume-Based Pointing Techniques

- Flashlight
- Aperture
- Sphere-casting



Pointing Metaphors

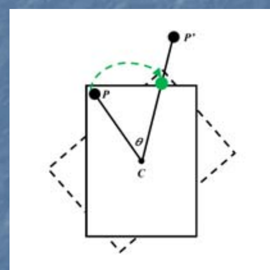
Enhancements for Pointing Metaphors

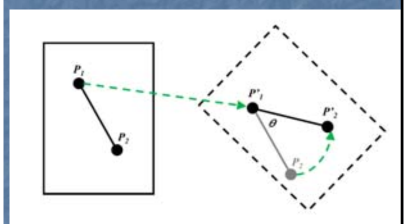
- Bendcast
- Depth ray
- Absolute and relative mapping

Surface Metaphors

Surface-Based 2D Interaction Techniques

- Dragging
- Rotating





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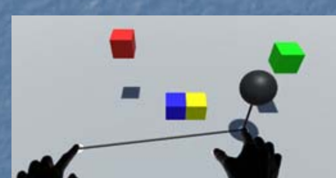
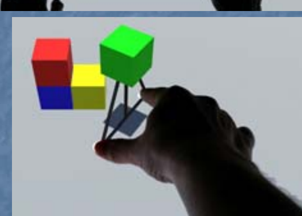
Surface Metaphors

Surface-based 3D Interaction Techniques

- Pinching
- Void shadows
- Balloon selection
- Corkscrew widget
- Triangle cursor





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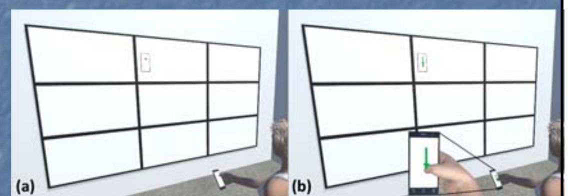
Indirect Metaphors

Indirect Control-Space Techniques

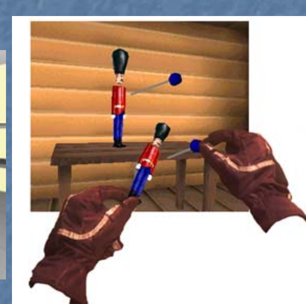
- Indirect touch
- Virtual interaction surface
- Levels-of-precision cursor
- Virtual pad



Indirect Metaphors

Indirect Proxy Techniques

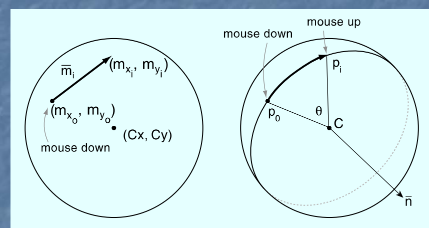
- World in miniature
- Voodoo Dolls



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)

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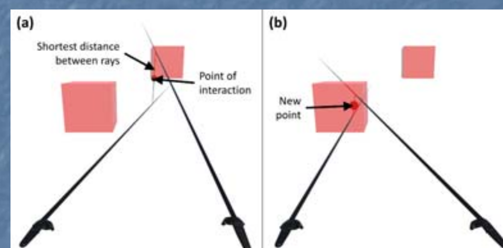
Bimanual Metaphors

Symmetric Bimanual Techniques

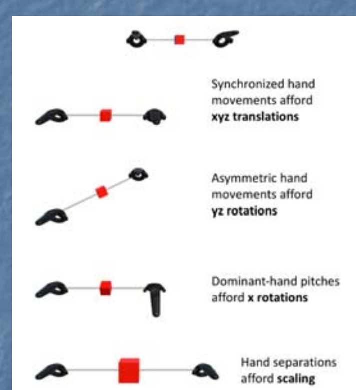
- Spindle
- iSith



Bimanual Metaphors

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 clutching
- 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 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

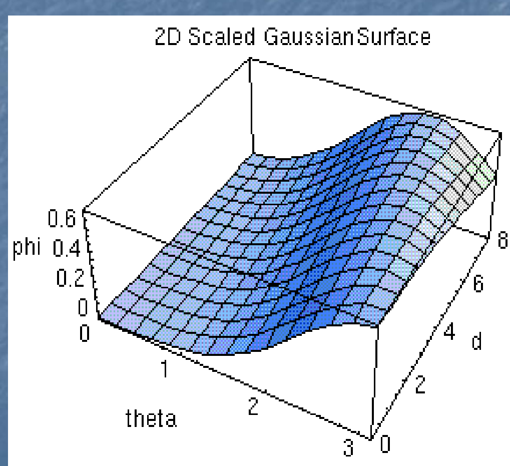
Amplified Non-Linear Rotation for VE Navigation (2)

- 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 $v_{final} = F \cdot v$

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

