3D Interaction Techniques

Hannes Kaufmann

Interactive Media Systems Group (IMS)
Institute of Visual Computing & Human-Centered Technology

Based on material by Chris Shaw, derived from Doug Bowman’s work
Why 3D Interaction?

Application

Input Device & Tracking

Output Device
3D Interaction Techniques

- Methods used to accomplish a given task via the interface
  - Hardware components: Input & Output devices
  - Software components = *control-display mappings*: translating information from input devices to system actions -> display to user
The Interface Challenge – The best of both Worlds

- **Naturalism**: make VE & interaction work exactly like real world.
- **Magic**: give user new abilities
  - Perceptual
  - Physical
  - Cognitive
The Interface Challenge

- Will the **cognitive overhead** required to use the interface **distract** users from the intended tasks and goals?
Goals of Interaction Design

• Performance
  – efficiency
  – accuracy
  – productivity

• Usability
  – ease of use
  – ease of learning
  – user comfort

• Usefulness
  – users focus on tasks
  – interaction helps users meet system goals
• But, most current VE apps either
  – are not complex interactively, or
  – have serious usability problems

What makes 3D Interaction difficult?

• Spatial input
• Lack of constraints
• Lack of standards
• Lack of tools

• Lack of precision
• Layout more complex
• Fatigue
Universal Interaction Tasks

- **Selection**: picking object(s) from a set
- **Manipulation**: modifying object properties (esp. position/orientation, shape, color, ...)
- **Navigation**
  - Travel – motor component
  - Wayfinding – cognitive component; decision making
- **System control**: changing system state or mode
- **Symbolic input** (covered in Input Devices Part 1)
- **[Modeling & Other tasks]** (create and modify 3d Obj.)
Selection & Manipulation

Goals of Selection:

• Indicate action on object
• Make object active
• Travel to object location
• Set up manipulation
Isomorphic vs. Nonisomorphic

• Isomorphic:
  – strict, geometrical 1:1 correspondence between physical <-> virtual world
  – Most natural
  – Imitates physical reality and its limitations

• Nonisomorphic:
  – Magic virtual tools that extend working volume or arm length
  – Depends on application
  – Majority of manipulation techn. nonisomorphic
Selection performance

• Variables affecting user performance
  – Object distance from user
  – Object size
  – Density of objects in area
Common Selection Techniques

• Pointing
  – Touching with virtual hand/pointer
  – Ray casting
  – Cone casting (Flashlight)
  – Aperture
  – Two-handed pointing
  – Image plane

• Naming (speech rec.)
Enhancements to Basic Techniques

• Arm-extension
  – Go-Go Technique (mapping)
  – Fishing-Reel Technique (additional device: distance)

• World in Miniature (WIM)
  – Select icon-like objects
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
Selection: Task Decomposition

Selection

Object indication
- object touching
- pointing
- indirect selection
- ...

Confirmation of selection
- button
- gesture
- voice

Feedback
- graphical
- tactile
- audio
- text…
Evaluation: Selection Task

• Ray-casting and image-plane generally more effective than Go-Go
  – Exception: selection of very small objects can be more difficult with pointing

• Ray-casting and image-plane techniques result in the same performance (2DOF)
Goals of Manipulation

• Object placement
  – Design
  – Layout
  – Grouping
• Tool usage
• Travel

Variables affecting user performance
  – Required translation distance
  – Amount of rotation (avoid clutching)
  – Required precision of placement
Manipulation Metaphors 1

- Simple virtual hand
  - Natural, easy placement
  - Limited reach, fatiguing, overshoot
  - 1:1 position mapping

- Ray casting
  - Little effort required
  - Exact positioning and orienting very difficult (lever arm effect)

- Indirect depth control (e.g. mouse wheel)
  - Infinite reach, not tiring
  - Not natural, separates DOFs
HOMER technique

Hand-Centered Object Manipulation Extending Ray-Casting

- Select: ray-casting
- Virtual hand moves to object
- Manipulate: hand
Manipulation Metaphors 2

• HOMER (ray-casting + arm-extension)
  – Easy selection & manipulation
  – Expressive over range of distances
  – Hard to move objects away from you

• Scaled-world grab
  – Selection by image plane
  – World scaled down around virtual hand
  – Easy, natural manipulation
  – Hard to move objects away
Image plane interaction

- Selection and manipulation
- Different gestures
Manipulation Metaphors 3

• World-in-miniature
  – All manipulation in reach
  – Doesn’t scale well for large environments
  – Indirect

• Voodoo Dolls
  – Two-handed (2 pinch gloves)
  – Create “dolls” by image-plane technique
  – Indirect manipulation
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
Evaluation: Positioning Task

• 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
Evaluation: Orientation Task

• 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
Manipulation notes

• No universally best technique
• Constraints and reduced DOFs
• Naturalism not always desirable
• If VE is not based in the real, design your environment for optimal manipulation
Navigation

• Travel: motor component
• Wayfinding: cognitive component
Travel

- Motor component of navigation
- Movement between 2 locations
- Setting the position (and orientation) of the user’s viewpoint
- Most basic and common VE interaction technique
  - used in almost any large-scale VE
- Travel often directly controlled in AR!
  - Viewpoint controlled by user
Travel Tasks

• Exploration
  – travel which has no specific target
  – build knowledge of environment

• Search
  – naive: travel to find a target whose position is not known
  – primed: travel to a target whose position is known
  – build layout knowledge
  – move to task location

• Maneuvering
  – travel to position the viewpoint for a task
  – short, precise movements
Traveling metaphors 1/2

- **Steering** metaphor: continuous specification of direction of motion
  - gaze-directed
  - Pointing (the “fly” gesture)
  - physical device (steering wheel, joystick)
  - Examples: Beckhaus – chair (video)
- **Target-based** metaphor: discrete specification of the goal location
  - point at object
  - choose from list
  - enter coordinates
  - Example: Reitmayr - Outdoor
Traveling metaphors 1/2

- **Route-planning** metaphor: one-time specification of path
  - place markers in world
  - move icon on map

- **Manipulation** metaphor: manual manipulation of viewpoint
  - “camera in hand”
  - fixed object manip.
    - Example: film camera movement
  - Grabbing in the air technique (2 gloves)
Evaluation results (by Bowman)

- “Teleportation” can lead to significant disorientation
- Environment complexity affects information gathering
- Travel IT and user’s strategies affect spatial orientation
Evaluation results

• Steering techniques best for naive and primed search
• Map-based techniques not effective in unfamiliar environments, or if any precision is required
“Natural” travel metaphors

• Walking techniques
• Treadmills
• Bicycles
• Other physical motion
  – VMC / Magic carpet
  – Disney’s river raft ride
  – Simulation of flying
Real Walking

- **Real Walking** in virtual worlds
  - Enhances sense of presence
  - Enhances perception of size and distance
  - Focuses attention
  - Improves task performance
But:
- Limits size of virtual environment to size of tracking space

Have to make the user believe to walk in a much larger space
Redirected Walking

- Same benefits as real walking
- Extends the possible size of the VE

Different methods:
- Way points
- Distractions
- Gains:
  - Translation
  - Rotation
  - Curvature
Change Blindness

- Changes are applied while the user is distracted

- Cyclic paths possible
Our approach:
Flexible Spaces

- Real world rules do **not** apply
- Real walking
- Natural constraints
- Focus on virtual content
- Bigger distance between the rooms – more overlap
- Procedural layout generation
Spatial Perception in Virtual Reality

• Self-overlapping rooms
  – *Simple layouts prevent spatial compression*
  – *Less virtual space fits in the real room*

• How people perceive the space?
  – *Where is the room you came from?*

• What parameters/layouts are more efficient?
  – *Same arrangement of rooms*
  – *Different corridors*
  – *Multiple parameters: corners, distances, curvature, walking direction...*

---

K. Vasylevska, H. Kaufmann, *Towards Efficient Spatial Compression in Self-Overlapping Virtual Environments*, IEEE Symposium on 3D User Interfaces (3DUI), March 2017, Los Angeles, CA, USA, *Best Paper Award*
Navigation: Myths

• There is one optimal travel technique for VEs.
• A “natural” technique will always be better than another technique.
• Desktop 3D, workbench, and CAVE applications should use the same travel ITs as HMD-based VEs.

WRONG !
Navigation: Design Guidelines

• Make simple travel tasks simple (target-based techniques for motion to an object, steering techniques for search).

• Provide multiple travel techniques to support different travel tasks in the same application.

• Use transitional motions (not teleportation!) if overall environment context is important.
System control

• Catch-all for other types of VE interaction
  – Issuing command
  – Changing mode
  – Choosing tool

• 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)
Floating menus in 3D

- Requires user knowledge
- Can occlude environment
- Using 3D selection for a 1D task
- Can be difficult to find
- Better than Heads-up-Display (HUD) but still very bad design – AVOID!
Pop-Up Menus - Radial

• Sundial
  – Pie menu with 3D selector
  – User rotates “Shadow stick” to occlude desired segment

• Example: iOrb
1 DOF menu

• Correct number of DOFs for the task
• Can be put away
• Only one menu level at a time
Pen & Tablet Interaction
Pen & Tablet Interaction

**Tablet** = real object:
- Can put away
- Handwriting input possible
- Can be used as a clipboard
- Constrained surface for input
- Usability: People are used to 2D input

- Combine 2D/3D interaction
- Use any type of 2D interface, not just menus

**Pen:**
- Direct manipulation
- [Magic Lens Metaphor](#)
2D interaction in a 3D world

- Quite useful for appropriate tasks
- Can integrate seamlessly with 3D
- If presence is important, the 2D interface should be *embedded*, not *overlaid*
Applications - Examples

- Real applications always **combine** interaction techniques

Examples:
- Projection Screen Interaction e.g. ArsBox
- Volumetric Displays e.g. Perspecta3D
- ARToolkit Interaction: Mozart MagicBook
- Handheld HMD
- Outdoor AR modeling: Tinmith
Philosophies of Interaction Design

• Artistic approach
  – Intuition about users, tasks
  – Heuristics, metaphors
  – Aesthetics
  – Adaptation

• Scientific approach
  – Formal analysis
  – Formal evaluation
  – Performance requirements

Own Experience:
Combination of both gives best results!
AR
Interaction Techniques
# IT Comparison VR – AR

<table>
<thead>
<tr>
<th></th>
<th>Virtual Reality / 3DUI</th>
<th>Augmented Reality</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Selection</strong></td>
<td>Raycasting, virtual hand, world scaling</td>
<td>same</td>
</tr>
<tr>
<td><strong>Manipulation</strong></td>
<td>Everything can be manipulated.</td>
<td>Distinction between real / virtual objects</td>
</tr>
<tr>
<td><strong>Navigation</strong></td>
<td>Viewpoint can be controlled freely.</td>
<td>Only passive hints</td>
</tr>
<tr>
<td><strong>System control, Symbolic input</strong></td>
<td>Menus, voice, gestures</td>
<td>same</td>
</tr>
</tbody>
</table>
Manipulation

• Direct VR Style
• Augmented Environments / Surfaces
• Tangible Interaction
Augmented Surfaces

• Touch leads to surfaces
• Often using projection (e.g. Digital Desk [Wellner93])
• Treat paper and electronic documents as the same
Touch Tables
Augmented Surfaces: Pros/Cons

• Good
  – Intuitive interaction
  – Same modalities for real + virtual objects

• Bad
  – only 2D
  – creates a spatial seam
Projected AR Environments 1/2

- MIT 6th Sense
- Microsoft Omni Touch
Projected AR Environments 2/2

- Microsoft Augmenting Indoor Spaces
Tangible Interaction

- Use real placeholder to manipulate virtual content
- Full 6DOF manipulation
- Popularized through ARToolkit

ReacTable
Tangible User Interaction

• Virtual Buttons
• Toggle buttons using Markers
• Proximity
Tangible: Tiles

- Tangible markers
  - data
  - operations
- Integration with real world
  - annotations
- See through HMD
- Collaborative
Luminous Tangible Workspace

• Urban planning tool
  – Tangible building models
  – Interactive simulations
    • Wind
    • Sunlight / shadows
    • Traffic patterns
Navigation Support

• Direct Overlays
  – Information registered to Environment
  – Easy to interpret
  – Small field of view
  – No overview no knowledge build-up

• Map integration
  – Provides overview
  – May require mental rotation to align
  – Occludes display
Example Navigation Apps

• Wikitude Drive

• ACrossAir Nearest Tube
Maps

- Map and spatial knowledge
- Rules for good map design
  - Provide you are here marker
  - Provide grid
  - Choose either north-up or forward-up map
  - Try mixing local and global maps
- Often as World-in-Miniature
Examples: Gestural Interaction

• Oblong Industries

• Movies / Visions
Interaction Techniques for Smartphones / Tablets
Point, Grab, Move, Release

- Relative to target 2D

- Relative to „world“ 3D
Intuitive Interaction for Handheld AR

**DrillSample**
- Trigger Ray-Casting
- Use built-in IMU to rotate DrillSample

**3DTouch**
- Projected Line

**HOMER-S**
- Selection
- Upon Selection
- Move & Rotate
- Upon Release
- Release
Layered Pie Menus

• Mobile device movements relative to head/target are used for menu selection
• Head movements relative to device

Mixed Interaction Space with face tracking
Social AR – A Vision?

- Users create content & model the world
  - “YouTube” of AR
  - Supported with automated methods
- Situated social networks
- AR 2.0
- Same Place / Different Time
Literature

• 3D User Interfaces – Theory and Practice (2nd edition)
Thank you for your attention!

Questions, Comments?