3D Interaction Techniques

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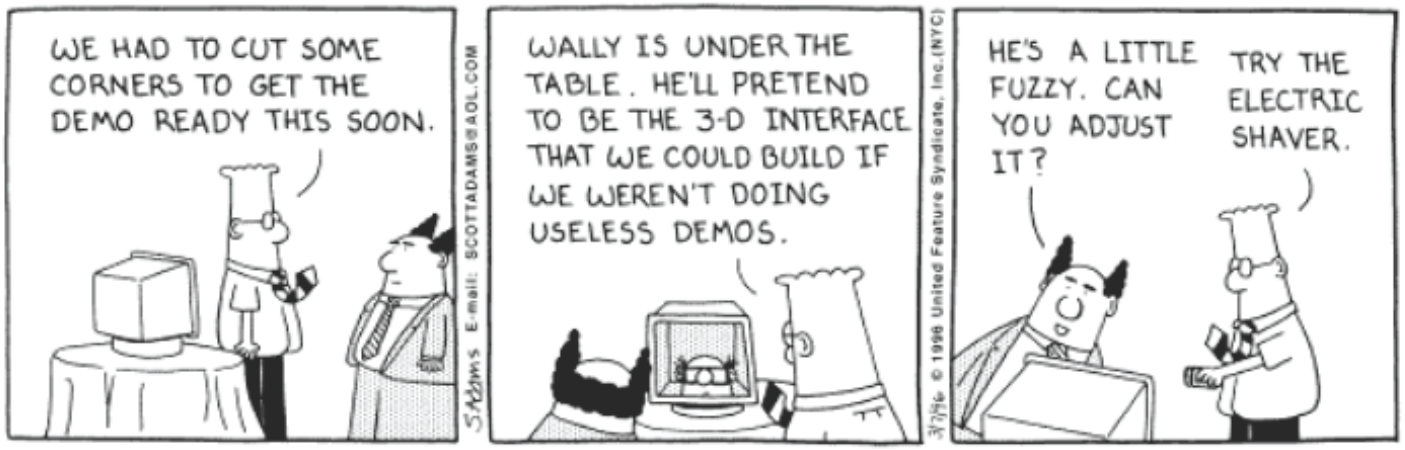
Based on material by Chris Shaw, derived from Doug Bowman's work



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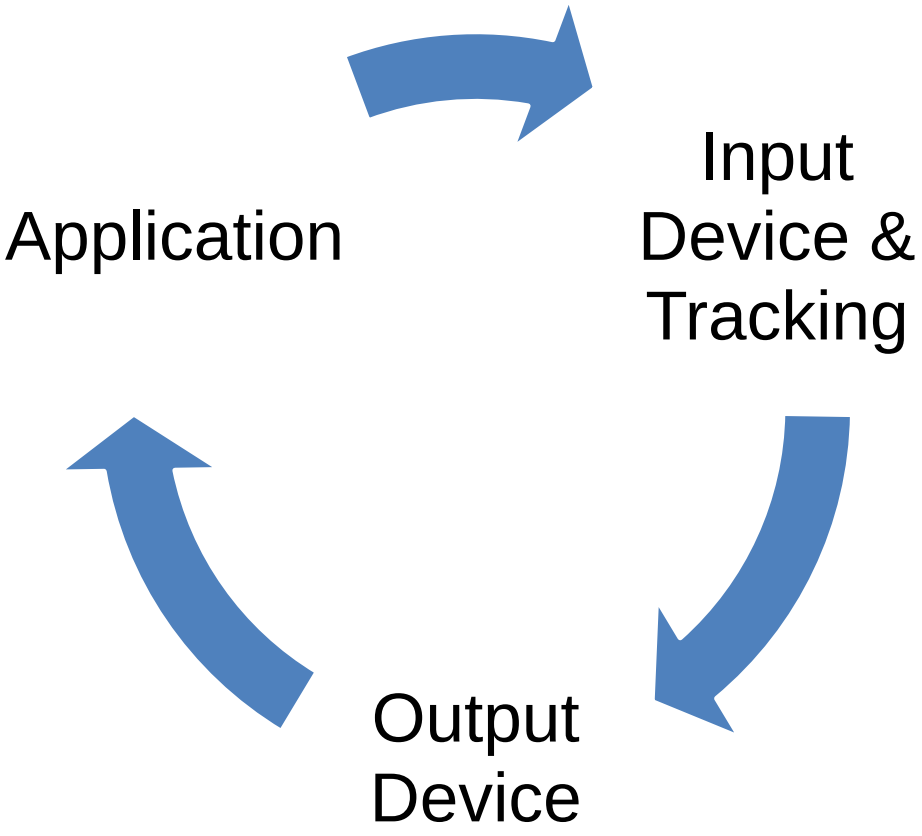
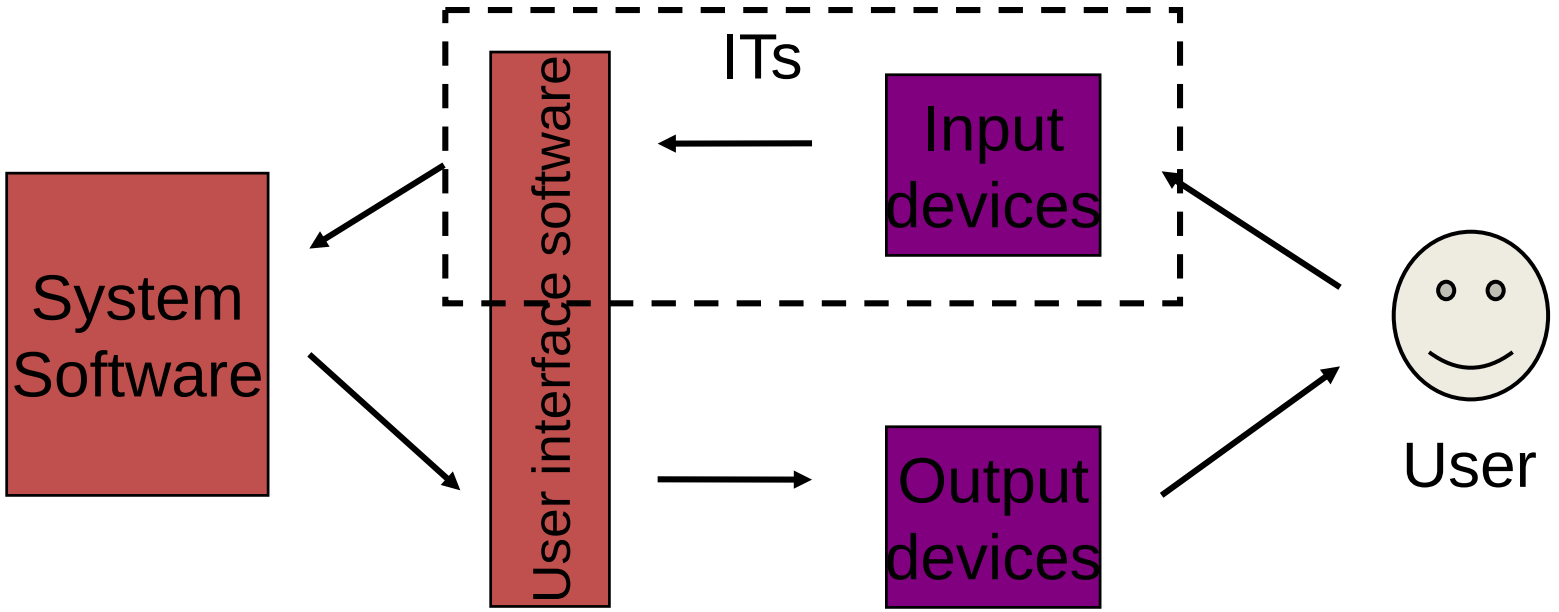
Why 3D Interaction?



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

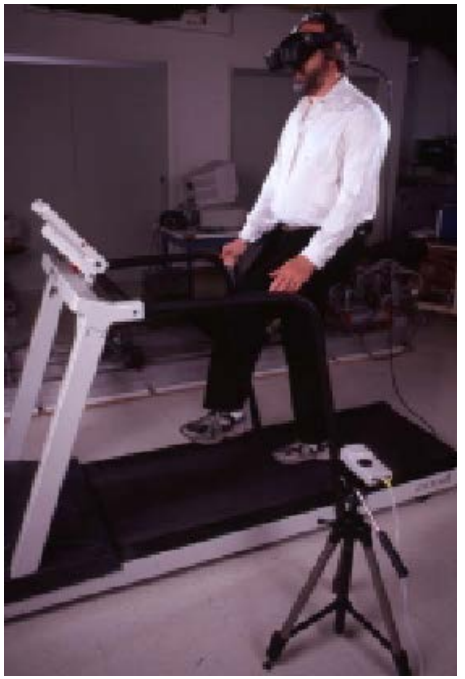


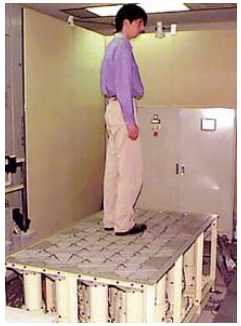
The Interface Challenge – The best of both Worlds

- 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

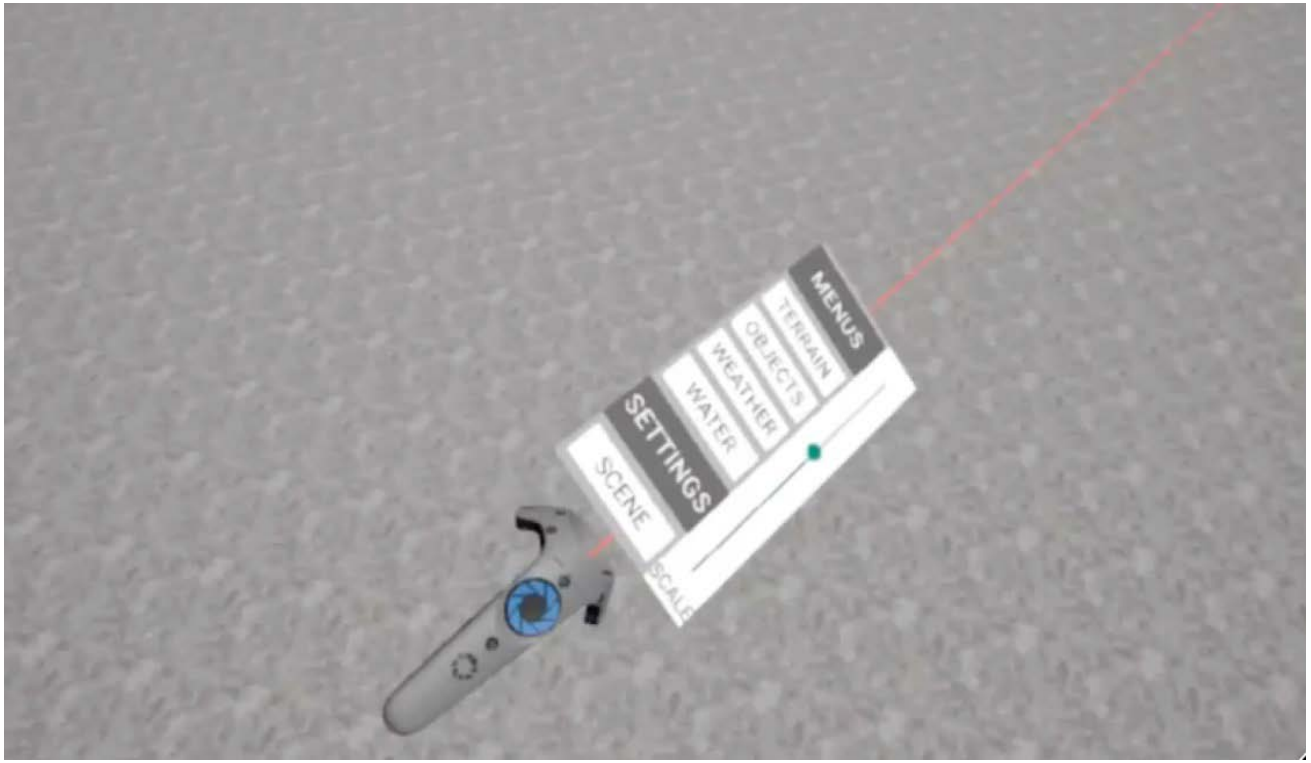
What makes 3D Interaction difficult?

- Spatial input
- Lack of constraints
- Lack of standards
- Lack of tools
- Lack of precision
- Layout more complex
- Fatigue

Natural Interface Concept: World Builder

https://www.youtube.com/watch?v=FheQe8rflWQ&t=43s

World Builder Today (Available on Steam)



https://www.youtube.com/watch?v=65u3W7wjXs0

Vision vs. Reality – Still Work to Do..

- Natural interface
- Gesture, speech
- Wide field of view
- Full body input

- Limited input
- Wireless, limited range tracking
- (Reduced field of view)
- 2D GUI in VR

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

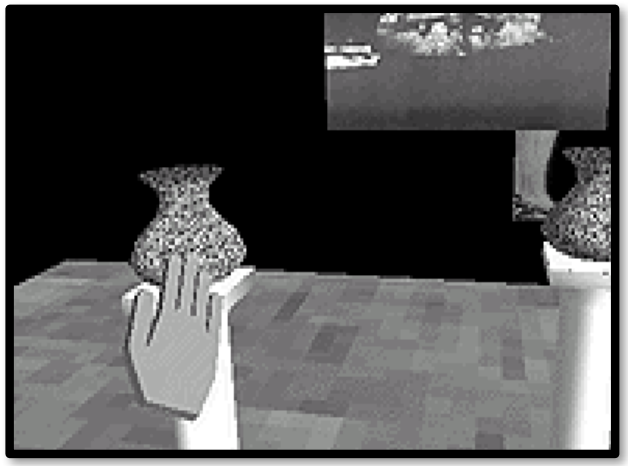
Goals of Selection:

- 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

Simple virtual hand technique



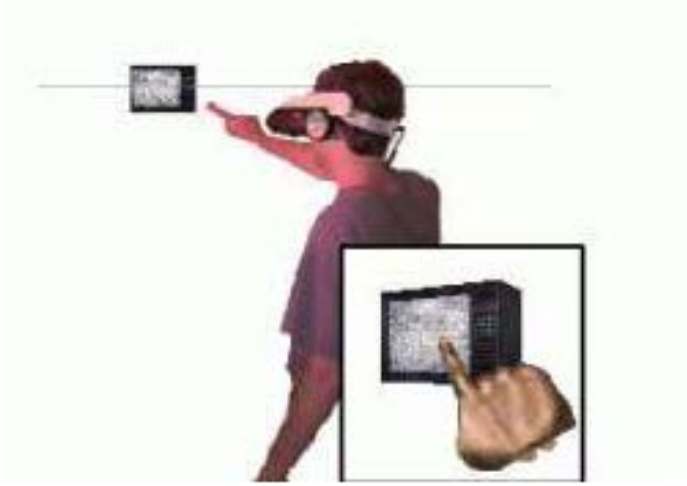
- Process:
  - One-to-one mapping between physical and virtual hands
  - Object can be selected by “touching” with virtual hand
  - “Natural” mapping
- Limitation:
  - Only select objects in hand reach

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 (Example: https://www.youtube.com/watch?v=W1ZUBTPCL3E)
  - Cone casting (Flashlight)
  - Aperture
  - Two-handed pointing
  - Image plane
- Naming (speech rec.)



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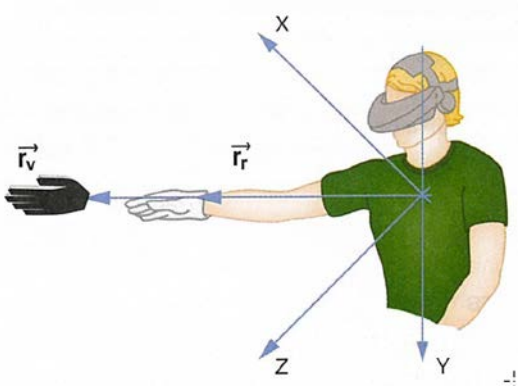
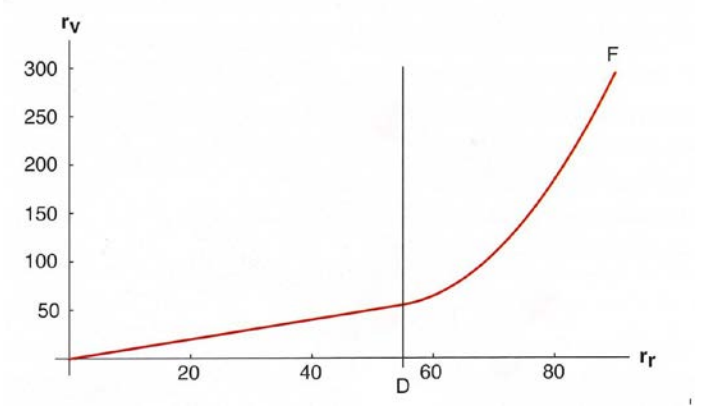
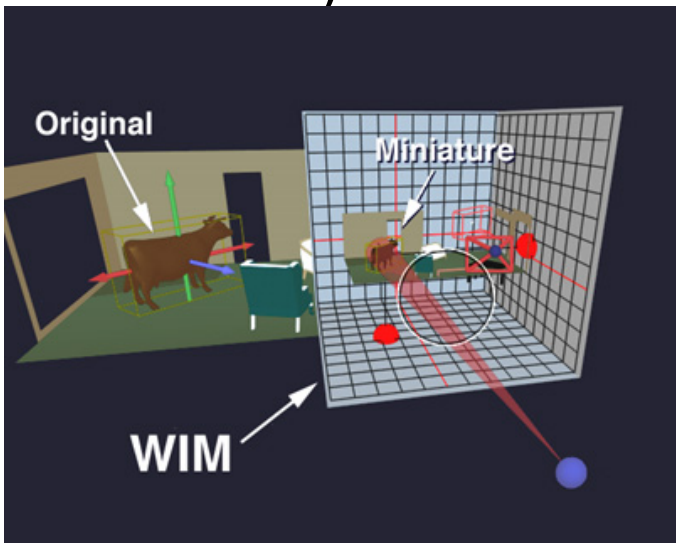
Enhancements to Basic Techniques





- Arm-extension
  - Go-Go Technique (mapping)
    - Non-linear mapping between physical and virtual hand position
  - Fishing-Reel Technique (additional device: distance)
- World in Miniature (WIM)
  - Select icon-like objects



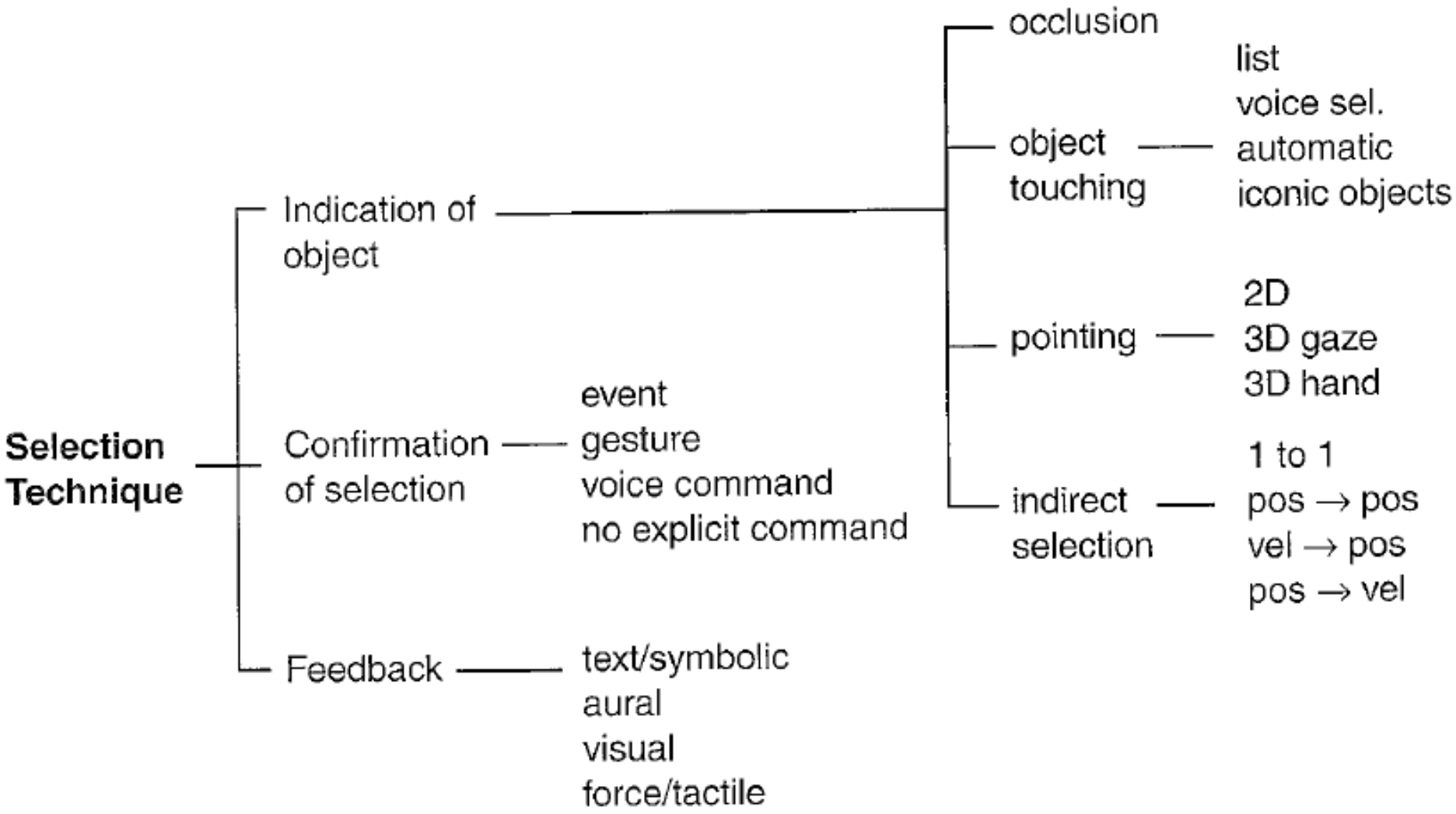
Precise 3D selection techniques

- Increase selection area
  - Cone-casting (Liang, 1993)
  - Snapping (de Haan, 2005)
  - 3D Bubble Cursor (Vanacken, 2007)
  - Sphere-casting (Kopper 2011)
- Increase control/display ratio
  - PRISM (Frees, 2007)
  - ARM (Kopper, 2010)

Not ideal for cluttered environments (high density, occlusion)

May require careful interaction

Classification of Selection Techniques



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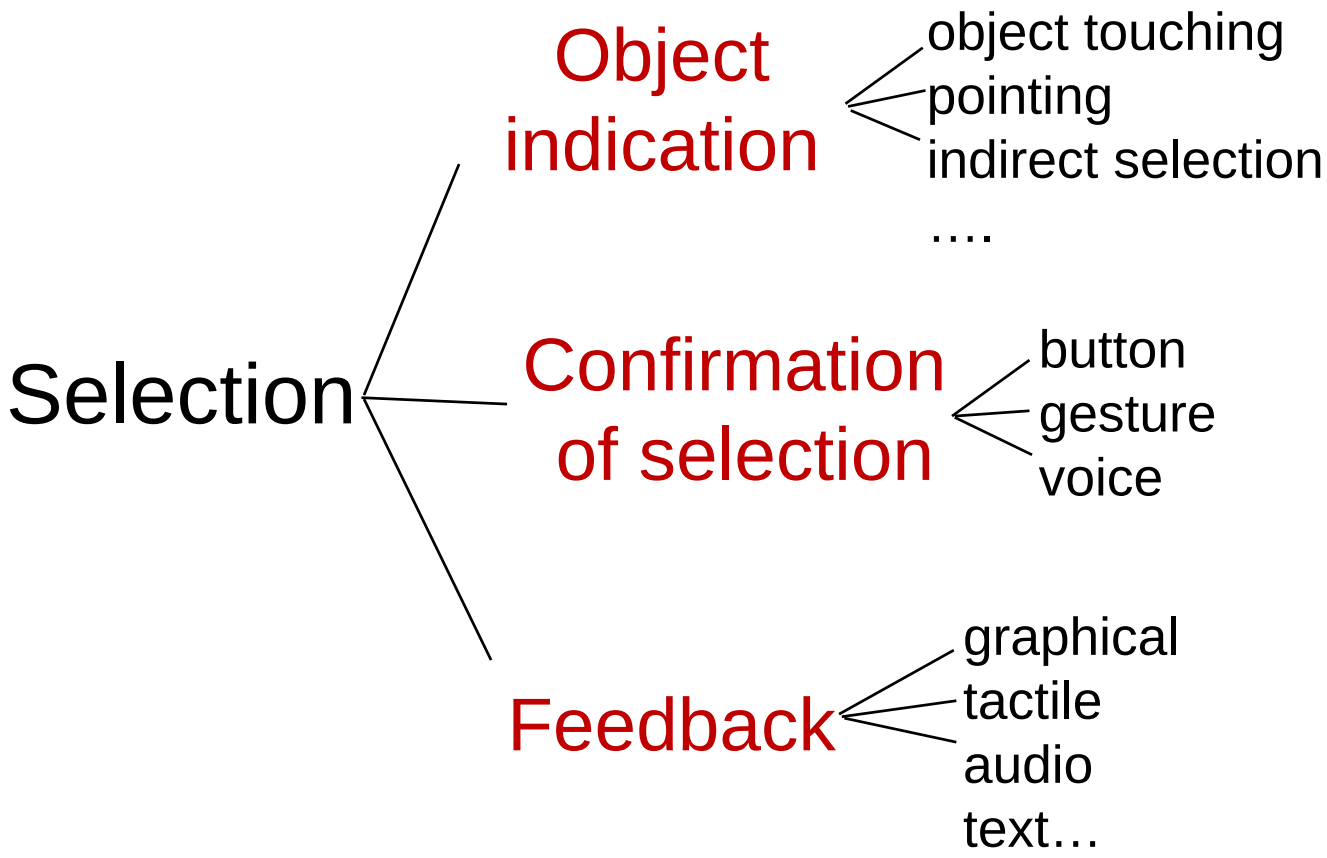
Selection: Task Decomposition



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

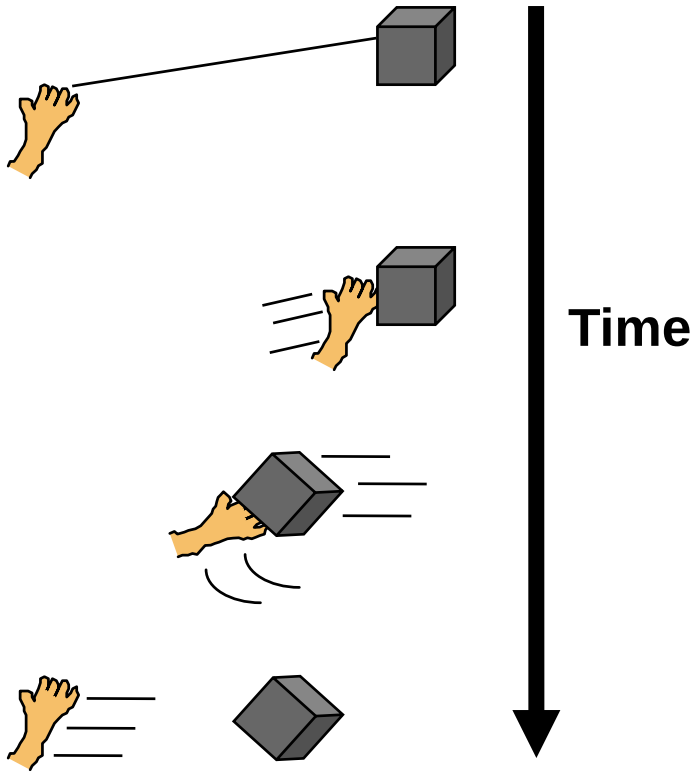
Manipulation Metaphors 1

- 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

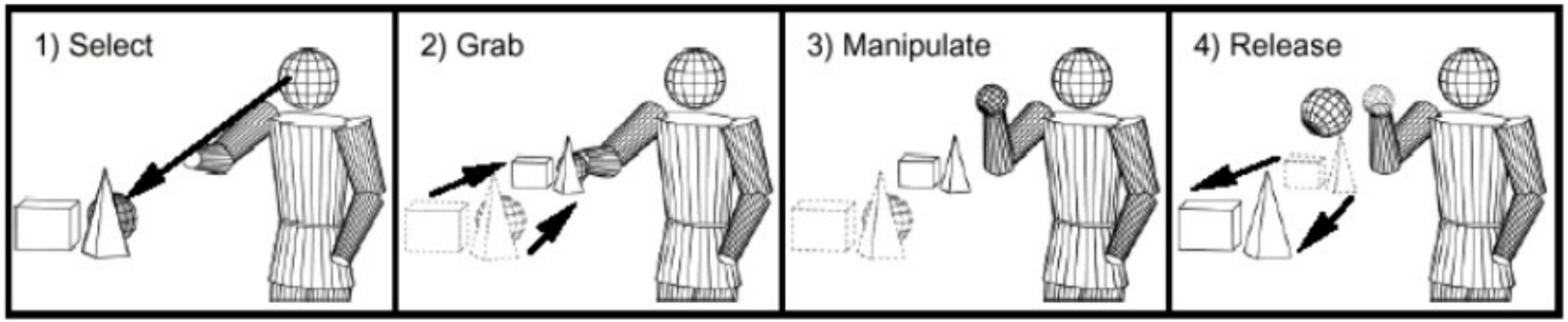
Hand-Centered **O**bject
Manipulation
Extending **R**ay-Casting

- Select: ray-casting
- Virtual hand moves to object
- Manipulate: hand



Scaled-world Grab Technique

- Often used with occlusion
- At selection, scale user up (or world down) so that virtual hand is actually touching selected object
- User doesn‘t notice a change in the image until he moves



Mine, M., Brooks, F., & Sequin, C. (1997). *Moving Objects in Space: Exploiting Proprioception in Virtual Environment Interaction.* Proceedings of ACM SIGGRAPH, 19-26

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 or occlusion
  - World scaled down around virtual hand
  - Easy, natural manipulation
  - Hard to move objects further away

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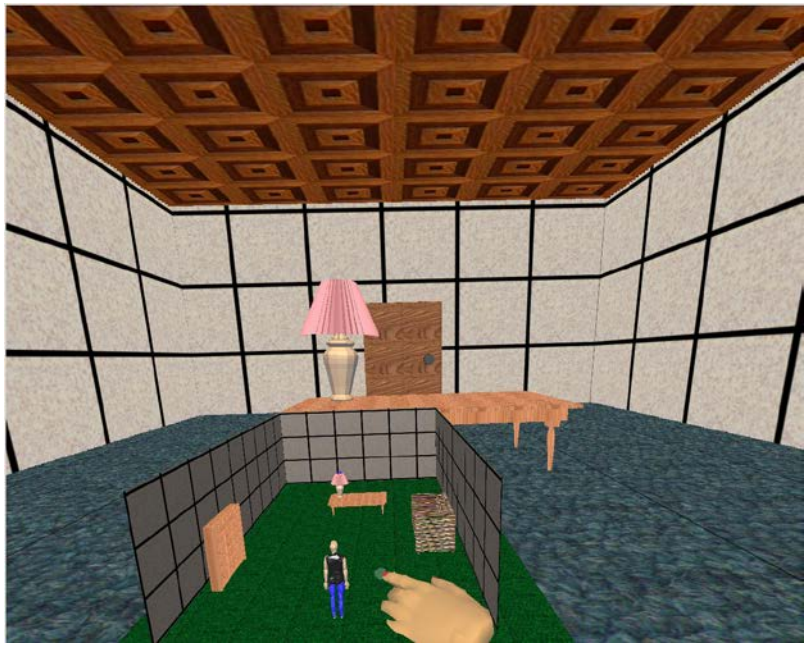
World-in-miniature (WIM) technique

- "Dollhouse" world held in user's hand
- Miniature objects can be manipulated directly
- Moving miniature objects affects full-scale objects
- Can also be used for navigation



Stoakley, R., Conway, M., & Pausch, R. (1995). *Virtual Reality on a WIM: Interactive Worlds in Miniature.* Proceedings of CHI: Human Factors in Computing Systems, 265-272, and Pausch, R., Burnette, T., Brockway, D., & Weiblen, M. (1995). *Navigation and Locomotion in Virtual Worlds via Flight into Hand-Held Miniatures.* Proceedings of ACM SIGGRAPH, 399-400.

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

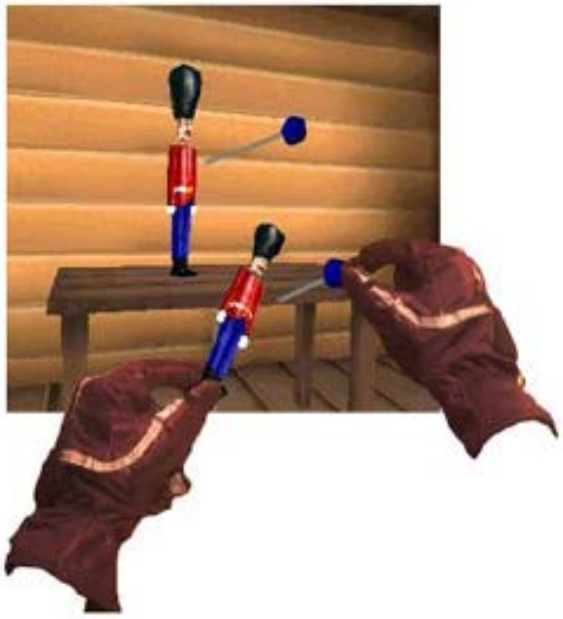
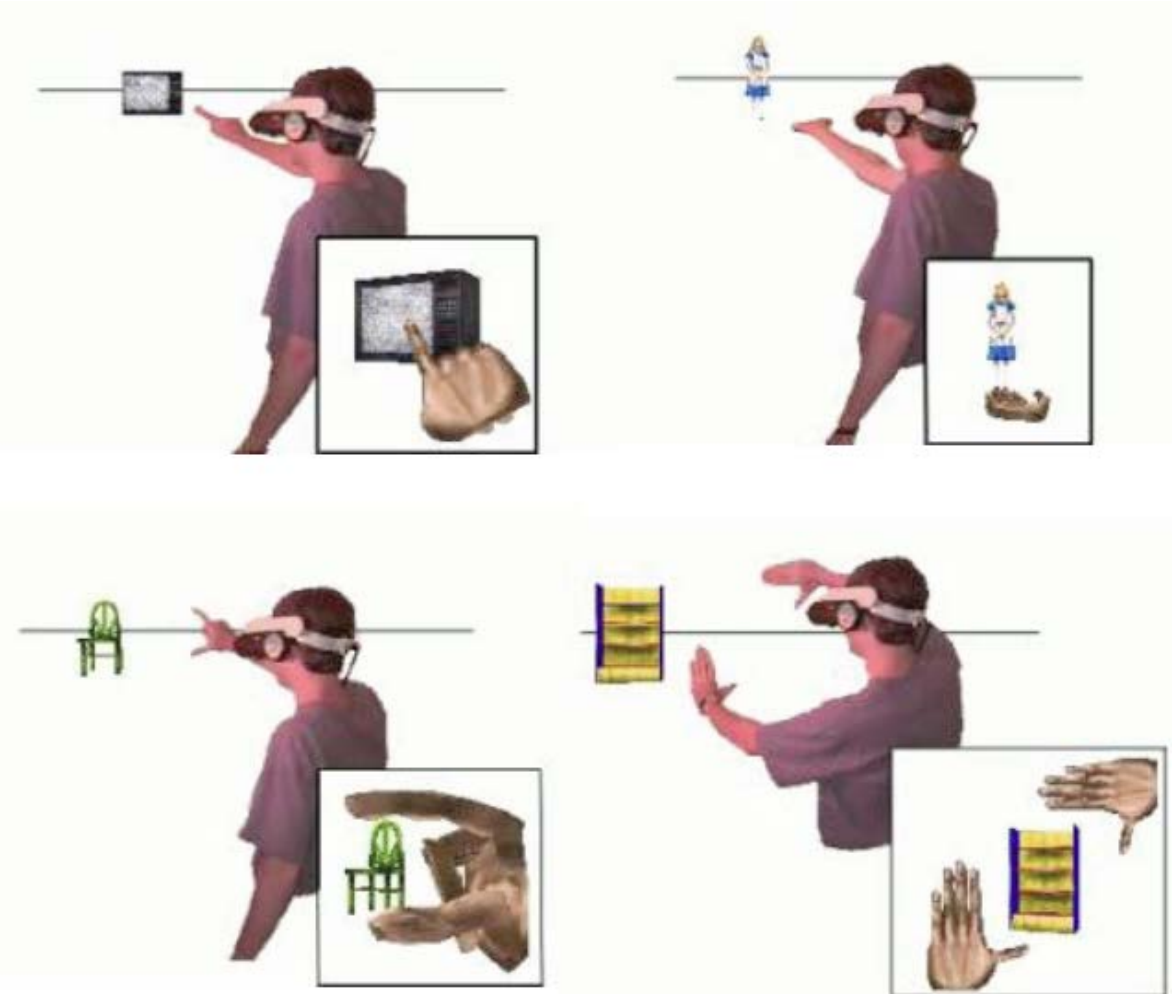
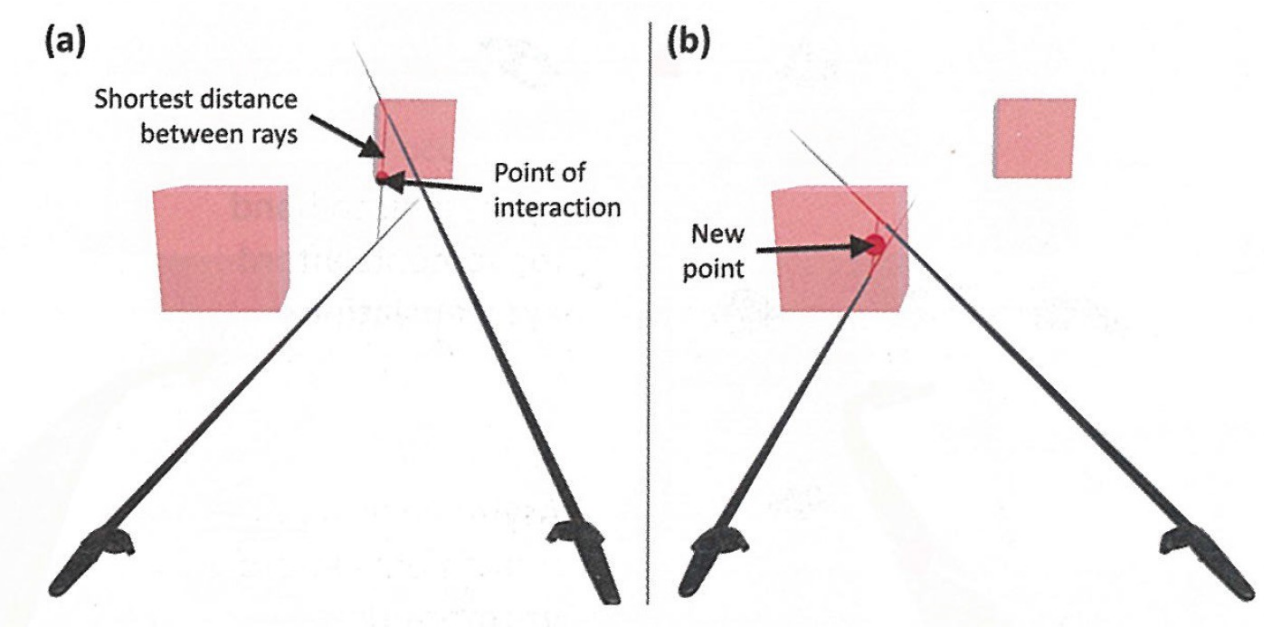


Image plane interaction

- Selection and manipulation
- Different gestures possible



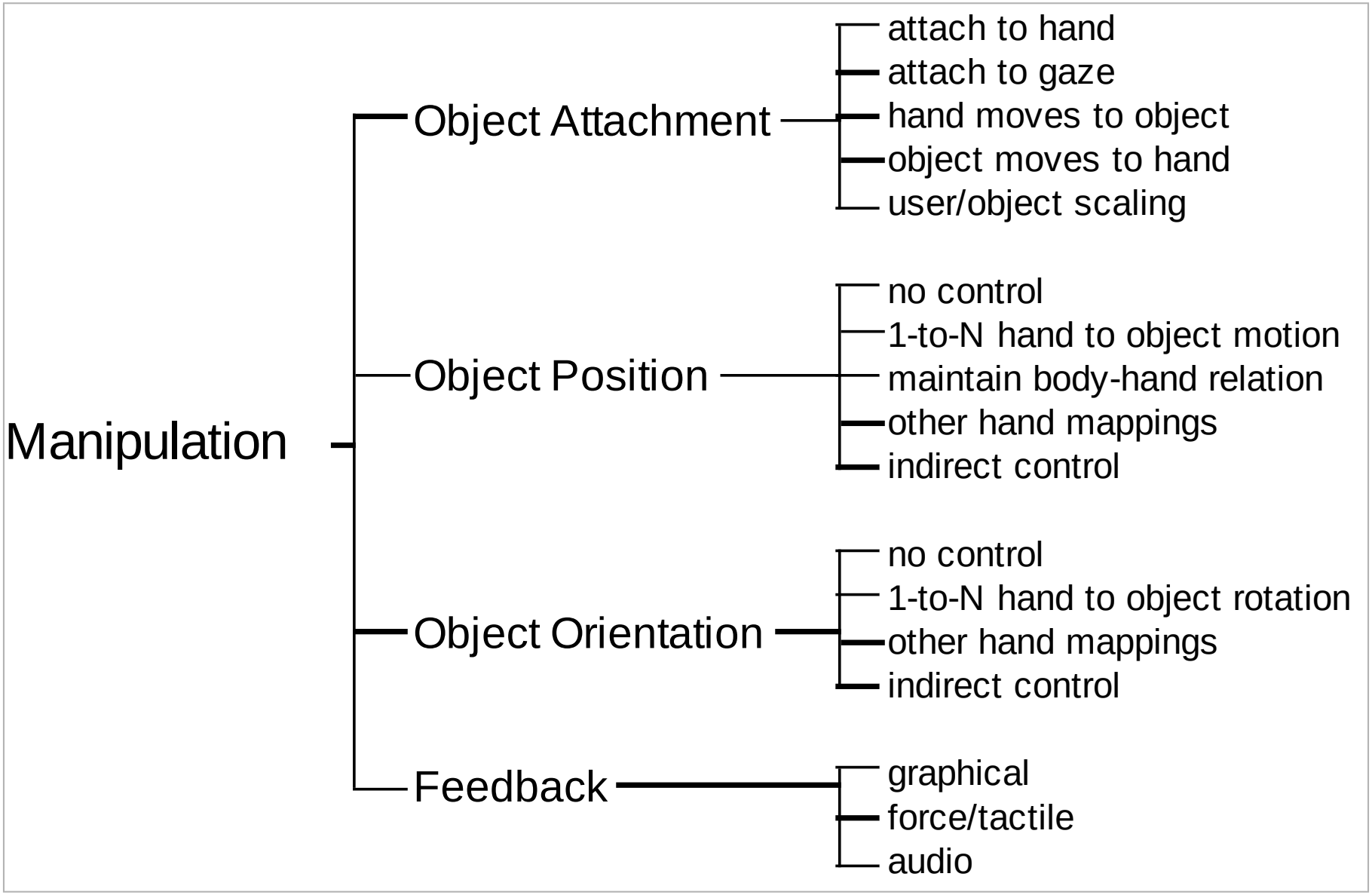
Symmetric Bimanual Technique



- iSith (Wyss 2006)
- Using two 6 DOF controllers each ray casting
- Intersection point of two rays determines interaction point

Wyss, H. P., Blach, R., & Bues, M. (2006, March). iSith-Intersection-based spatial interaction for two hands. In *3D User Interfaces, 2006. 3DUI 2006. IEEE Symposium on* (pp. 59-61). IEEE.

Classification by Components



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

Design Guidelines for Manipulation

- There is no single best manipulation technique
- Naturalism not always desirable
- Map the interaction technique to the device
- **Reduce degrees of freedom when possible**
- Use techniques that can help to reduce clutching
- Consider the use of grasp-sensitive object selection
- Use pointing techniques for selection and grasping techniques for manipulation
- Use existing techniques unless there is a large amount of benefit from designing a new application-specific method
- Consider the trade-off between technique design and environmental design
  - If VE is not based in the real, design your environment for optimal manipulation

Navigation

- Travel: motor component
- Wayfinding: cognitive component

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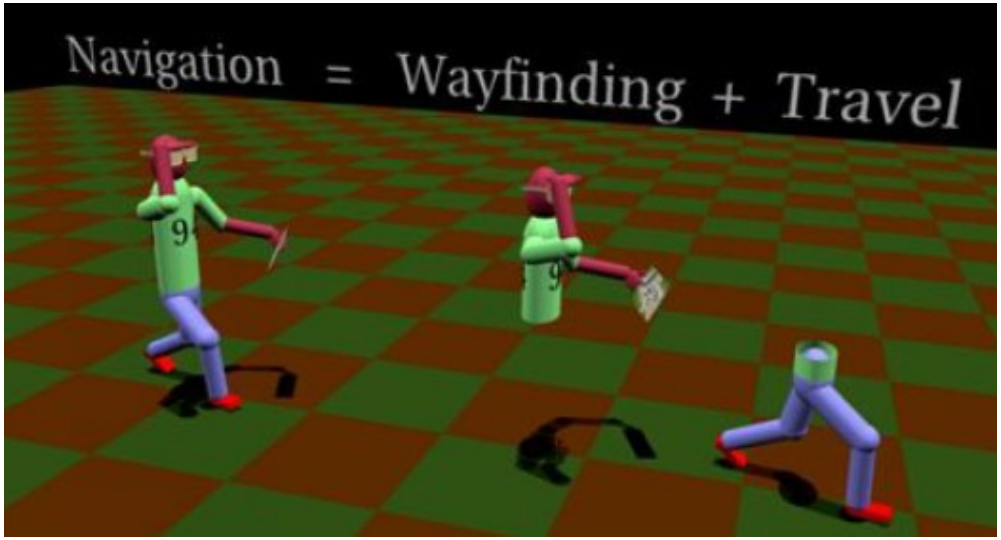
Navigation



- How we move from place to place within an environment
- The combination of travel with wayfinding
  - *Wayfinding*: cognitive component of navigation
  - *Travel:* motor component of navigation
- Travel without wayfinding: "exploring", "wandering”

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
  - move to target location
  - naive: target position not known
  - primed: position of target is known
  - build layout knowledge
- Maneuvering
  - short, precise movements
  - E.g. travel to position the viewpoint for a task

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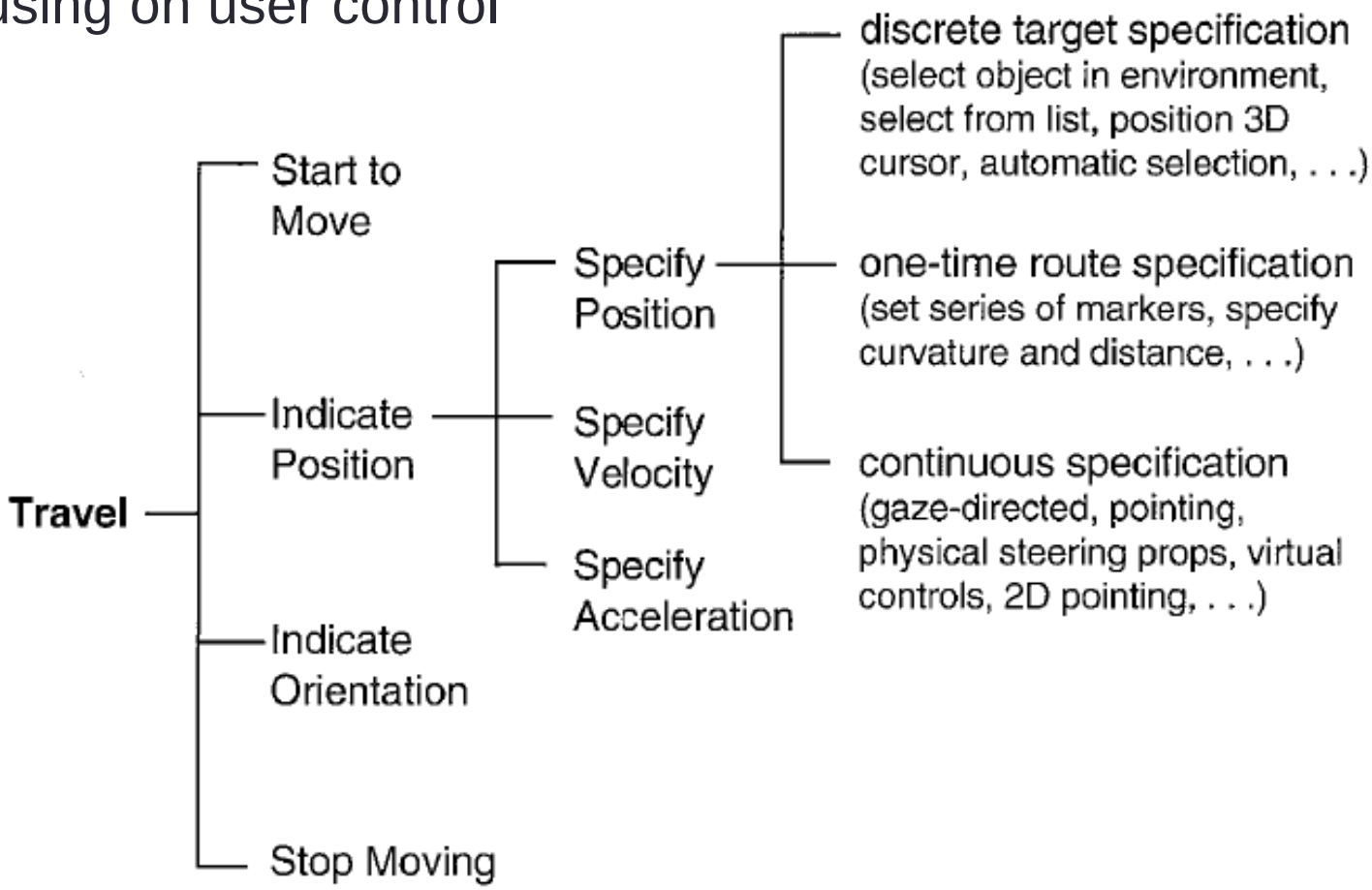
Movement Process

- Focusing on user control



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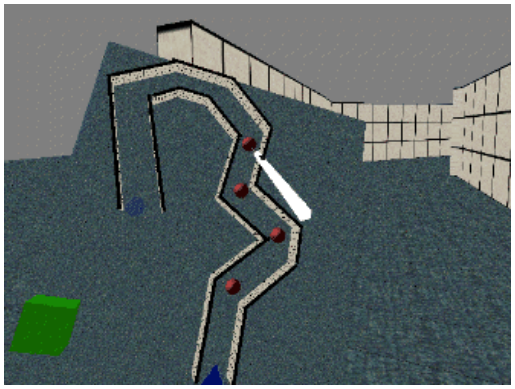
Traveling metaphors 1/2

- 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)

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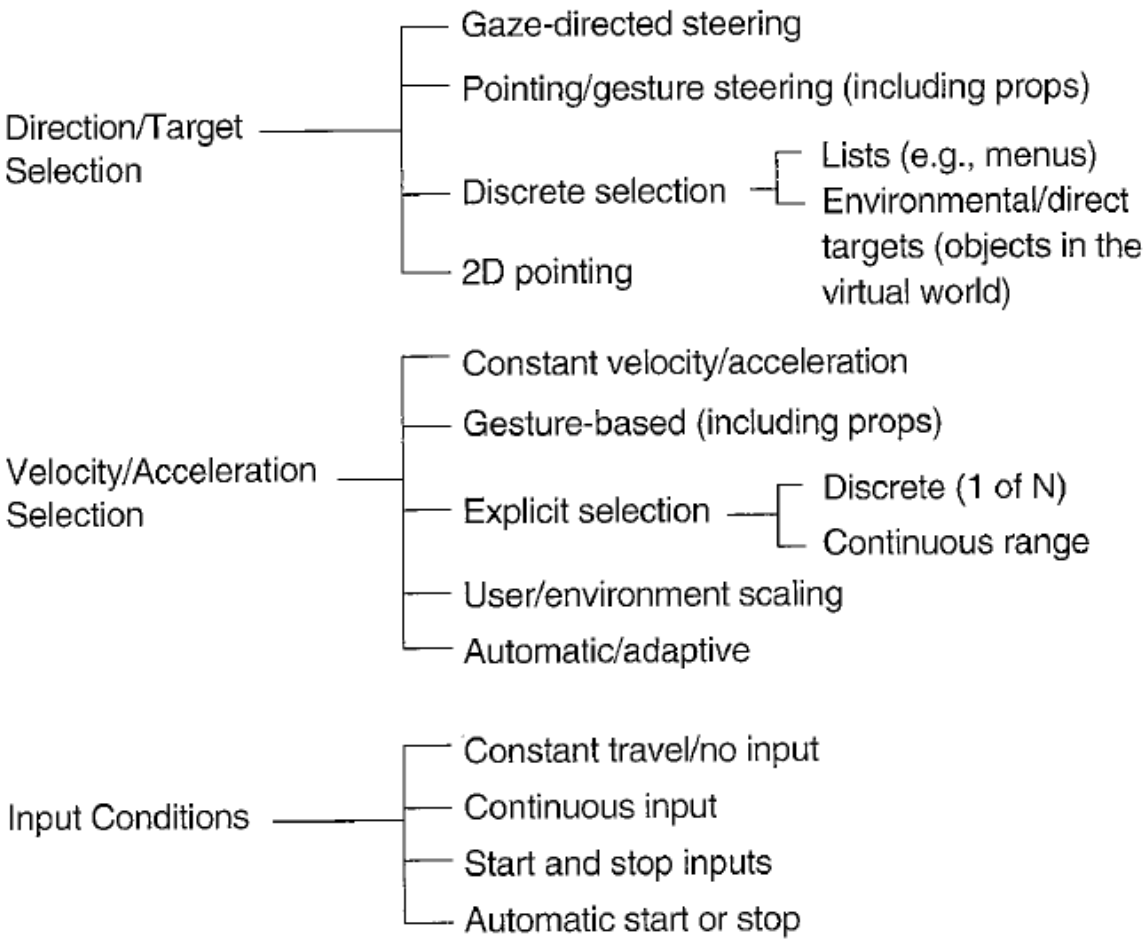
Taxonomy of Travel Techniques

- Focusing on sub-task of travel



Bowman, D. A., Koller, D., & Hodges, L. F. (1997, March). Travel in immersive virtual environments: An evaluation of viewpoint motion control techniques. In *Virtual Reality Annual International Symposium, 1997., IEEE 1997* (pp. 45-52). IEEE.

Evaluation results (by Bowman)

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

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Evaluation results

- Steering techniques best for naive and primed search
- Map-based techniques not effective in unfamiliar environments, or if any precision is required

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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

Design Guidelines for Navigation

- Match the travel technique to the application
- Use an appropriate combination of travel technique, display devices, and input devices
- The most common travel tasks should require a **minimum of effort** from the user
- **Use physical locomotion technique if user exertion or naturalism is required**
- Use target-based techniques for goal-oriented travel and steering techniques for exploration and search
- Provide multiple travel techniques to support different travel tasks in the same application
- Choose travel techniques that can be easily integrated with other interaction techniques in the application

“Natural” travel metaphors

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

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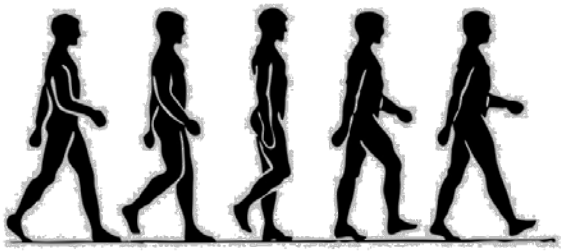
Real Walking



- **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

ImmersiveDeck

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

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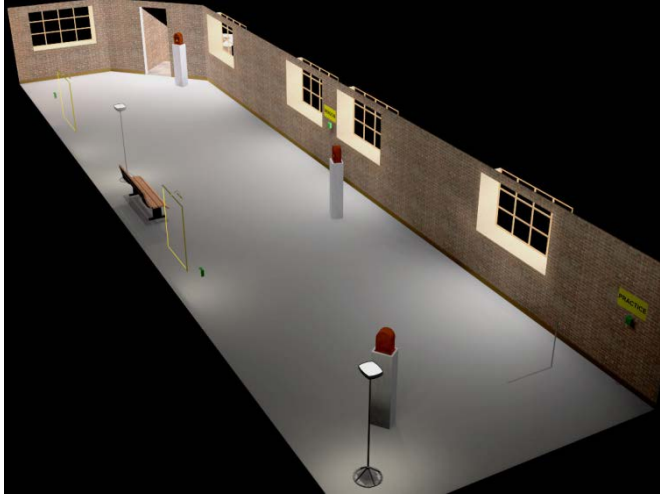
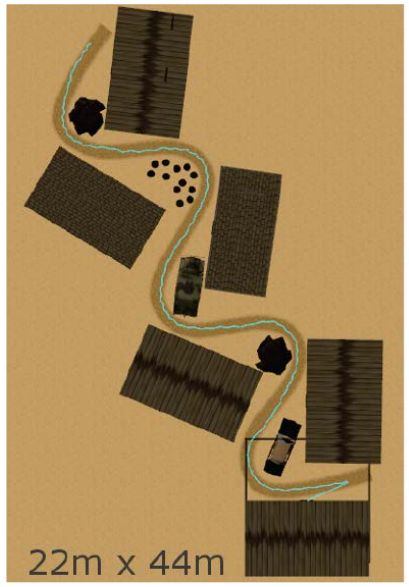
Redirected Walking

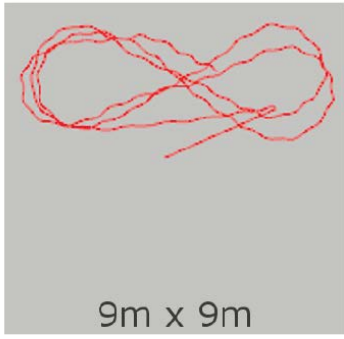


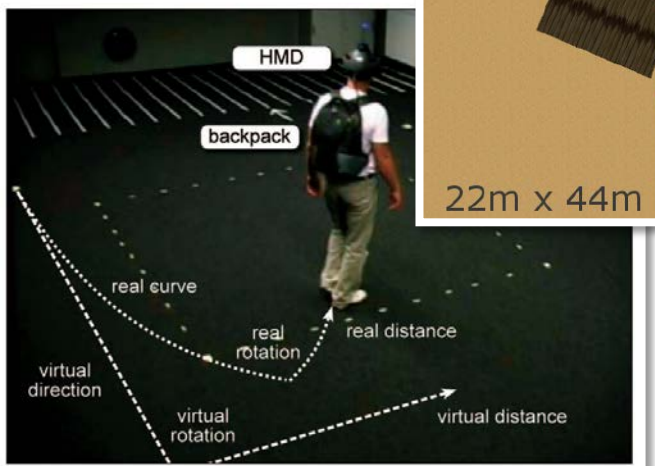
- Same benefits as real walking
- Extends the possible size of the VE

Different methods:

- Way points
- Distractions
- Gains:
  - Translation
  - Rotation
  - Curvature







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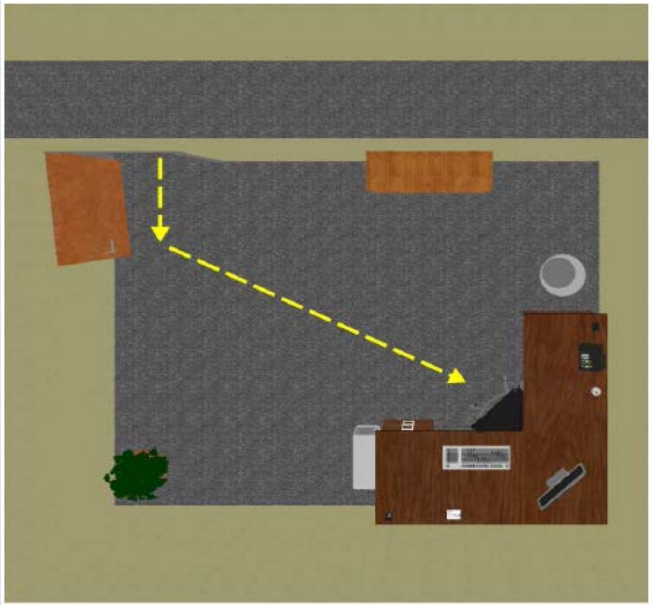
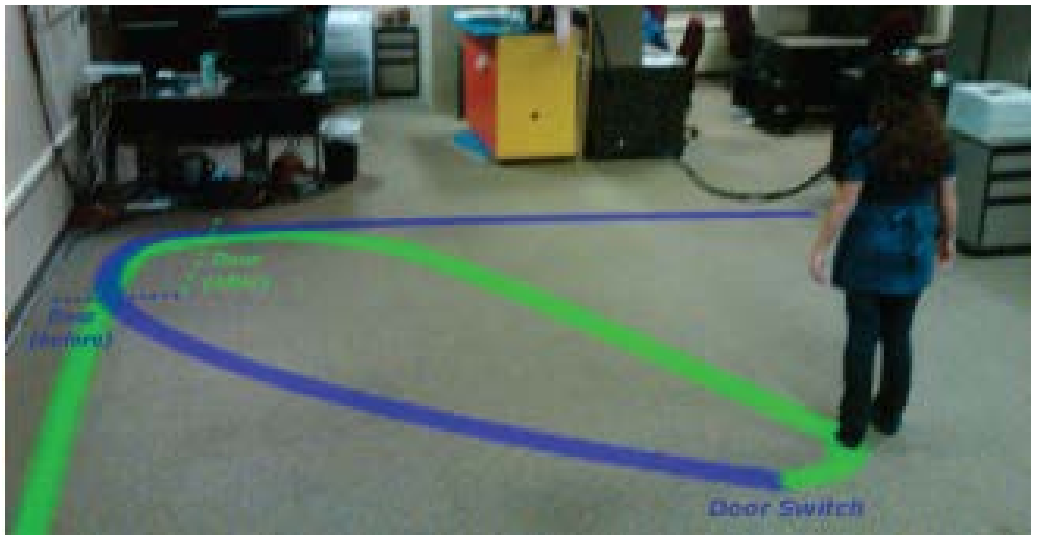
Change Blindness

- Changes are applied while the user is distracted

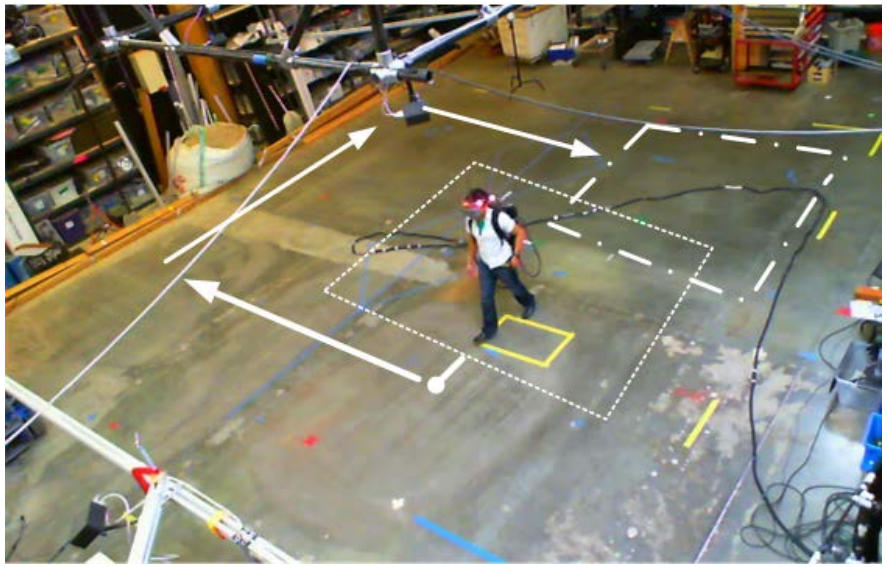
- Cyclic paths possible





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

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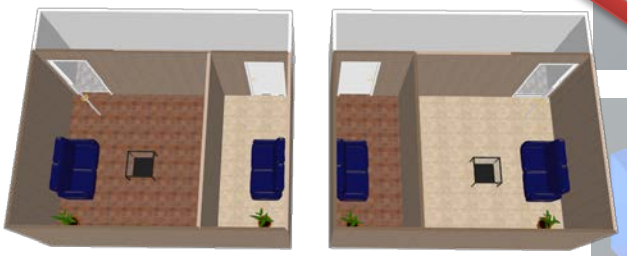
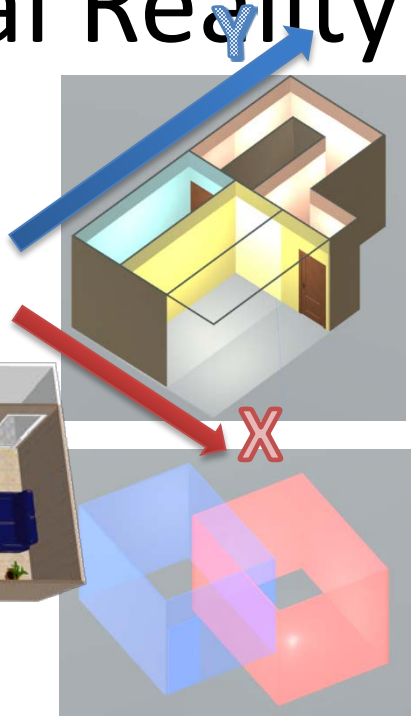
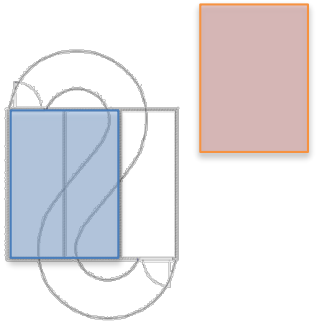
Spatial Perception in Virtual Reality

- 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…*



S-shaped

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.*

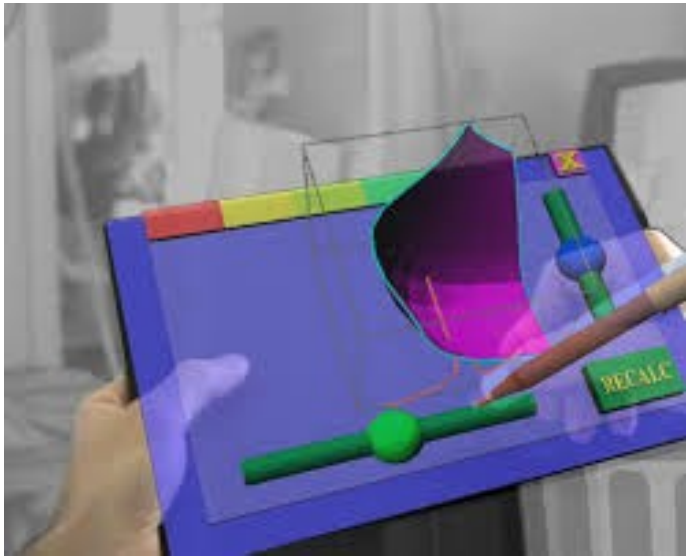
WRONG !

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

- Issuing a command to change system state or mode
- Examples
  - Launching application
  - Changing system settings
  - Opening a file
  - Etc.
- Key points
  - Make commands visible to user
  - Support easy selection



Common types of system control techniques

- Menu systems
- Voice commands
- Gestures/postures
- Implicit control (e.g. pick up new tool to switch modes)

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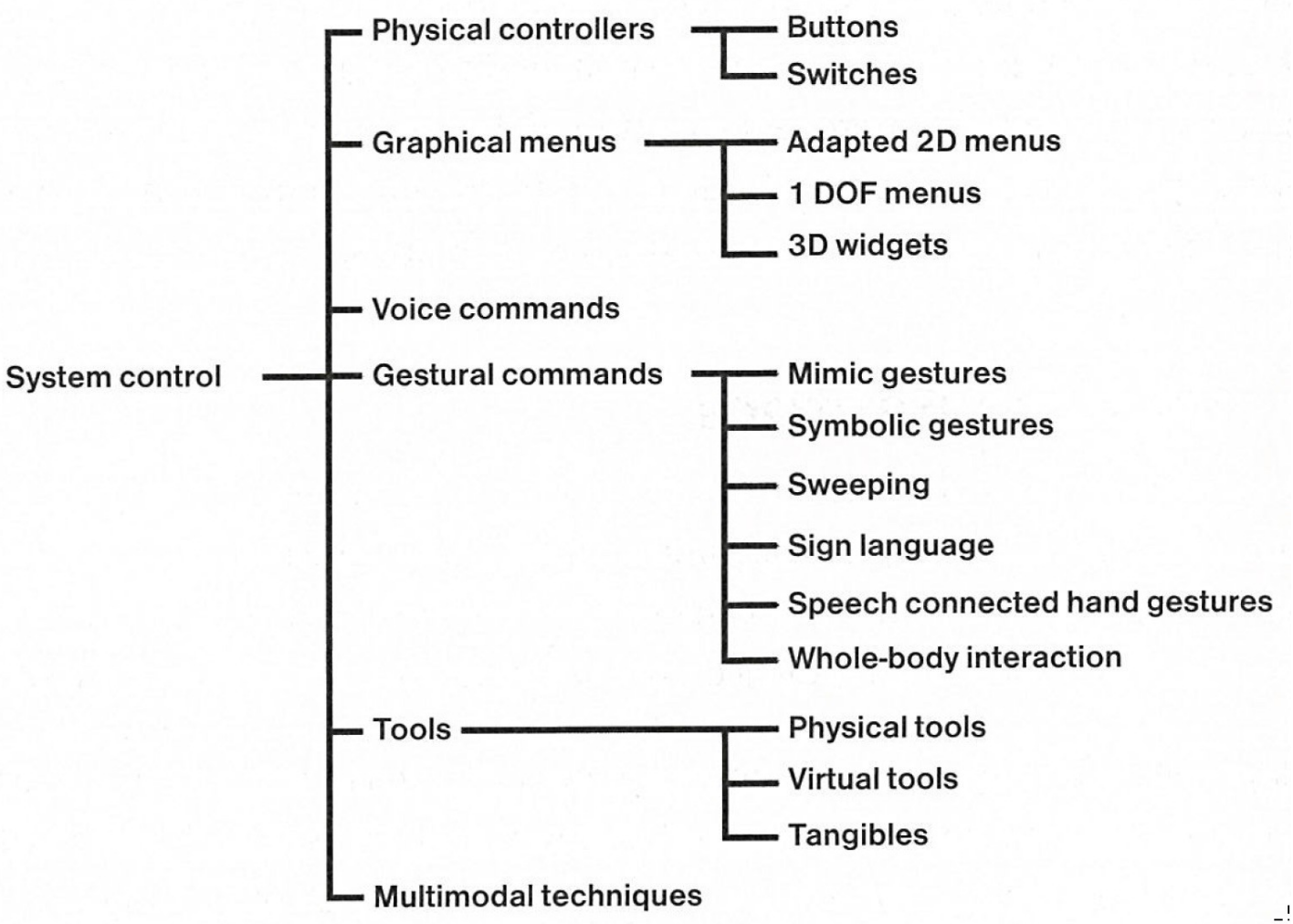
System Control Options



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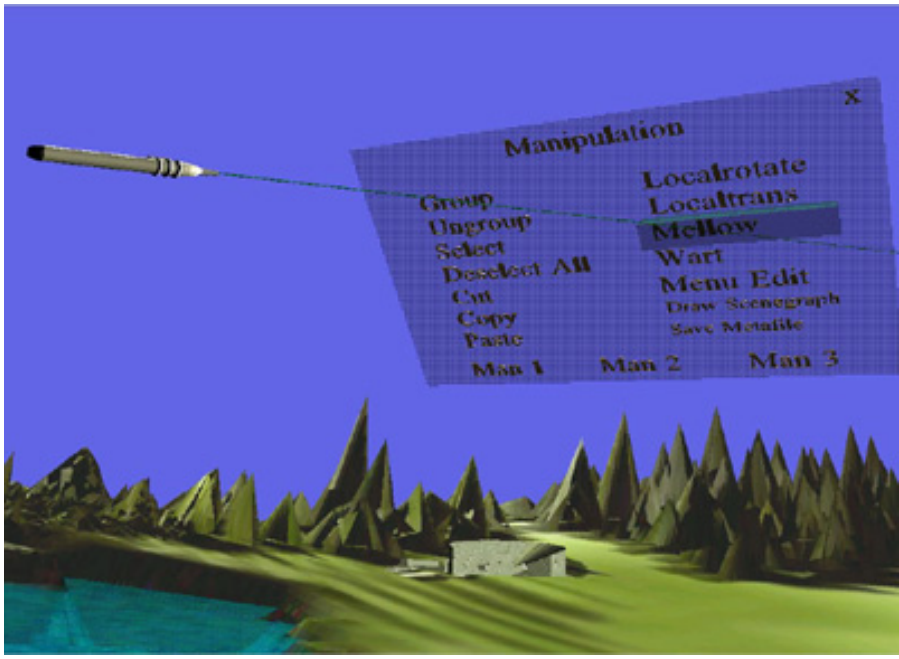
Floating menus in 3D

- 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 bad design
- Better if menu follows user



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Example: GearVR Interface

- 2D Interface in 3D Environment
- In this case: Dedicated menu environment
- Head pointing and click to select

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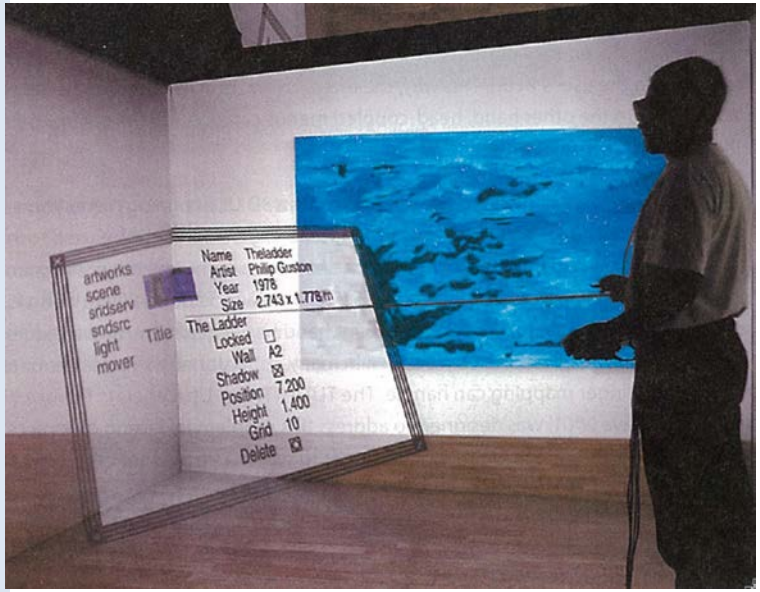
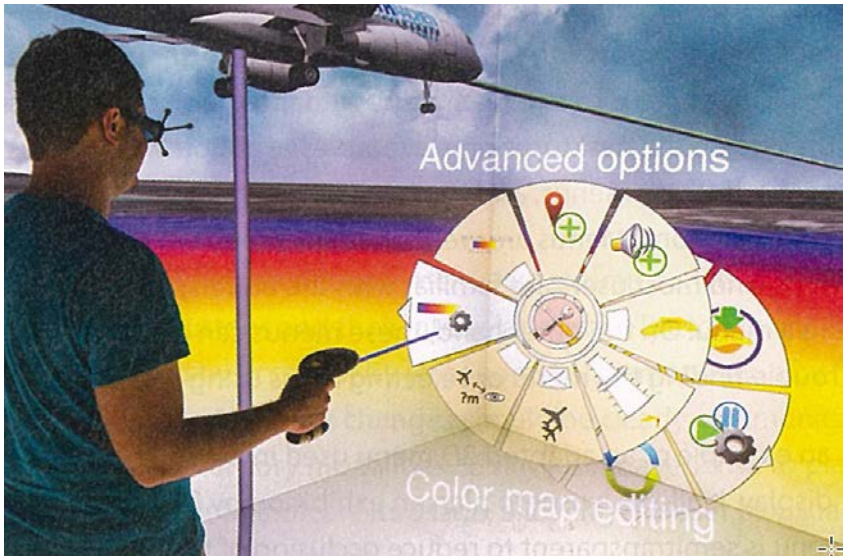
2D Menus in VR



2D Menu in VR CAVE



Nested Pie Menu

- Many examples of 2D GUI and floating menus in VR

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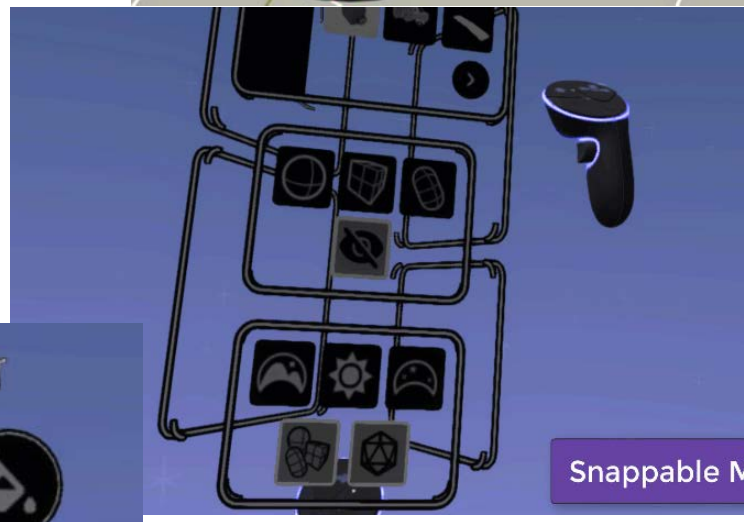
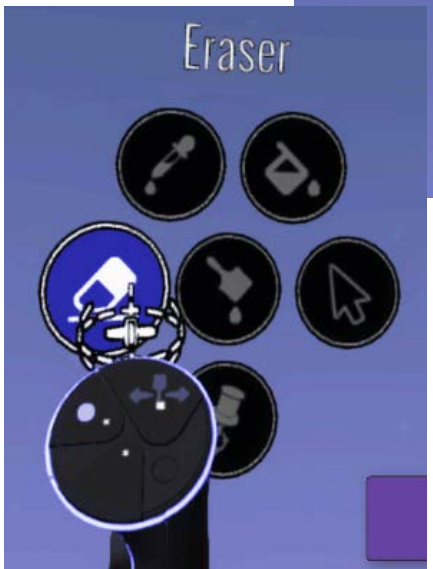
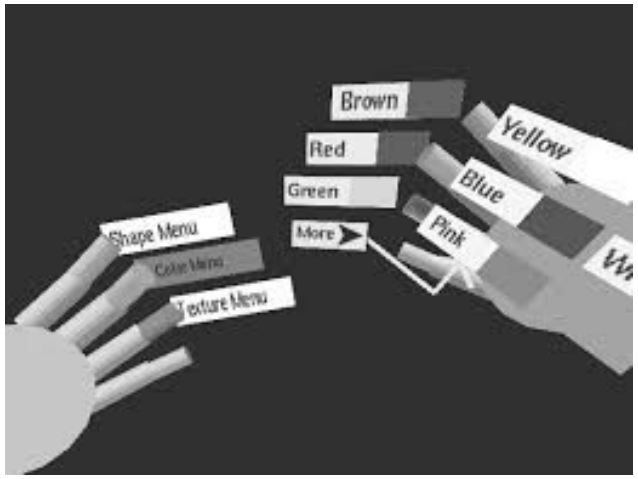
Pop-Up Menus - Radial

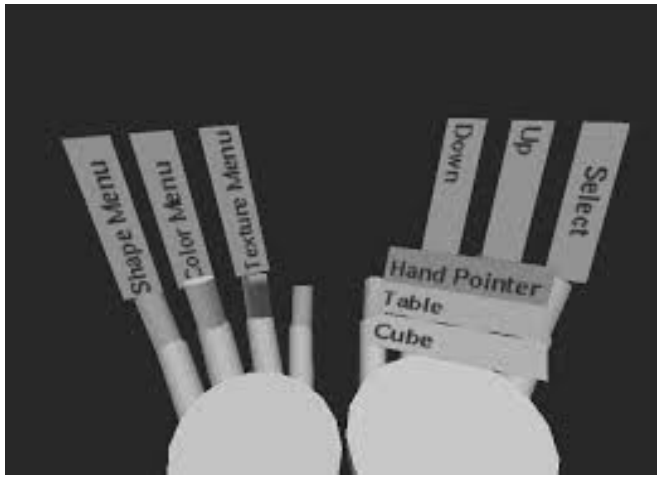
- Sundial
  - Pie menu with 3D selector
  - User rotates “Shadow stick” to occlude desired segment
- Example: iOrb





TULIP Menu



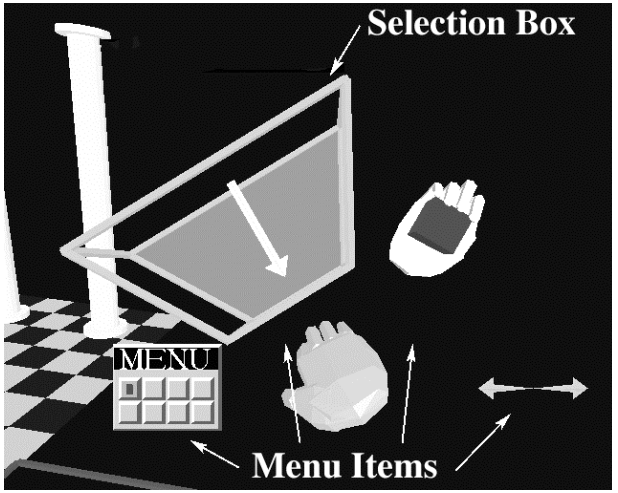


- Menu items attached to virtual finger tips
- Ideal for pinch glove interaction
- Use one finger to select menu option from another

Bowman, D. A., & Wingrave, C. A. (2001, March). Design and evaluation of menu systems for immersive virtual environments. In *Virtual Reality, 2001. Proceedings. IEEE* (pp. 149-156). IEEE.

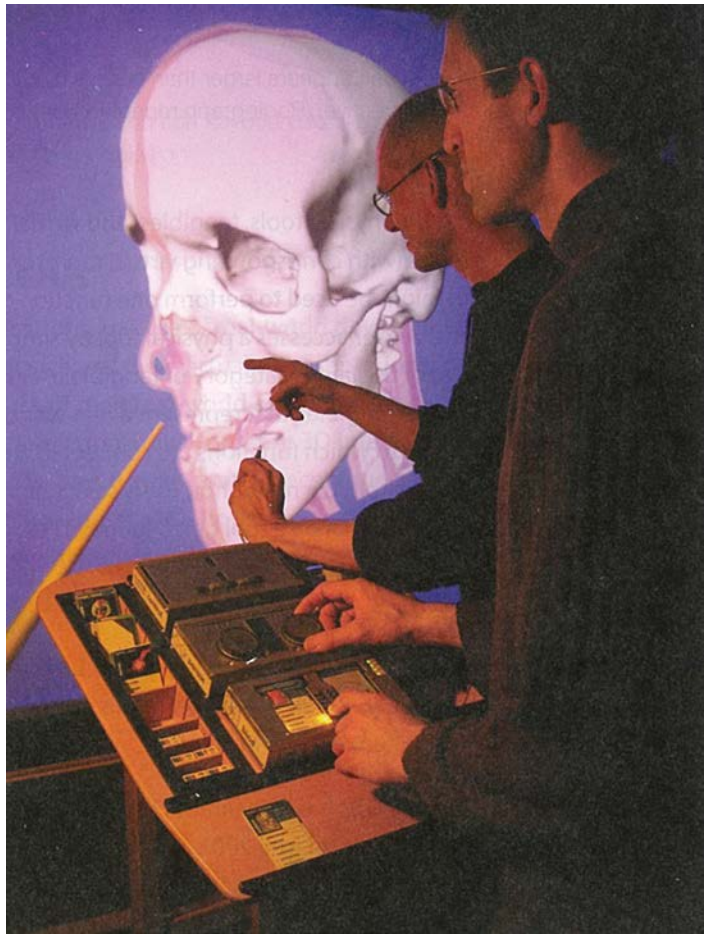
1 DOF menu

- Correct number of DOFs for the task
- Can be put away
- Only one menu level at a time



Tools

- Use tools for system commands
  - Tangible user interfaces (real tools)
  - Virtual tools (3D objects)
- Design issues
  - Support eyes-off use
  - Use of physical affordances
  - Base on familiar objects
  - Provide tactile feedback
  - Map real tool to virtual operation



Tangible interface for CAVE

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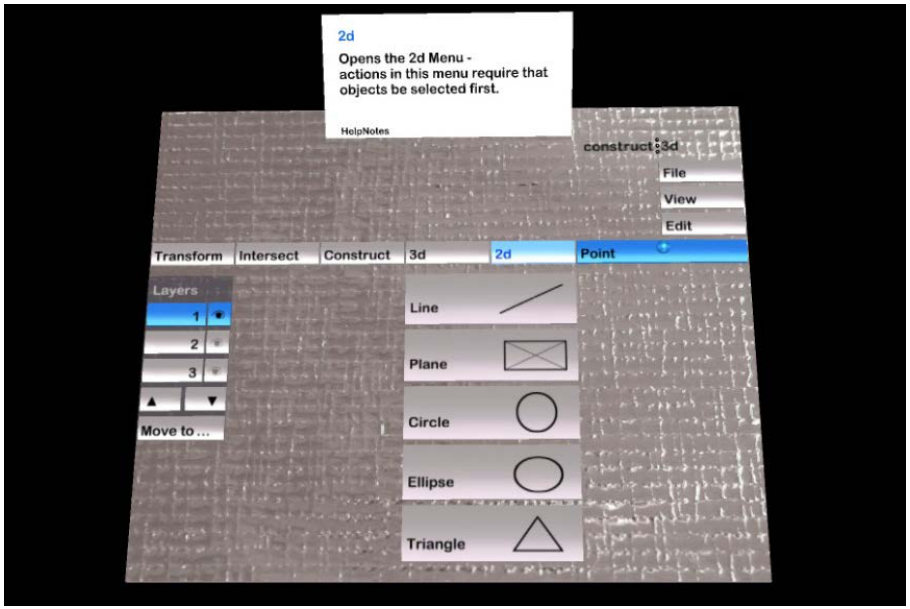
Pen & Tablet Interaction



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

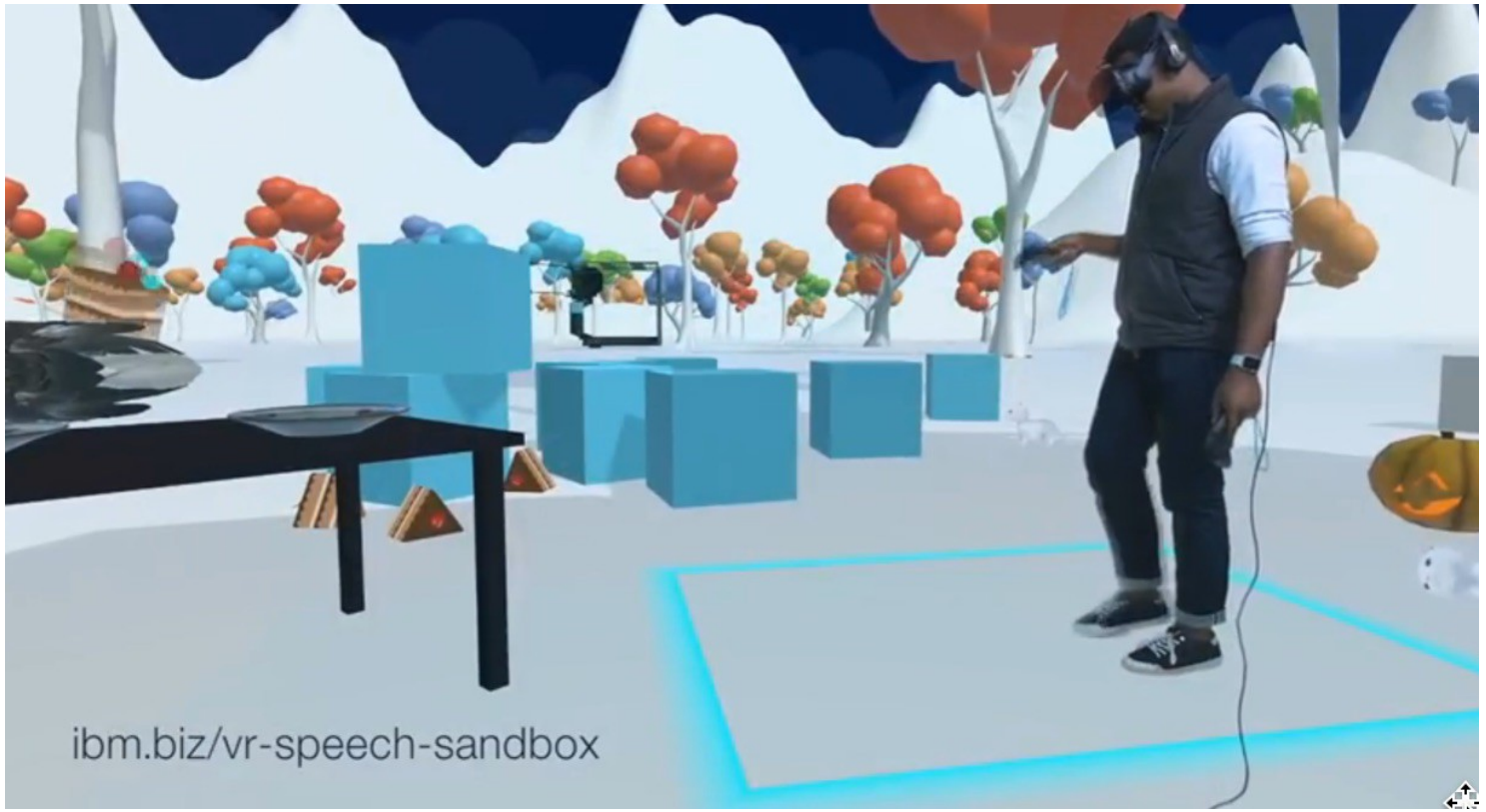
2D interaction in a 3D world

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

Voice Input

- Implementation
  - Wide range of speech recognition engines available
  - E.g. Unity speech recognition plug-in, IBM VR speech sandbox
- Factors to consider
  - Recognition rate, background noise, speaker dependent/independent
- Design Issues
  - Voice interface invisible to user
    - no UI affordances, overview of functions available
  - Need to disambiguate system commands from user conversation
    - Use push to talk or keywords
  - Limited commands – use speech recognition
  - Complex application – use conversational/dialogue system

Example – IBM VR Speech Sandbox



- https://www.youtube.com/watch?v=NoO2R3Pz5Go
- Available from: http://ibm.biz/vr-speech-sandbox

Design Guidelines for System Control

- Avoid mode errors
- Design for discoverability
- Consider using multimodal input
- Use an appropriate spatial reference frame
- Prevent unnecessary focus and context switching
- Avoid disturbing the flow of action of an interaction task
- **Structure the functions in an application and guide the user**
- **3D is not always the best solution – consider hybrid interfaces**

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!

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IT Comparison VR – AR

	Virtual Reality / 3DUI	Augmented Reality
Selection	Raycasting, virtual hand, world scaling	same
Manipulation	Everything can be manipulated.	Distinction between *real / virtual* objects
Navigation	Viewpoint can be controlled freely.	Only *passive* hints
System control, Symbolic input	Menus, voice, gestures	same

Examples for MR Interaction

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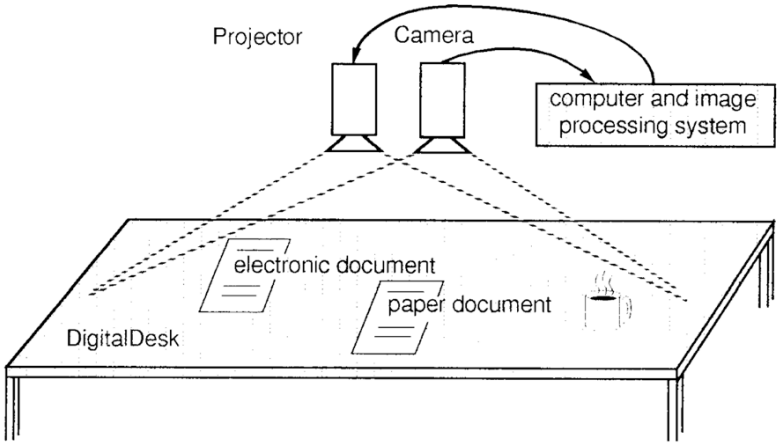
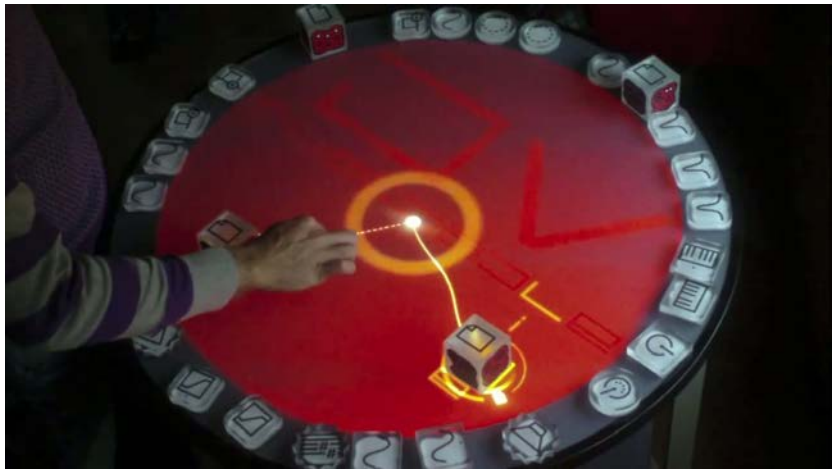
Augmented Surfaces

- Touch leads to surfaces
- Often using projection
  (e.g. Digital Desk [Wellner93]
- Treat paper and electronic documents as the same



Tangible Interaction

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

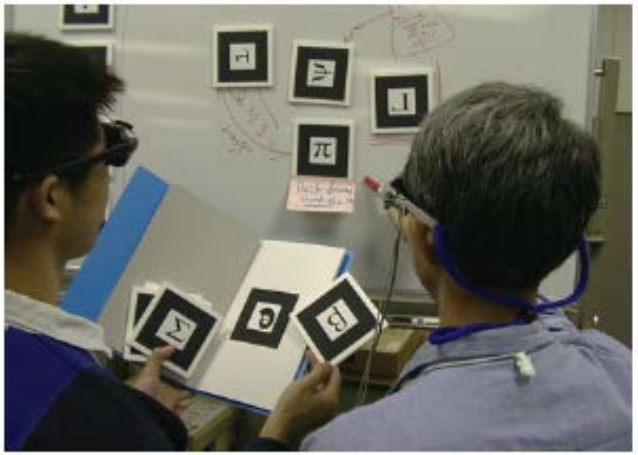


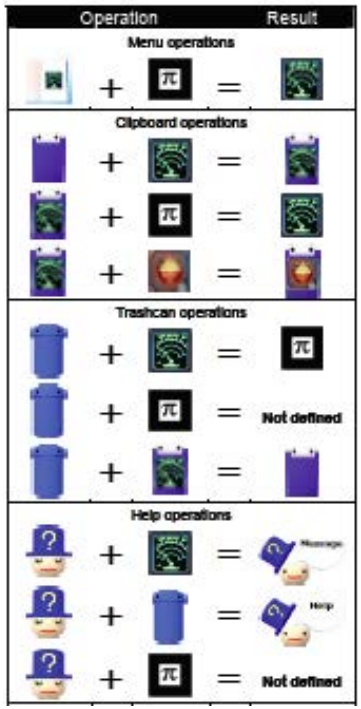
ReacTable

Touch Tables

Tangible: Tiles

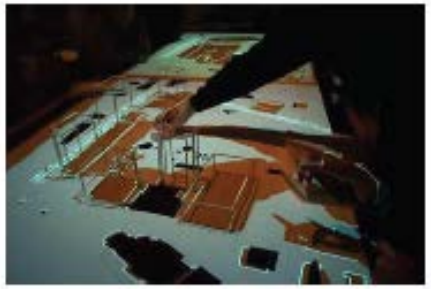
- Tangible markers
  - data
  - operations
- Integration with real world
  - annotations
- See through HMD
- Collaborative

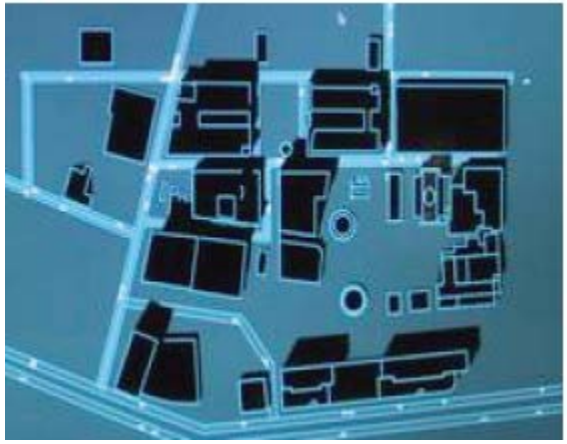




Luminous Tangible Workspace

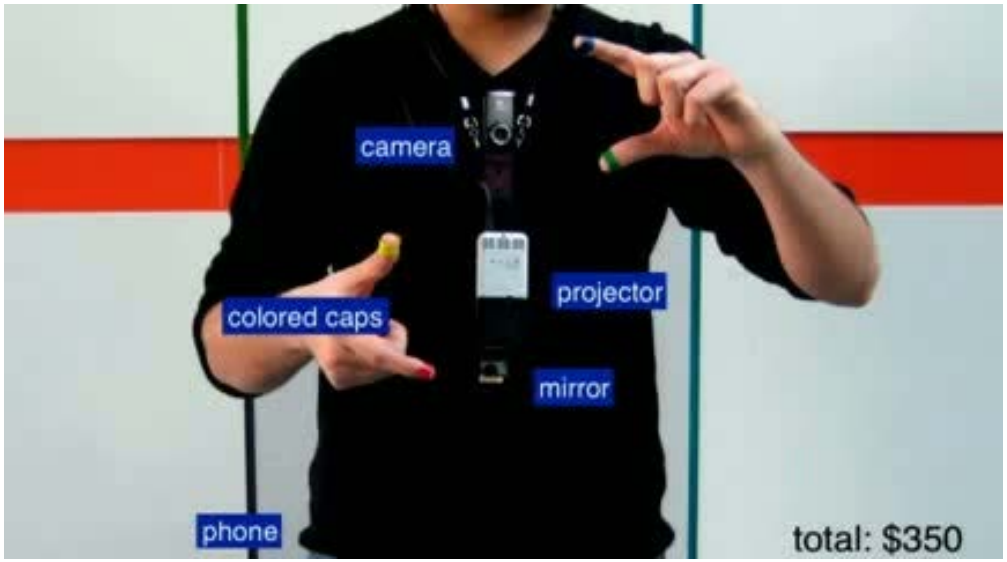
- Urban planning tool
  - Tangible building models
  - Interactive simulations
    - Wind
    - Sunlight / shadows
    - Traffic patterns



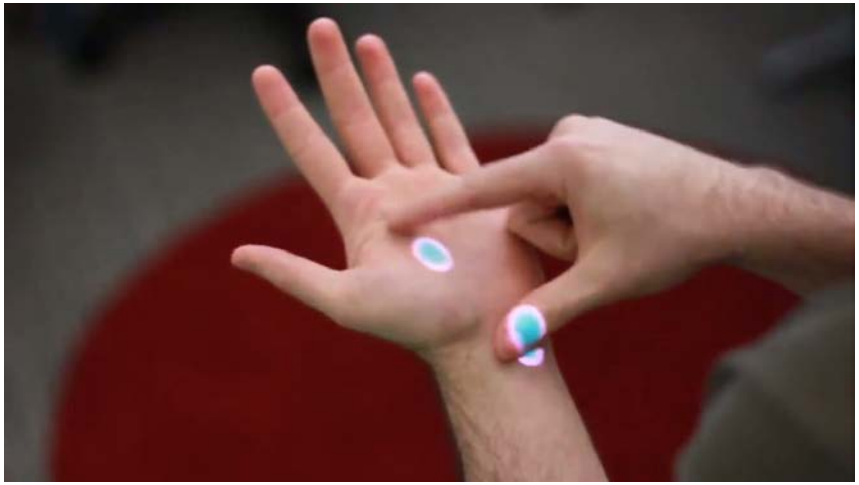


Projected AR Environments 1/2

- MIT 6th Sense



- Microsoft Omni Touch



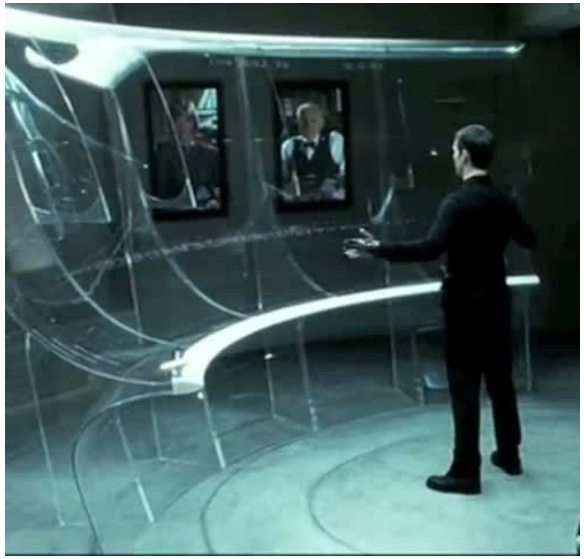
Projected AR Environments 2/2

- Microsoft Augmenting Indoor Spaces

Examples: Gestural Interaction

- Oblong Industries

- Movies / Visions



3D Interaction Techniques for Smartphones / Tablets

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

Oh,no,officer - it's not graffiti. it's an analog real-time augmented reality application.

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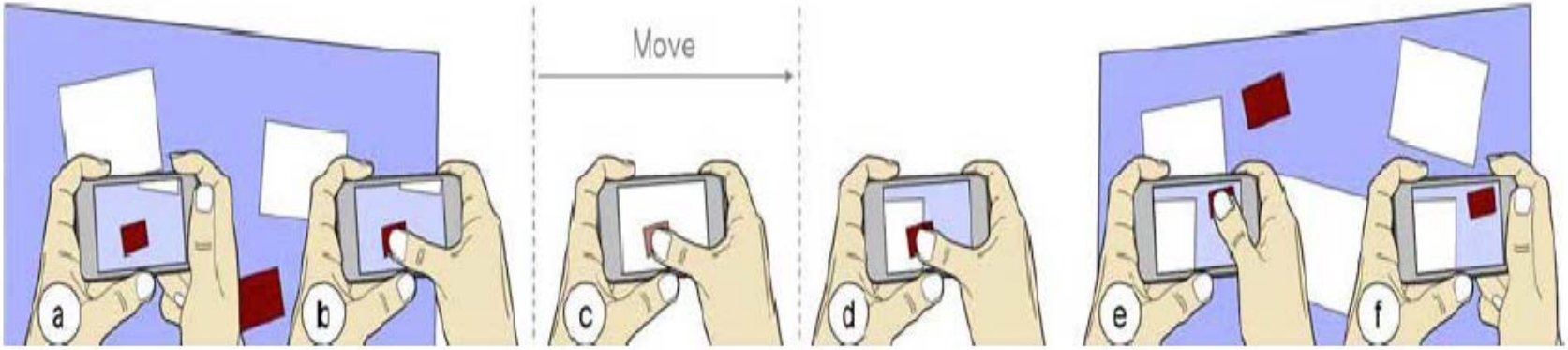
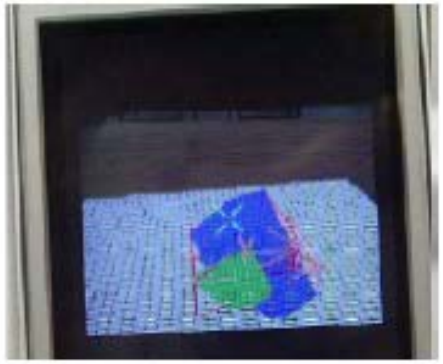
Point, Grab, Move, Release

- Relative to target 2D



- Relative to „world“ 3D





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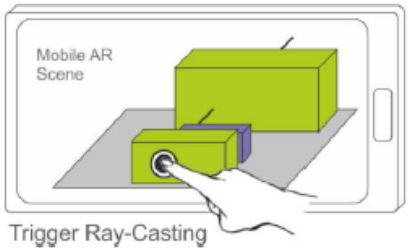
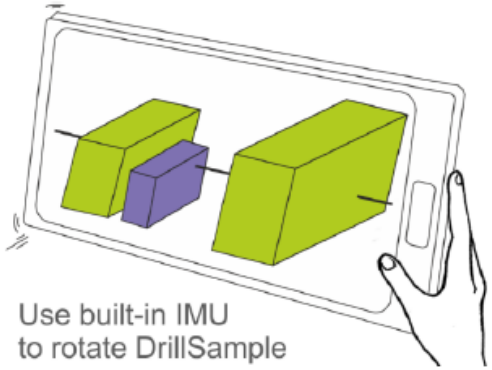
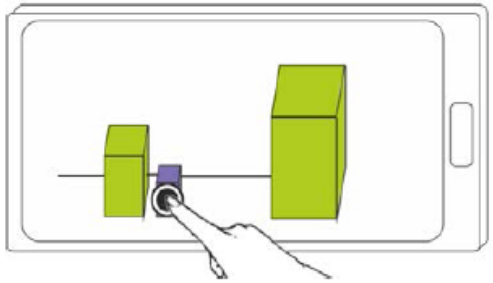
Intuitive Selection & Manipulation for Handheld AR

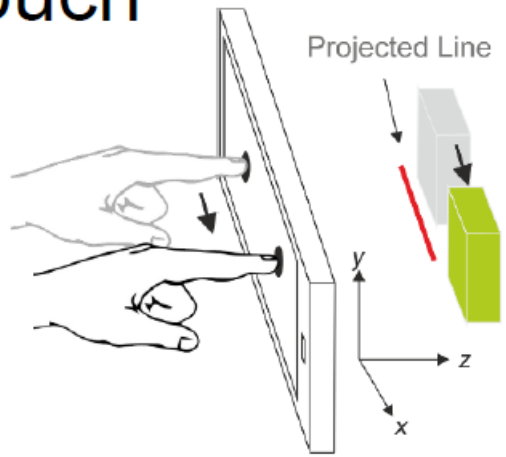
DrillSample



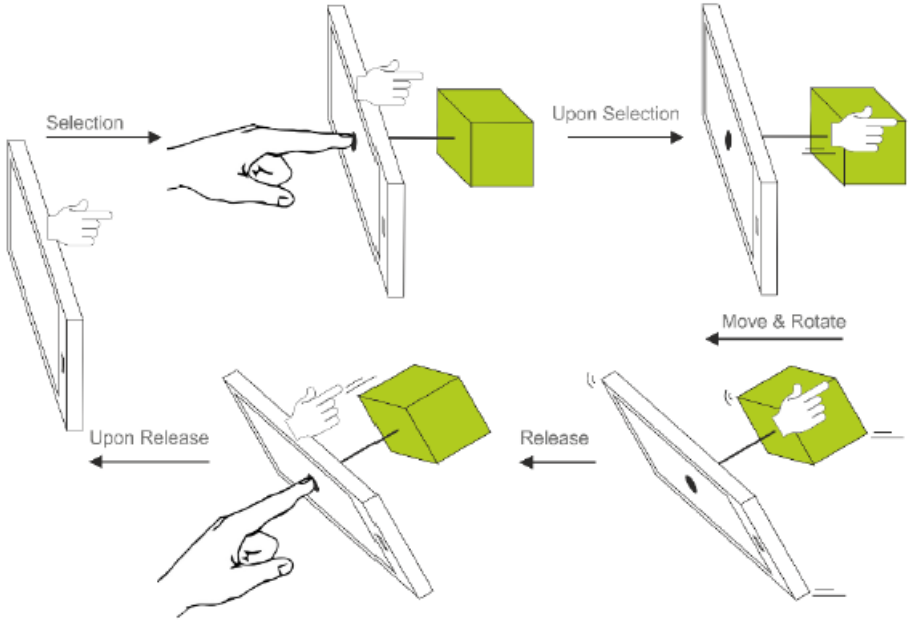




3DTouch

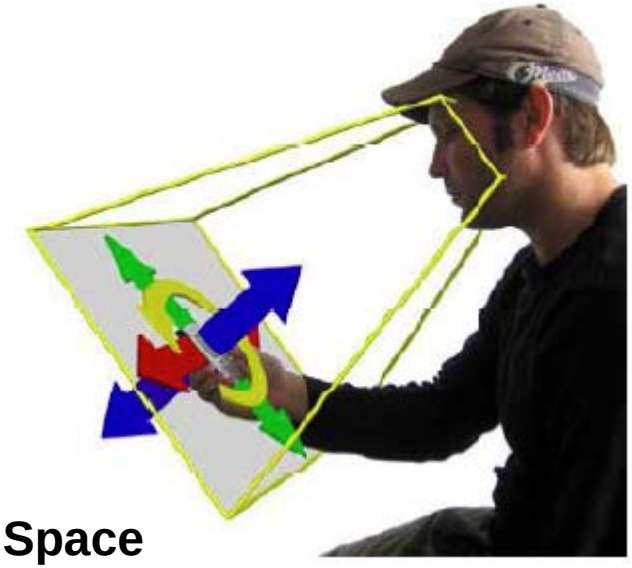


HOMER-S



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

Example Navigation Apps

- Wikitude Drive

- ACrossAir Nearest Tube

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

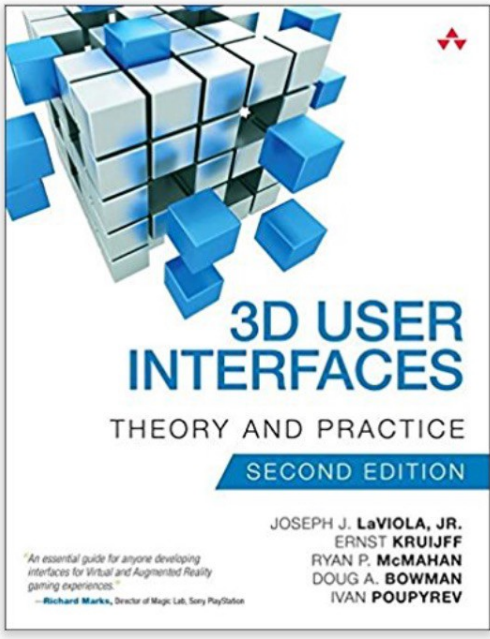
Conclusions

- Usability one of the most crucial issues facing VE applications
- Implementation details critical to ensure usability
- Ease of coding not equal to ease of use
- Simply adapting 2D interfaces is not sufficient

Conclusions

- User interface key for good VR experience
  - Need 3D user interface techniques
- Design for
  - Selection
  - Manipulation
  - Navigation
  - System control
- Follow good design guidelines
  - Cannot just implement 2D techniques in VR

Resources



- Excellent book
  - 3D User Interfaces: Theory and Practice
    - Doug Bowman, Ernst Kruijff, Joseph, LaViola, Ivan Poupyrev
- Great Website
  - http://www.uxofvr.com/
- 3D UI research at Virginia Tech.
  - research.cs.vt.edu/3di/
- Review of menu interaction in current VR applications:
  - https://blog.sketchbox3d.com/vr-design-review-2-menus-b0d7ddc3078

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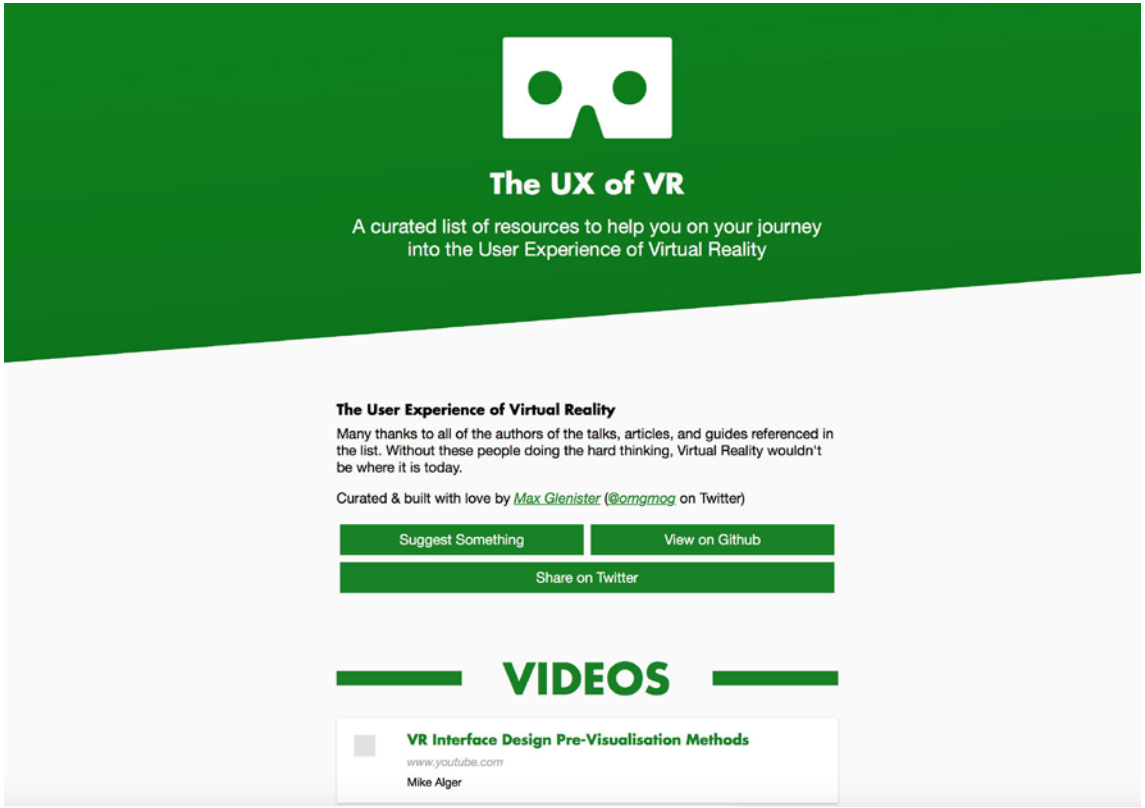
UX of VR Website - www.uxofvr.com



- Many examples of great interaction techniques
- Videos, books, articles, slides, code, etc..

Acknowledgments – Content From

- Mark Billinghurst
- Doug Bowman, Virginia Tech
- Joe LaViola, University of Central Florida
- Ernst Kruijff, Graz Univ. of Technology
- Ivan Poupyrev, Google

Doug Bowman