# 3D User Interface

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## What are 3D User Interaction?

- Human-computer interaction in which the user's tasks are performed directly in a 3D spatial context.
- Interactive systems that display 3D graphics do not necessarily involve 3D interaction – e.g. using 2D menu to control 3D interactive environments
- 3D interaction does not necessarily mean that 3D input devices are used – e.g. using 2D mouse input to perform 3D interaction
- 3D user interface is a UI that involves 3D interaction

## Challenges in 3D Interaction

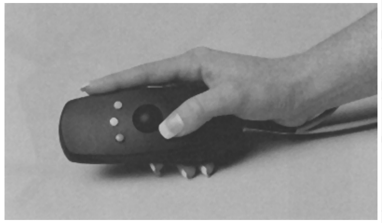
- Limited (or expensive) input devices.
- Too many variables needed to accurately interact with objects (i.e. 6 DOF).
- Information in the world can become overwhelming (Sestito et al., 2002)
- Users can get lost/sick while navigating the environment.
- User's have difficulty moving their arms and hands precisely in free space.
- Interaction is often done with arms outstretched and/or head bent over - arms and neck fatigue.

## 3D User Interfaces

- 6-DOF Input Device for the 3D Interaction on the desktop
  - Examples are SpaceMouse, SpaceBall, etc.
  - Slight push and pull pressure of the fingers on the cap of the device generates small deflections in x, y, z - which moves virtual objects dynamically in the corresponding 3-axes.
  - Slight twisting and tilting of the cap generates rotational motions along the 3-axes.

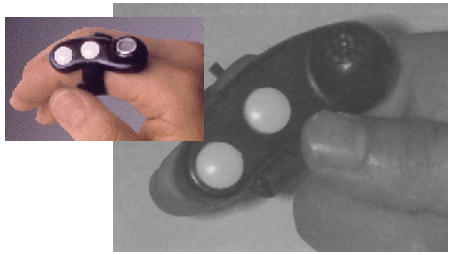
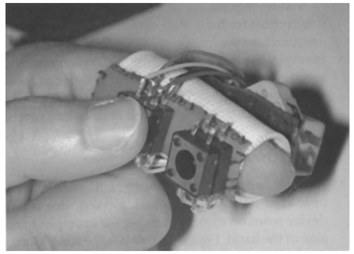
# 3D User Interfaces

- 3D Mice
  - The "bat", developed by Colin Ware, is a mouse that flies - It's simply a 6-DOF tracking device with three buttons.
  - Wand is commonly used in conjunction with surround-screen VR displays, such as CAVE and ImmersaDesk.
  - Another example is the 3D Joystick modeled after a flight stick.
  - Cubic Mouse, developed at Fraunhofer, is a 3D mouse designed primarily as an interactive prop for handling 3D objects.



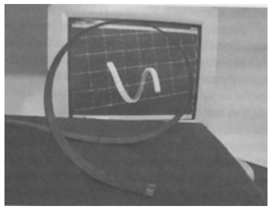
# 3D User Interfaces

- User-Worn 3D Mice
  - Another approach to the design of 3D mice is to have the user wear them instead of holding them.
  - Ring Mouse is a small, two-button, ring-like device that uses ultrasonic tracking that generates only position information.
  - FingerSleeve is a finger-worn 3D mouse (similar to Ring Mouse) in that it is small and lightweight, but it adds more buttons.

# 3D User Interfaces

- Special-Purpose 3D User Interfaces
  - Many other types of input devices are used in 3D user interfaces.
  - ShapeTape is a flexible, ribbon-like tape of fiber-optic curvature sensors that comes in various lengths and sensor spacing – It senses bend and twist information.
  - Interaction Slippers embed a wireless trackball device (the Logitech Trackman) into a pair of common house slippers. Touching a cloth patch on the left slippers to a cloth patch on the right slipper completes the button press circuit.

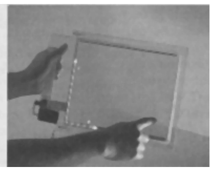



# 3D User Interfaces

- Special-Purpose 3D User Interfaces
  - CavePainting Table used in 3D CavePainting, a system for painting 3D scenes in a virtual environment – multiple cups of paint, a single tracked paint-brush, and a paint-bucket.
  - Transparent Palettes allows writing and selection of objects and commands from 2D palettes, as well as 3D interaction techniques, such as volumetric selection by sweeping the device through the virtual world.







## 3D User Interfaces

- Special-Purpose 3D User Interfaces
  - Control Action Table (CAT) - looks like a circular tabletop - was designed for use in surround-screen VR display. It combines 6DOF input with 2D tablet interaction. It uses angular sensors to detect orientation information using three nested orientation axes & a potentiometer to detect forces in any 3D direction.
  - In Jeffrey Shaw's "configuring the CAVE", the movement of a near life-size wooden puppet body and limbs dynamically modulates the parameters of image and sound generation.

## Interaction Design Principles

- Performance
  - Quantitative measures indicating how well the task is being done by the user and the system in cooperation
  - Efficiency, accuracy, productivity
- Usability
  - Qualitative experience of the user
  - Ease of use, ease of learning, user comfort
- Usefulness
  - Interaction helps users perform work or meet system goals
  - Users focus on tasks

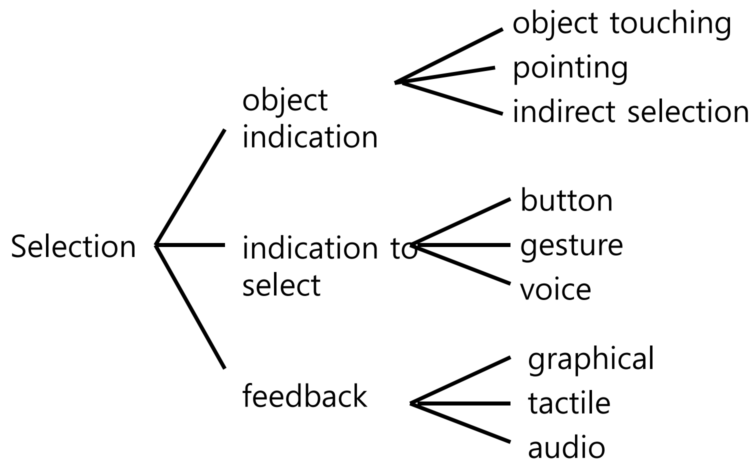
## Universal Interaction Tasks

- Selection & Manipulation
  - Selection: Specifying one or more objects from a set
  - Manipulation: Modifying object properties (position, orientation, scale, shape, color, texture, behavior, etc)
- Navigation
  - Travel: Physical movement from place to place, setting the position (and orientation) of the user's viewpoint
  - Wayfinding: Cognitive process of defining a path through an environment, using and acquiring spatial knowledge, helped by (artificial) cues
- System control
  - Issuing a command to change the system state or the interaction mode (In 2D systems, menus & command-line interfaces)

## Selection

- Goal of selection
  - Indicate action on object
  - Query object
  - Make object active
  - Travel to object location
  - Set up manipulation
- Variables affecting user performance in selection
  - Object distance from user
  - Object size
  - Density of objects in area
  - Occluders
- Common selection techniques
  - Touching with virtual hand
  - Ray casting
  - Occlusion/framing
  - Naming
  - Indirect selection

## Selection Classification



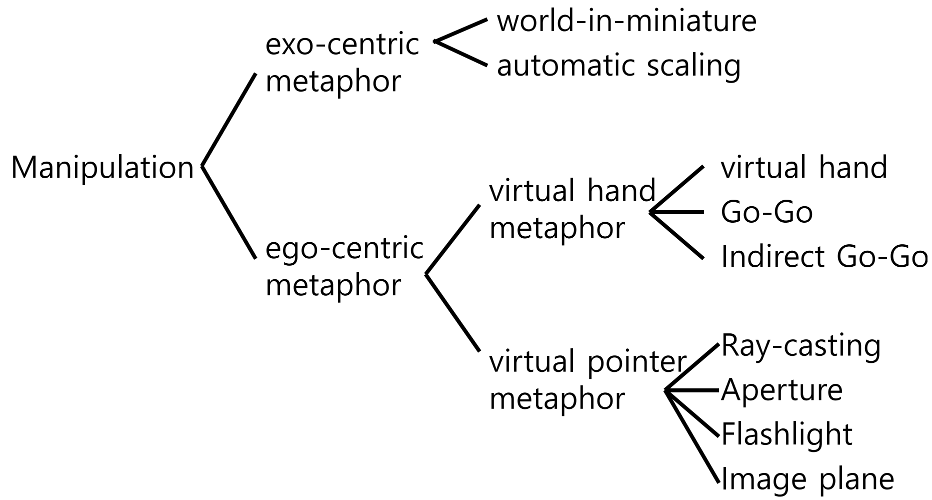

## Implementation issues for selection techniques

- How to indicate that the selection event should take place
- Need efficient algorithms for object intersections
- Feedback (graphical, aural, tactile) indicating which object is about to be selected
- Virtual hand avatar (virtual representation for user hand)
- List of selectable objects, to increase efficiency

## Manipulation

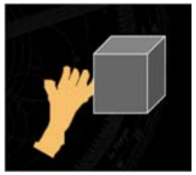
- Goal of manipulation
  - Object placement
  - Design layout
  - Grouping
  - Tool usage
  - Travel
- Variables affecting user performance in manipulation
  - Required translation distance
  - Amount of rotation
  - Required precision of placement
- Common manipulation techniques
  - Simple virtual hand
  - Ray-casting
  - Hand-position mapping
  - Indirect-depth mapping
  - HOMER
  - Scaled-world grab
  - WIM

## Manipulation Classification



## Manipulation Metaphors

- Simple virtual hand
  - One-to-one mapping between physical and virtual hands
  - Natural but limited
- Ray casting
  - Pointer attached to virtual hand
  - little effort required
  - Exact positioning and orienting very different
- Hand position mapping
  - Natural, easy placement
  - Limited reach, fatiguing, overshoot



Virtual hand

Ray-casting

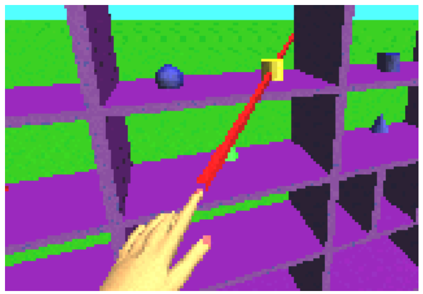
## Manipulation Metaphors

- Indirect depth mapping
  - Infinite reach, not tiring
  - Not natural, separates DOFs
- HOMER (ray-casting + arm-extension)
  - Easy selection & manipulation
  - Expressive over range of distances
  - Hard to move objects away from you
- Scaled-world grab
  - Easy, natural manipulation
  - User discomfort with use
- World-In-Miniature
  - All manipulation in reach
  - Doesn't scale well, indirect

## Implementation issues for manipulation techniques

- Integration with selection technique
- Disable selection and selection feedback while manipulating
- What happens upon release?

## Ray Casting Technique

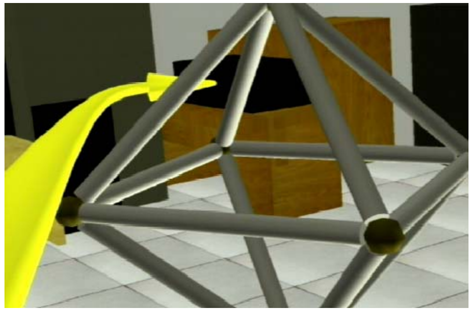


- User selects objects by intersecting them with a ray or beam
- Shoot a ray in hand "forward" direction

## Ray Casting Technique

- Advantages
  - No need to move to far away objects to select them
  - Less fatiguing (user can "shoot from the hip")
- Drawbacks:
  - Cannot select occluded objects
  - Difficult to manipulate selected object
  - Small movements in hand result in larger translations of distant objects
  - Difficult to move in a direction parallel to the ray
  - Rotates relative to the user's position, not the object's origin

## Two-handed Pointing Technique

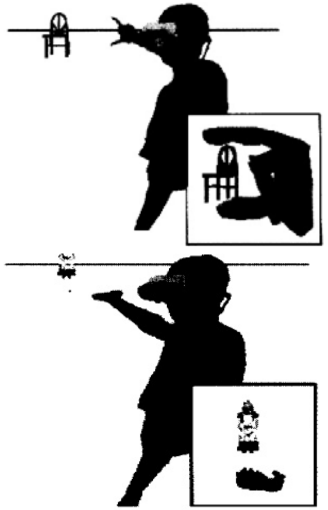


- Flexible Pointer (Olwal and Feiner, 2003)
- Simplify pointing to fully or partially obscured objects
- Using the distance between the two hands to control the length of the virtual pointer
- Twisting the hands slightly the user can curve the virtual pointer

## Flashlight Technique

- Spotlight or flashlight was developed to provide a soft selection technique that does not require precision and accuracy of pointing to virtual objects with the ray.
- The pointing direction is defined in the same way as in the simple ray-casting, but it replaces the virtual ray with a conic selection volume.
- Easy selection of small objects
- Disambiguation of the desired object when more than one object falls into the spotlight.
  - If two objects fall into the selection volume, the object that is closer to the center line of the corn volume is selected.
  - If the angle between the center line of the selection cone is the same for both objects, then the object closer to the device is selected.

## Image Plane Technique

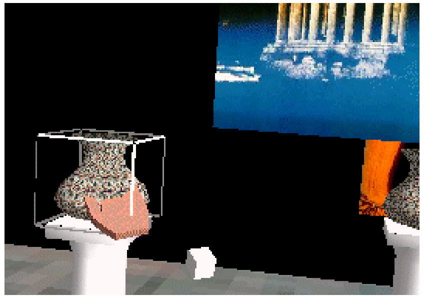


- Image-Plane technique simplifies the object selection task by requiring the user to control only 2DOF. (Pierce et al., 1997)
- Users operate on objects in their image plane as if the object was right in front of them.
- Translations and Rotations relative to object's origin.
- Suffers from the same occlusion problems as ray cast.
- Can be fatiguing.

## Fishing-Reel Technique

- Previous approach is difficult to control the distance to the virtual object in z-axes.
- Additional input device, such as fishing-reel (e.g. a mechanical slider or up-down button), dedicated to controlling the length of the virtual ray.
- It allows the user to select an object with a ray-casting, then reel it back and forth using the dedicated input device.

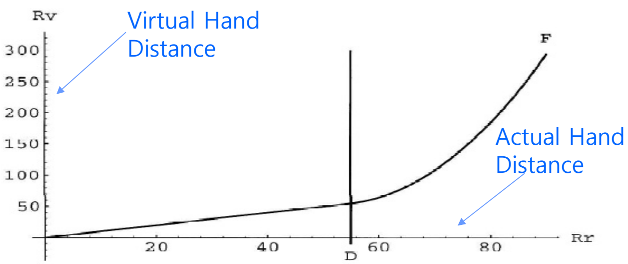
## Go-Go Interaction Technique



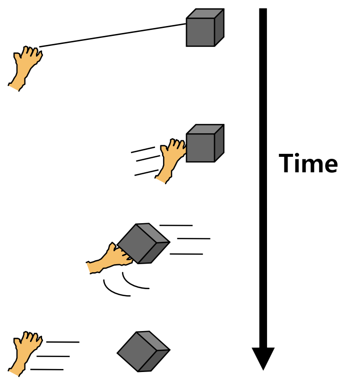
- Poupyre et. Al., 1996
- Interactively grows the length of user's arm length
- Allows user to manipulate near and distant objects directly
- Translations relative to user, rotation relative to object's origin

## Go-Go Implementation

- Requires "torso position" t – tracked or inferred
- Each frame:
  - Get physical hand position h in world coordinate system
  - Calculate physical distance from torso dp = dist(h, t)
  - Calculate virtual hand distance dv = gogo(dp)
  - Normalize torso-hand vector
  - V hand position v = t + dv * th (in world coordinate system)




## HOMER (Hand-centered Object Manipulation Extended Ray Casting) Technique




- Bowman and Hodges, 1997
- Combination of Ray Casting and Go-Go
- User selects an object by ray casting, then the virtual hand manipulates to the object
- Translations done relative to the user's body
- Rotations done around object's origin
- Unlike Go-Go, no maximum arm length (ray casting is infinite)

## HOMER Implementation

- Requires “torso position” t
- Upon selection
  - Detach virtual hand from tracker
  - Move v. hand to object position in world coordinate system
  - Attach object to v. hand (without moving object)
- Get physical hand position h and distance dh = dist(h, t)
- Get object position o and distance do = dist(o, t)
- Each frame:
  - Copy hand tracker matrix to v. hand matrix (to set orientation)
  - Get physical hand position hcurr and distance dh-curr = dist(hcurr, t)
  - v. hand distance
  - Normalize torso-hand vector
  - v. hand position vh = t + dvh * (thcurr)

## Selection Task Evaluation

- Poupyrev, et al. (1998) evaluated ray-casting and Go-Go interaction technique with 5 levels of the distance and 3 levels of the object size
- Bowman, et al. (1999) evaluated ray-casting, image plane and Go-Go technique with 3 levels of the distance and 2 levels of the object size
- Ray-casting and image-plane techniques generally more effective than Go-Go, except that selection of very small objects can be more difficult with pointing
- Ray-casting and image-plane techniques result in the same performance (2DOF)
- Image-plane technique less comfortable

## Object Positioning Task Evaluation

- Ray-casting effective if the object is repositioned at constant distance
- Scaling techniques (HOMER, scaled world grab) difficult in outward positioning of objects: e.g. pick an object located within reach and move it far away
- If outward positioning is not needed then scaling techniques might be effective

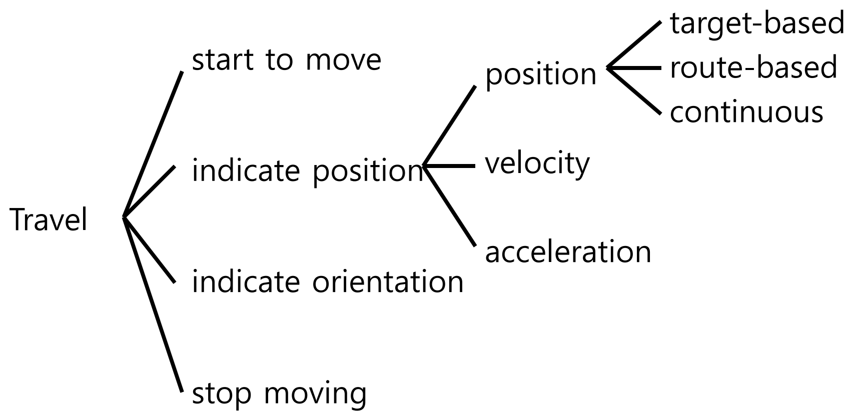
## Object Orientation Task Evaluation

- Setting precise orientation can be very difficult
- Shape of objects is important
- Orienting at-a-distance harder than positioning at-a-distance
- Techniques should be **hand-centered**

## Travel

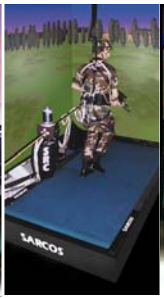
- Goal of travel
  - Setting the position (and orientation) of the user's viewpoint
- Variables affecting user performance in travel
  - Direction or target position
  - Velocity/acceleration
  - Conditions of input (e.g. start, stop, continue)
- Common travel techniques
  - Physical locomotion
  - Steering
  - Target-based
  - Route planning
  - Manual manipulation
  - Travel-by-scaling
  - Viewpoint orientation
  - Velocity specification

## Travel Classification




## Travel Metaphors

- Physical locomotion
  - Walking & walking in place
  - Device simulating walking (e.g. treadmills & bicycles)
  - Other physical motion (e.g. magic carpet, Disney's river raft ride)




Omni-directional treadmill

## Travel Metaphors

- Physical locomotion interfaces

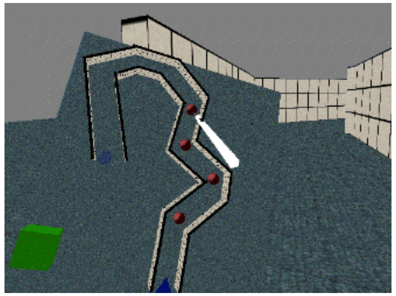
CirculaFloor

Sphere

## Travel Metaphors

- Steering
  - Continuous control of the direction of motion
  - Gaze-directed steering
  - Pointing ("flying" gesture)
  - Physical device (e.g. steering wheel, flight stick)
- Target-based
  - Discrete specification of the end goal of the motion, then the system actually performs the movement in between the two points
  - Point at object
  - Choose from list
  - Enter coordinates

## Travel Metaphors



- Route-planning
  - One-time specification of path (user specifies the end goal and also some intermediate path information)
  - Place markers in world
  - Move icon on map

## Travel Metaphors

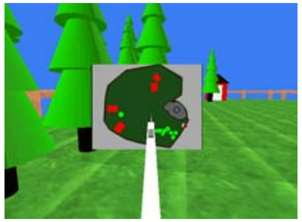
- Map-based
  - User represented by icon on 2D map
  - Drag icon with stylus to new location on map
  - When released, viewpoint animated smoothly to new location
- Manual manipulation
  - Manual manipulation of viewpoint in which the user's hand motions are mapped in some way to viewpoint motion
  - "Camera in hand"
  - Fixed object manipulation

## Gaze-directed Steering

- Move viewpoint in direction of gaze
- Cognitively simple, but doesn't allow user to look to the side while traveling
- Implementation
  - Each frame while moving:
  - Get **head tracker** information
  - Get **gaze direction**
    - by transforming vector [0, 0, -1] in head coordinate system to v=[x,y,z] in world coordinate system
    - Normalize v
  - Translate viewpoint by v * current_velocity

## Map-based Travel

- User represented by icon on 2D map
- Drag icon with stylus to new location on map
- When released, viewpoint animated smoothly to new location



2D map used in Virtual Gorilla Project

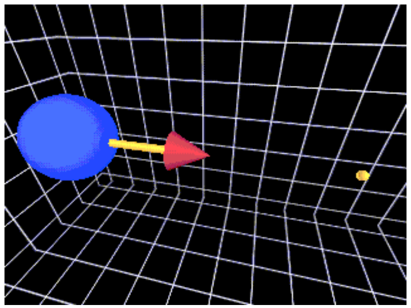
2D map view displayed on a PDA interface in Virtual Harlem

2D map control embedded on top of a table in Tangible Moyangsung

## Map-based Travel

- Implementation
  - Must know:
    - Map scale relative to world: s
    - Location of world origin in map coordinate system: o=(xo, yo, zo)
  - On button press:
    - If stylus intersects user icon, then each frame:
      - Get stylus position in map coordinate system: (x, y, z)
      - Move icon to (x, y, 0) in map coordinate system
  - On button release:
    - Get stylus position in map coordinate system (x,y,z)
    - Move icon to (x, y, 0) in map coordinate system
    - Desired viewpoint: pv = (xv, yv, zv) where xv = (x – xv)/s, yv = (y – yv)/s, z = desired height at (xv, yv)
    - Move vector: m = (xv-xcurr, yv-ycurr, z-zcurr) * (veclocity/distance)
    - Each frame for (distance/velocity) frames: translate viewpoint by m

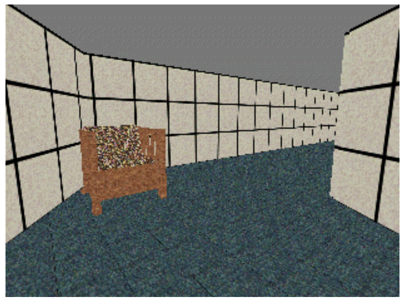
## Travel Task Evaluation



Relative motion task

- Relative motion task - move to a point along the 3D line defined by the pointer
- Steering techniques have similar performance on absolute motion tasks
- Non-head coupled steering better for relative motion

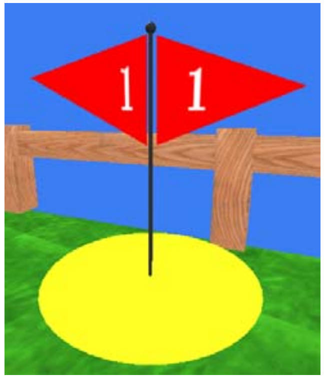
## Travel Task Evaluation



Spatial orientation task

- Spatial orientation task - remember the locations of objects within a maze while moving through it
- “Teleportation” can lead to significant disorientation
- Environment complexity affects information gathering
- Travel and user’s strategies affect spatial orientation

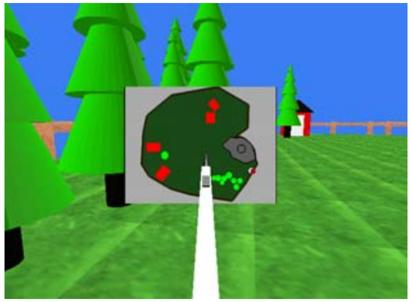
## Travel Task Evaluation




The yellow ring is the radius within which the user had to move to end the task

- A study of "cross-task" techniques (i.e., requiring manipulation for travel) shows that manipulation-based travel techniques efficient for relative motion.
- Manipulation-based techniques not requiring an object efficient for search, but tiring (Bowman99)

## Travel Task Evaluation

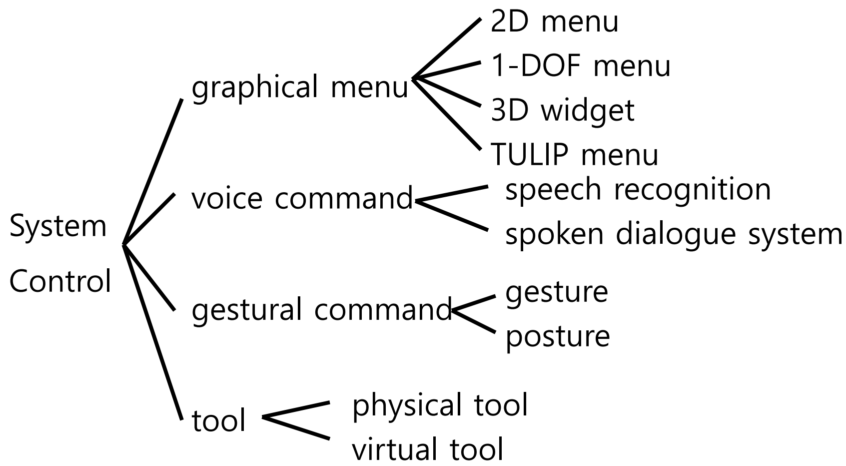


- Steering techniques best for naïve and primed search
- Map-based techniques not effective in unfamilar environments, or when any precision is required

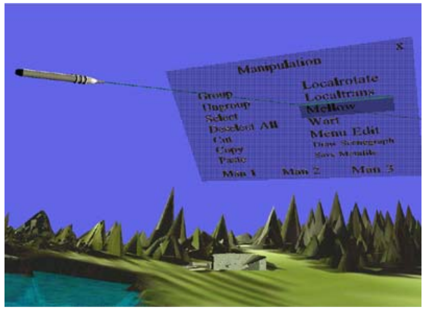
## System Control

- Goals of system controls
  - Catch-all for other types of virtual environment interaction
  - Issuing a command to change the system mode & choose the system state
  - Often composed of other tasks
- Common types of system control techniques
  - Menu systems
  - Voice commands
  - Gestures/postures
  - Implicit control (e.g. pick up new tool to switch modes)

## System Control Classification

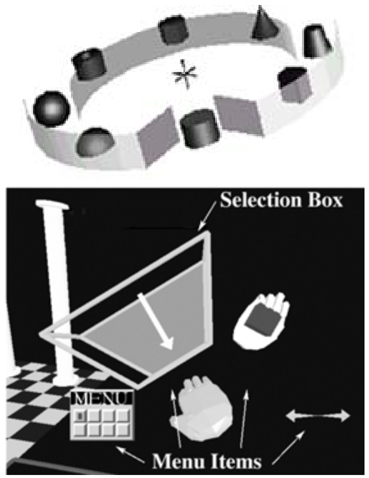


## Floating 2D Menus



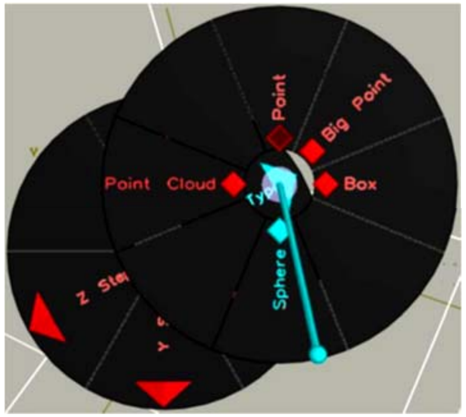

- Group of graphical menus
- Can be seen as 3D equivalent of 2D menus
- Can occlude environment
- Using 3D selection for a 1D task

## 1-DOF menus



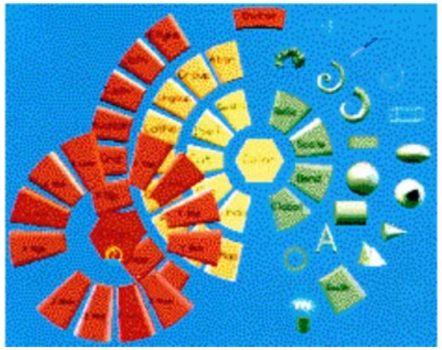

- Menus using a circular object on which several items are placed
- Correct number of DOFs for the task
- Can be put away
- Only 1 menu level at a time
- Can be made in several forms:
  - Ring menus
  - Sundials
  - Spiral menus (spiral formed ring menu)
  - Rotary tool chooser

## Radial Pop-Up Menus



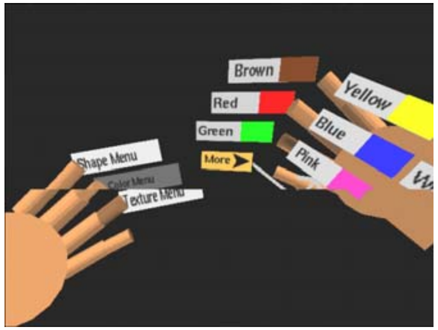

- Menus using a circular Sundial
- Pie menu with 3D selector
- User rotates "Shadow stick" to occlude desired segment

## Fade-Up Menus



- Radial Layout
- Translate cursor to select
- Hierarchical

## TULIP (Three Up Labels in Palm) Menus




- Menu system using pinch gloves
- Non-dominant hand controls menus
- Dominant hand controls menu items
- Only three items available for selection
- Other items appear in sets of three on the palm
- More item linked to next set
- Goal: display all options but retain efficiency and comfort

## Menus Task Evaluation

- Compared with pull-down vs. pen vs. pen-and-tablet menus
- Pen-and-tablet found to be faster
- Users preferred TULIP
- TULIP had higher comfort level

## 2D Interaction in 3D Virtual Environments

- Quite useful for appropriate tasks (match task and input DOFs)
- Can integrate seamlessly with 3D
- If presence is important, the 2D interface should be embedded, not overlaid
- Examples:
  - Interaction on the projection surface or viewplane
  - Using a PDA for input

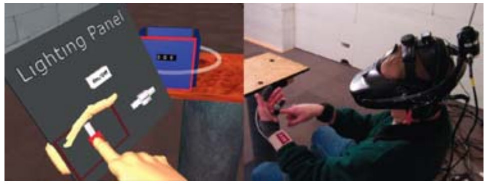
## Constraints

- Artificial limitations designed to help users interact more precisely or efficiently
- Examples are
  - Snap to grid
  - Intelligent objects
  - Single DOF controls

## Snap Dragging in 3D

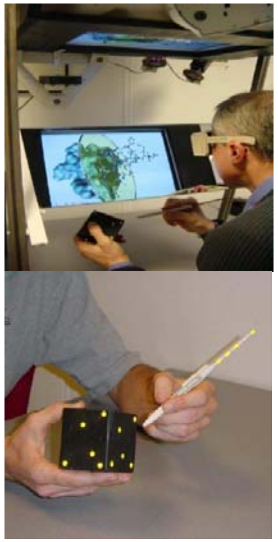
- Beir, 1990
- Desktop (2D) interface
- Positions objects along gridlines
- Allows for arbitrary positioning of object in a 3D world
- Allows objects to be repeatedly placed in the same position precisely.
- Precision limited to granularity of grid lines
- Smaller grid lines lead to more finely tuned positioning

## Passive Haptic Feedback




- Props or "near-field" haptics
- Increase presence, improve interaction
- Examples:
  - Flight simulator controls
  - Pirates steering wheel
  - Elevator railing

## Two-handed Interaction

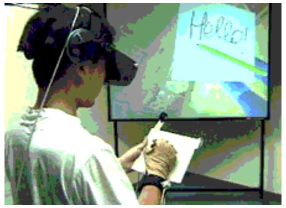


- Symmetric vs. Asymmetric
- Dominant vs. Non-dominant hand
- Design principles:
  - Non-dominant hand provides frame of reference
  - Non-dominant hand used for coarse tasks & Dominant hand for fine-grained tasks
  - Manipulation initiated by Non-dominant hand

## Hand-held Indirect - Pen & Tablet Interaction


- Involves 2D interaction, two-handed interaction, constraints, and props
- Can put away
- Constrained surface for input
- Combine 2D/3D interaction
- Hand-writing input
- Use any type of 2D interface, not just menus

## Hand-held Indirect - Virtual Notepad

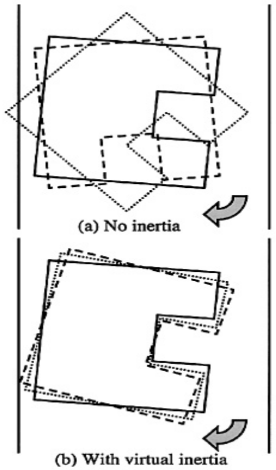


- Tool for writing, taking notes, & adding annotations or comments in virtual environments
- Using a spatially tracked pressure-sensitive graphics tablet from Wacom tech.
- Handwriting as a mean of interacting in immersive virtual environments

## Hand-held Indirect - Transparent Pad

- Transparent prop for the Virtual Table
- The pad is tracked and graphics are projected on the primary display but appear as if they are on the surface and even above the pad
- Tool and object palette
- Window tools
- Through-the-plane tool
- Volumetric manipulation

## Virtual Inertia




- Ruddle and Savage, 2002
- Virtual objects are "weightless" - They can be moved rapidly
- Rapid Movements can be error prone
- Inertia slows the movement of the object.
- Useful when high precision is needed (to avoid collisions)
- Increases minimum time to complete task.
- Not helpful when task is straightforward and easy.

## Reference


- Bowman, D., Kruijff, E., LaViola, J.J., Poupyrev, I., 3D User Interfaces: Theory and Practice.