3D User Interface design for Virtual Reality applications

Which is better: Naturalism or Magic?

The 3 universal tasks:
Navigation, Selection, Manipulation

Based on [3DUI theory & practice 2nd edition 2017], [A2012],
D. Bowman course notes, Virginia Tech. and [CACM sept. 2012]
Why 3D interaction?

• 3D / VE apps. should be useful
  – Immersion
  – Leverage on human natural skills
  – Immediacy of visualization (real-time feedback)

• But, current VE apps have serious usability problems

[D. Bowman]
What makes 3D interaction difficult?

• Spatial input
• Lack of constraints
• Lack of standards
• Lack of tools
• Lack of precision
• Fatigue
• Layout more complex
• Perception conflicts
Two approaches: naturalism vs magic

• Naturalism (or *interaction fidelity*):
  – use natural movement and body parts to make the VE work exactly like the real world
    • walking
    • full-body action used partially (sport games) or totally (to drive an avatar posture or training)

• Magic: give user new abilities
  – Perceptual
  – Physical
  – Cognitive
Naturalism vs magic (2)

• The level of naturalism depends on the interaction technique and the application:
  – steering wheel metaphor:
    • is natural for driving simulator
    • is not for shooting a virtual basketball [B2012]

• Some actions in VR/game have no natural equivalent, e.g. teleportation
• in-between case: mapping a bicycle riding movement with hand and arm movement, or running with only the arm movements [Disney Pixar Incredibles game]
Naturalism vs magic [B2012] (3)

- Are 3D UIs inherently more natural than traditional UIs?

- Should we strive primarily for high-level of naturalism, or are other interaction design criteria more important (next slide) ?

- Does a more natural interface result in better performances, greater user engagement, or increased ease of learning?

- When the most natural mapping cannot be used, is it better to use a moderately natural technique, or are traditional techniques more appropriate?
Interaction design criteria

- **Performance**
  - efficiency, accuracy, productivity

- **Usability**
  - ease of use, ease of learning, user comfort

- **Usefulness**
  - users focus on tasks, interaction helps users meet system goals, transfert of skill in the real world.
Components of 3D interactions

The three universal tasks:
- **Navigation**
- **Selection**
- **Manipulation**

Other 3DUI components
- System control
- Symbolic input
- Constraints
- Passive haptic feedback
- Two-handed interaction
The **Navigation** component

- Most common task
- is composed of:
  - Travel: the physical movement from place to place
    - Natural travel (walk) is not always the best
    - Steering a vehicle
    - Target-based: choose from a list, point at object, etc
  
  - Wayfinding: where am I? where do I have to go? How do I get there?
    - Map-based, e.g. GPS metaphor
Travel: naturalistic techniques

• walking and turning the head is obviously natural but technically difficult
  – Head-Mounted-Display (HMD) with 6D tracking of the head and sufficient space
  – without HDM -> constrained by the display location

• redirected walking [Razzaque PhD 2005 UNC]
  – tricks the brain about the actual walking direction
  – very active research field but still requires a significant walking surface
  – Ex: [Q18] takes advantage of blindness during saccades to manipulate the orientation

https://youtu.be/eDk4HrEtGrM

• walking-in-place [Usoh et al,1999]
• dedicated interfaces (next slides)
Travel naturalistic interfaces (1)

Ground-referenced haptic device: bidirectional treadmill [EU Project Cyberwalk]

**Goal:** offer omnidirectional navigation through effective 2D body displacement instead of resorting to a metaphor.

**Concept:** synchronized linear belts $C_1$, $C_2$, ..., $C_N$, are displaced with a common velocity $V_x$ in the blue direction, which is orthogonal to the individual velocities $V_y$ (orange) of each belt. Hence it is possible to synthesize a combined velocity with any direction (green) in the plane.
Travel naturalistic interfaces (2)

System Architecture:

• The control always pulls the walker towards the platform center \((x_0, y_0)\).
• The combined walker + platform movement is used to update the viewpoint in the virtual scene.
• The user free displacement is measured with a VICON system.
• Given the current platform movement, user location, velocity \(V_d\) and estimated acceleration, the Observer component determines an update of the platform velocity to bring the user back in the middle without sudden change.

Results:

• Max \(V_x\) or \(V_y\): 1.4 m/s
• Max combined: 2 m/s
• Max acc. along y (a belt): 1.3 m/s²
• Max acc. along x (all belts): 0.25 m/s²

Issue:

• drift in case of sudden user stop
• walking on a treadmill is not natural walk
Travel naturalistic interfaces (3)

concept/proto evolving since 2015:
• infinadeck.com
• sold to labs / price range: 40-60 KUSD

Updated tradeoff:
• low inertia but less space for navigating
• circular safety protection

https://youtu.be/RyFof9GpWac
Naturalistic navigation interfaces (4)

• Disney prototype for (slow) multi-user locomotion: the Holotile [2024]
  • floor composed of 100s of (motorized) miniature treadmills.
  • Omnidirectional for multiple simultaneous users

• Limitations:
  • prototype surface is limited but the principle seems to scale well to bigger surfaces
  • current allowed velocity seems low
  • cost is likely to be high => affordable only for theme parks & industry

https://www.youtube.com/watch?v=68YMEmaF0rs&t=2s
Naturalistic navigation interfaces (4)

• **Locomotion tracking with virtusphere**
  • An omni-directional free-rolling sphere
  • 10 feet diameter (~3m)
  • To be used with head-mounted display for walkthrough applications, games, etc...

• Limitations:
  • balance control on spherical floor,
  • sphere inertia at fast speed
  • mechanical sound of the movement,
  • small field of view of HMD
Naturalistic navigation interfaces (5)

- **Locomotion tracking with Cyberith (Austria)**
  - An omni-directional interface with sensor in the base plate, pillars and ring
  - flat slippery surface => sliding movement
  - Use overshoes
  - Can jump or seat too
  - Price ~6KEURO
  - Cyberirth2 integrates a floor that can automatically tilt so as to create a slope in the walking direction to ease the performance of the (slippery) walk

[http://www.cyberith.com/]
Travel **magic** techniques

- Side note on coordinate systems and orientation control
  - No standard convention regarding handeness
    - **UNITY is left-handed**, vs right handed (most graphic libraries)
  - No standard regarding the vertical direction
    - **UNITY is Y-Up** (vs Z-Up in CAD-CAM)
  - Some agreement on the choice of angles to control head, body, hand orientation (same as a plane)
    - **Yaw** (turn around the vertical axis)
    - **Pitch** (forward/backward inclination)
    - **Roll** (less used but see teleportation example)
Travel magic techniques (2)

• **Steering:** (like in most games / driving metaphor)
  – input device provides front, back, left, right constant speed
    • handheld device, or leaning on wiiBalance (inspired by [Wells96])
    • "human joystick": user stepping is mapped into oriented velocity
  – variants regarding which direction is considered *forward*
    • towards the center of the display vs device pointing direction
    • beneficial to separate viewing direction from travel direction

• **Target-based / Teleportation / Dash transmission**
  – point in 3D with ray & jump (instantaneous or fast blurred movement = dash)
  – specify a point of interest from a list (easier but constrained if predefined targets)

• **Map-based** (with additional 2D map)
  – manipulate user icon on the map
Travel magic techniques: teleportation

The **Yaw** angle around the vertical axis defines the radial pointing direction.

**Pitch** angle

**Roll** angle can be used to define the target radial direction [F2019]+video

Recent parabolic curve selection metaphor
- less fatiguing for pointing a target location on the floor
• Seated steering with the feet: 3d Rudder

  – Dedicated to navigation; frees the hands for other actions
  – Low inertia, relatively precise input device (~foot mouse)
  – 3 degrees of mobility in rotation (with low amplitude)

Possible steering mapping:
- Yaw to direction changes (turning)
- Pitch to front-back translation (car)
- Roll to side translation (walk)

Other mapping are possible for generating events from short movements
Naturalistic/Magic travel technique

• **Grab the Air [M1995]**
  - grab the world and pull yourself through it (or pull it to yourself)
    • naturalistic inspiration: crawling, pulling a rope, swimming, climbing, browsing a book
  - can be achieved with one or two hands
  - can be combined with scaling
  - rotation should be ignored
  - activate through explicit trigger or gesture recognition
Navigation design guidelines

– There is no unique technique that suits all needs

– The simpler the better
  • Target-based technique for motion to an object
  • Steering technique for search/exploration
  • involve low inertia

– Provide transitional motion to maintain awareness of space (teleportation does disorient users)

– Naturalistic technique is best if the goal is training a real-world task, or to increase presence
The **Selection** component

- specifying one or more objects from the environment
- Goal:
  - indicate action on object (e.g. delete, duplicate, etc.)
  - Make object active, travel to object, ...

- Natural metaphors:
  - *touching* or *pointing at* with a virtual hand
  - *touching* requires travel if target not within arms' reach
  - *pointing at* with *ray/cone casting* is still considered natural
    - ray built from hand/device/head orientation
    - or from eye-to-finger direction (Image Plane)
Selection by ray-casting

Ray casting technique:
- get world hand/device/head pos & orientation
- compute objects distances to ray segment
- continuously highlight closest visible object to ray
- select the closest one when a dedicated event is produced by the user (e.g. button press on google cardboard HMD or simply a timeout event when an object has been the closest for $X$ seconds).

Weakness:
- difficult to select small/far objects
- target object can be occluded
selection by occlusion or framing (image-plane technique)

Ray casting from eye through the finger tip [Pierce 1997]:

• get world head pos/orient -> eye position
• get hand pos/orient -> finger tip position
• compute objects distances to "eye-through-finger" ray
• highlight/select visible object closest to ray
  
  <=> the finger tip is occluding the object in the image plane

Alternate approaches:
• use 2 fingers or 2 hands to frame the desired object
Magic selection technique

extended "hyper-natural" touching or pointing metaphors

- ex: the Go-Go technique [Poupirev96]:
  - compute the torso-to-hand vector
  - apply the scaling factor
    - 1:1 scaling factor near the body
    - non-linear scaling above a threshold

![Diagram showing motor space, control space, scaled hand reach, normal hand reach, and torso CS with hand CS in the world CS context.](image-url)
Magic selection technique

* World in Miniature (WIM)
  - scale-down the model to enhance user reach ability [Stoakley 1995]
  - remove part of the model (cut-aways) to ease the WIM visualization [Andujar 2010]
The **Manipulation** component

- modify object properties: position, orientation, scale, shape, color, texture, behavior, etc.
  - For positioning: Virtual hand, ray casting, scaling
  - For orienting: the object should be hand-centered
    - apply the hand (re)-orientation to the manipulated object

- **Haptic** feedback *(future lecture)* is required for highly specialized and high risk training *(surgery)*

- Magic technique: miniature proxy copy of objects
Magic manipulation technique

• HOMER (Hand-centered Object Manipulation Extending Raycasting) [B2005]
  – similar to the Go-Go technique:
    • select with the ray
    • manipulate with the hand
  – easy selection & manipulation
  – large distances
  – hand-centered orientation is easy
  – hard to move objects away

• the Clutching issue:
  – clutching occurs when a manipulation cannot be achieved in a single motion. The object must be released and regrasped to complete the task.
  – also means: relocate the working space within a more comfortable reach space to be able to complete a manipulation task. -> see image on the right
Selection & Manipulation design guidelines

– How to validate a selection and report the event?
  • provide feedback: graphical, audio, tactile
    – highlight candidate objects for selection
    – confirm user decision when a candidate object is chosen

– Display a virtual hand as a position/orientation ref

– selection should not be activated while manipulating
  • Beware of the « Midas touch »!

– Minimize clutching in manipulation
  • grasp-release-regrasp- etc...

– what happen after manipulating?
  • remain there ? snap to grid ? fall gently ?
Benefits & Limitations of Naturalism (1)

[Bowman, MacMahan, Ragan, CACM Sept 2012]

Benefits and limitations of natural 3D interaction for particular user tasks, taken from our prior research.

<table>
<thead>
<tr>
<th>Task</th>
<th>Benefits of naturalism</th>
<th>Limitations of naturalism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viewpoint rotation</td>
<td>Users prefer physical turning.</td>
<td>Users prefer virtual turning to a combination of physical and virtual turning.</td>
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<tr>
<td>have better performance</td>
<td>Natural turning techniques have better performance than virtual turning.</td>
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<td>than virtual turning for</td>
<td>Visual search.</td>
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<td>Hyper-natural techniques enhance users' abilities.</td>
<td>Hyper-natural techniques often reduce precision.</td>
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<tr>
<td>Vehicle steering</td>
<td>It is possible to design hyper-natural techniques that feel natural and have high levels of precision.</td>
<td></td>
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<tr>
<td>Aiming</td>
<td>Higher levels of interaction fidelity can be more fun for users.</td>
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<td>mouse-based techniques.</td>
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<tr>
<td>Multiple tasks</td>
<td>High levels of interaction fidelity, when paired with high display fidelity, can have</td>
<td>High levels of naturalism may not be beneficial if the overall interface is unfamiliar.</td>
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Benefits & Limitations of Naturalism (2)

- Traditional interaction interfaces (2D/desktop/mouse, joystick, etc...)
  - are limited in their potential for naturalism
  - but have minimal HW and sensing requirements and are well established & ubiquitous
- 3D Natural interfaces can be seen as more fun & engaging

- Naturalism is most effective when very high level of fidelity can be achieved and when the user interface is familiar to the user
  - can provide a significant advantage
  - already well-mastered skills
  - ex: travel with head tracking ->

- Hypernatural techniques outperform natural ones. However they may reduce presence, the understanding of actions, and the ability of transfer to real world
Components of 3D interactions

The three universal tasks:
- Navigation
- Selection
- Manipulation

Other 3DUI components
- System control
- Symbolic input
- Constraints
- Passive haptic feedback
- Two-handed interaction
System control

• Sometimes seen as a “catch-all” for 3D interaction techniques other than travel, selection, & manipulation

• Issuing a *command to*:
  – Change the system state
  – Change the system mode (*interpretation of user input*)

• Broad variety of tasks
Floating menus

• Can occlude environment
• Using 3D selection for a 1D task

• Other types:
  – Rotating menu
  – TULIP (3 items)

• Body-centered enhance usage [Mine97]
Gestural commands

- Can be “natural”
- limited **vocabulary**
- Fuzzy recognition issues
  - HMM [Be2009] & ML
- Gesture as command - doesn’t mimic our use of gestures in the real world
- Tradeoff between direct control/fatigue [O2014]
- pen-based sketch can be powerful

- More appropriate in multimodal interfaces *(provide more than one technique, e.g. voice)*
System control design guidelines

- Don’t disturb flow of action
- Use consistent spatial reference
- Allow multimodal input (redundancy)
- Structure available functions hierarchically
- Prevent mode errors by giving feedback
Symbolic input

- Communication of symbols (text, numbers, and other symbols/marks) to the system
- Is this an important task for 3D UIs?

Keyboards: miniature, low key-count, tracked, etc.

Pen-based: pen stroke recognition

Gestures: sign language, numeric, etc

Speech: single char, whole words, general

[Gruber 2018]
Constraints

• Artificial limitations designed to help users interact more precisely or efficiently

• Examples:
  – Snap-to grid
  – Intelligent virtual objects / tools
  – Single Degree Of Freedom controls
    • projected movement in 1D (translation or rotation)
Passive haptic feedback/Tangible

• Tangible interfaces
• Props or “near-field” haptics
• Examples:
  – Flight simulator controls
  – Torch and tomb (above right)
  – Pirates’ steering wheel, cannons =>
• Increase presence
• Improve interaction

[concept of Tokyo Disney attraction, IEEE Comp. 12]
Two-handed interaction

- Symmetric vs. Asymmetric
- **Dominant** vs. **Non-Dominant** hand
- Guiard’s principles
  1) ND hand provides frame of reference

[Scott Mackenzie 2003]
Two-handed interaction (2)

• Guiard’s principles

2) ND hand used for coarse tasks,
   D hand used for fine grained tasks

3) Manipulation initiated by ND hand

[Ken Hinkley et al 1999]
Two handed interaction (3)

• Combining gesture recognition and continuous input
  • Allows surgeon to explore patient image stack data while operating in a sterile environment [O2014]
  • ND hand for mode selection
  • D hand for continuous control of image parameters
  • Currently experimented clinically

• Pen & tablet
  • Involves 2D interaction, two-handed interaction, constraints, and props
  • Example: Google Tilt Brush with HTC Vive HMD
Conclusions

• Usability one of the most crucial issues facing VE applications, including ergonomy (fatigue)

• Implementation details critical to ensure usability

• Simply adapting 2D interfaces is not sufficient

• Strengths of 3D interactions:
  – complex 3D data exploration
  – professional tool gesture /protocole training in 3D
  – touchless interaction (e.g. surgeon, driving,...)
  – simple cases of Rehabilitation & ExerGame
More work needed on...

• System control performance (e.g. latency)
• Symbolic input
• Mapping interaction techniques to devices
• Integrating interaction techniques into complete UIs
• Development tools for 3D UIs

• main conferences: ACM CHI, IEEE 3DUI & VR
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[R2005] Razzaque S., Redirected walking ,PhD UNC 2005
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