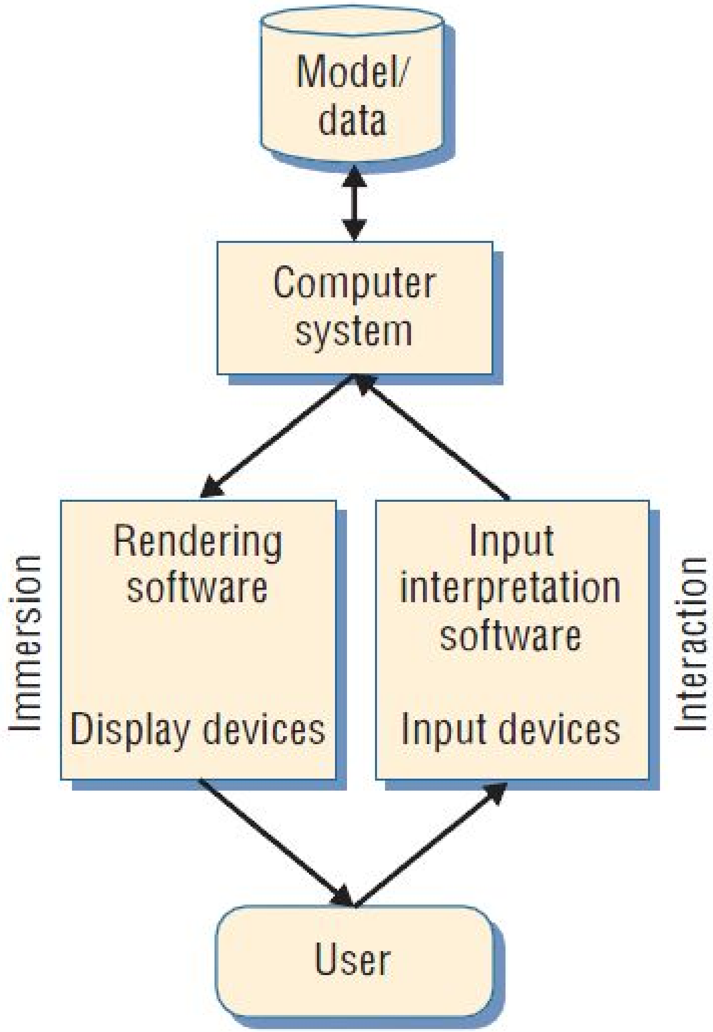
3D User Interface design for Virtual Reality applications

Which is better: Naturalism or Magic ?

The 3 universal tasks:
Navigation, Selection, Manipulation

Based on [3DUI theory & practice], [A2012],
D. Bowman course notes, Virginia Tech. and [CACM sept. 2012]

Focus : Interaction techniques



[3DUI theory & practice]

Why 3D interaction?

- 3D / VE apps. should be useful
  - Immersion
  - Natural skills
  - Immediacy of visualization (real-time feedback)

- But, current VE apps have serious usability problems

What makes 3D interaction difficult?

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

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 metaphore :
    - is natural for driving simulator
    - is not for shooting a virtual basket ball [B2012]

[Youtube:watch?v=6cLvkTCryBY]

- Some actions in VR/game have no natural equivalent, e.g. teleportation
- in-between case: mapping a bycicle riding movement with hand and arm movement

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) ?

[Youtube:watch?v=JFTRXG1y0r8]

- 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.

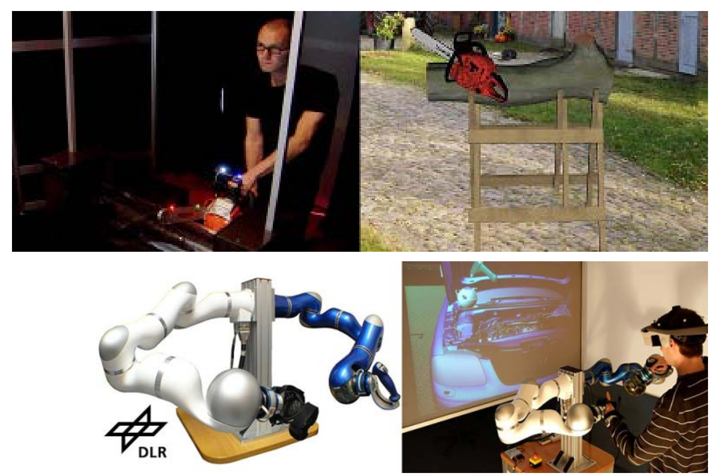
Components of 3D interactions

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 metaphore

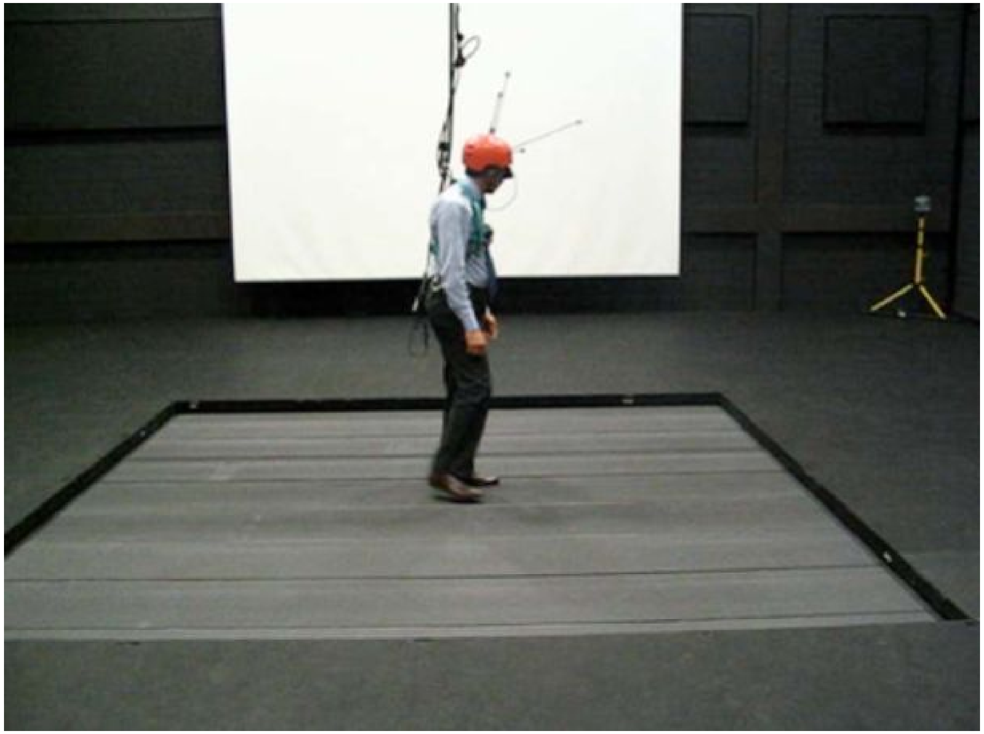
Travel: naturalistic techniques

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

- redirected walking [Razzaque PhD 2005 UNC]
- walking-in-place [Usoh et al,1999], Wiibalance
- dedicated interfaces (next slides)

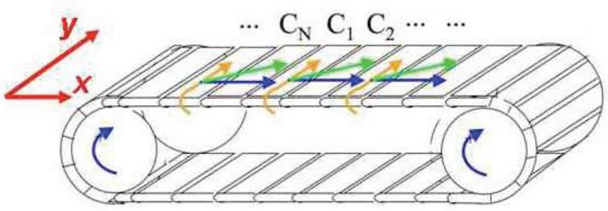
Travel naturalistic interfaces (1)

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



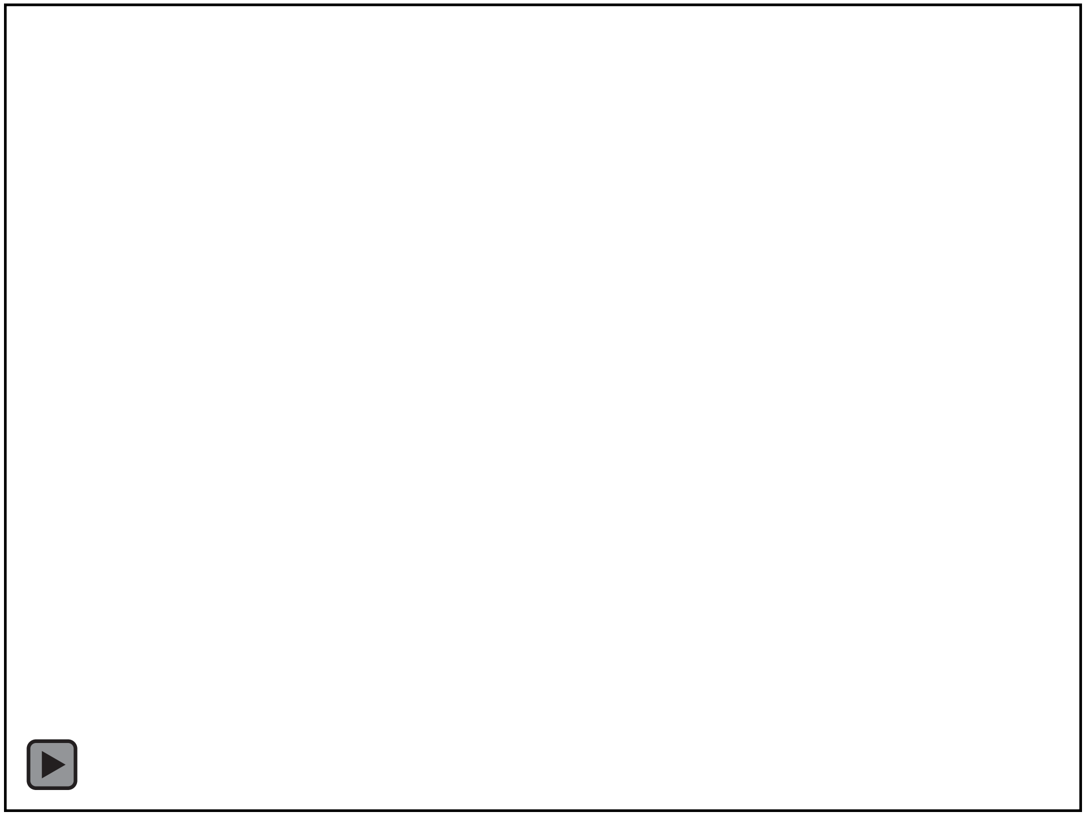
Control Design and Experimental Evaluation of the 2D CyberWalk Platform, De Luca, Mattone & Giordano, Buelthoff, IROS2009 / MPI, TUM, ETHZ, URoma

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



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)



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/s^2
- Max acc. along x (all belts): 0.25 m/s^2

Issue:

- drift in case of sudden user stop
- walking on a treadmill is not natural walk

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 Oberver component determines an update of the platform velocity to bring the user back in the middle without sudden change.

Travel naturalistic interfaces (2.5)

Recent concept/proto:

- infinadeck.com
- not yet on the market

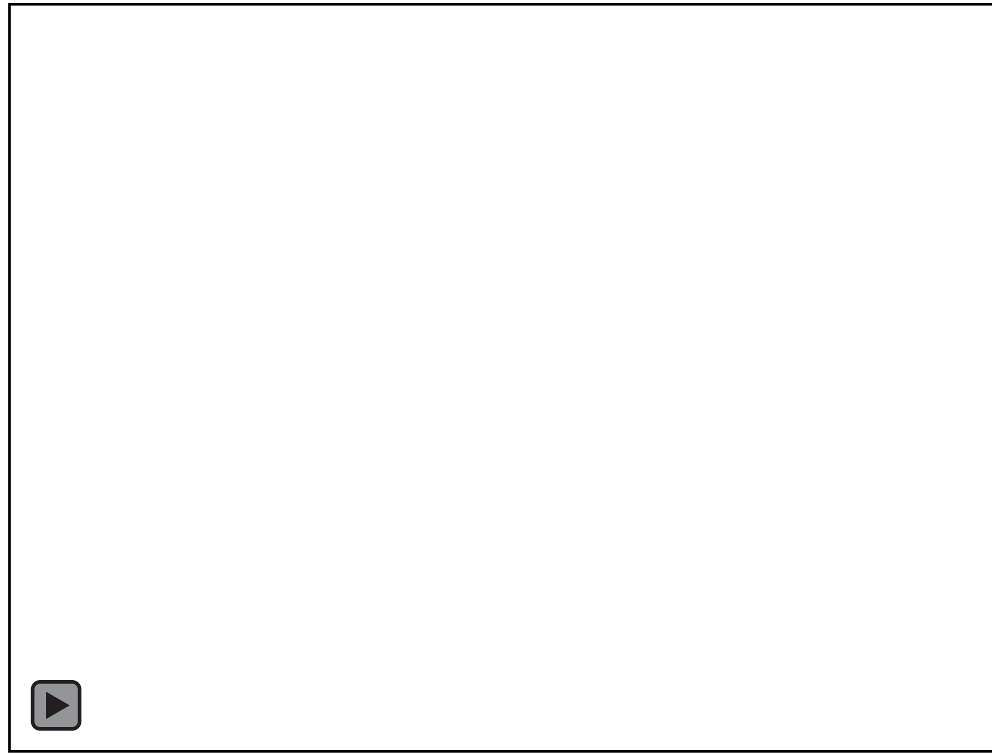
Updated tradeoff:

- smaller size -> less inertia but less space for navigating
- compensated by the tethered system

https://youtu.be/seML5CQBzP8?t=4

Naturalistic navigation interfaces (3)

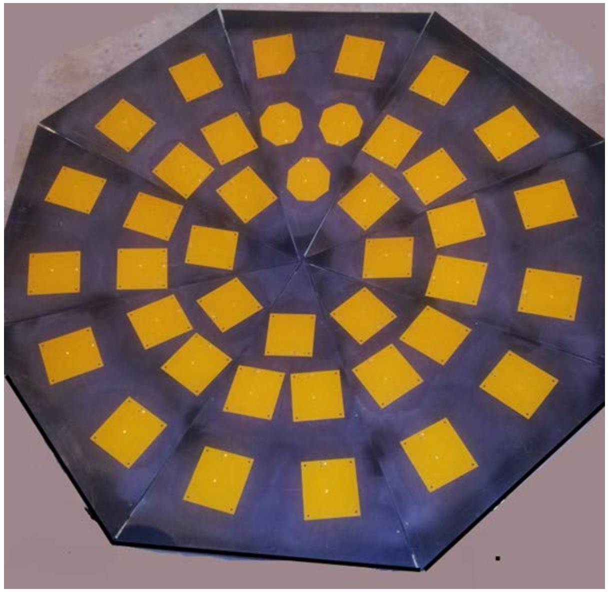
- **Locomotion tracking with virtusphere**
  - An omni-directional free-rolling sphere
  - 10 feet diameter (~3m)
  - To be used with head-mounted display for walkthrough applications, games, etc...



  - 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 (4)

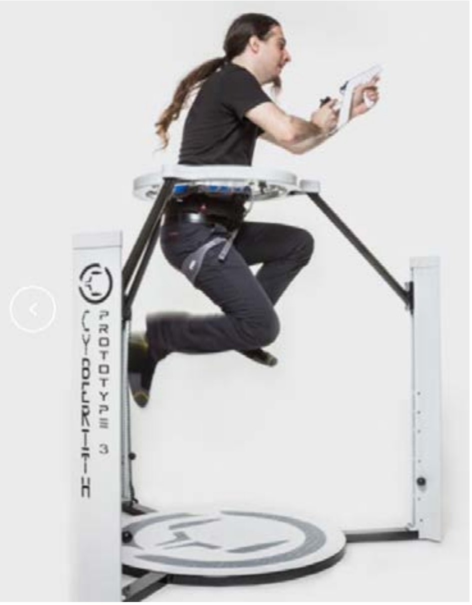
- **Locomotion tracking with virtuix OMNI (prototype)**
  - An omni-directional interface, feet tracking with capacitive sensors in the base
  - 3 feet diameter (~1m)
  - To be used with head-mounted display
  - not yet fully evaluated
    - 2016/03: start shipping to first subscribers
    - non-flat surface



[http://www.virtuix.com/]

Naturalistic navigation interfaces (4.5)

- **Locomotion tracking with Cyberith (Austria)**
  - An omni-directional interface with sensor in the base plate, pillars and ring
  - flat slippery surface
  - Use overshoes
  - Can jump or seat too
  - Price on demand

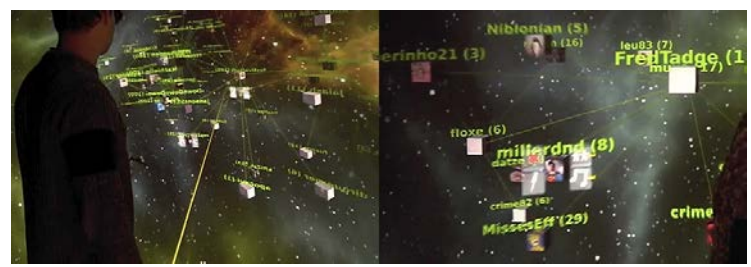


[http://www.cyberith.com/]

Travel magic techniques

- **Steering:** (like in most games / driving metaphor)
  - input device provides front,back,left,right constant speed
    - handheld device, 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**

  (easier but constrained)
  - point at object
  - specify a point of interest from a list



- **Map-based** (with additional 2D map)
  - manipulate user icon on the map

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

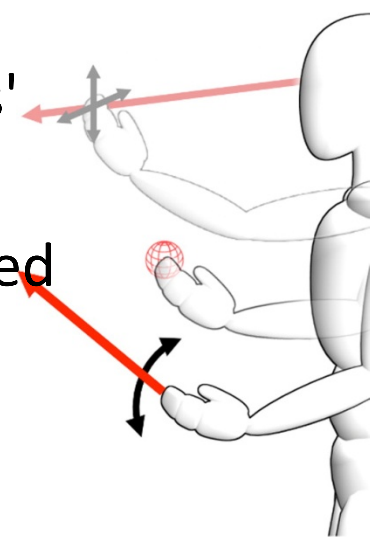
– Provide transitional motion to maintain awareness of space (teleportation does disorient users)

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

The Selection component

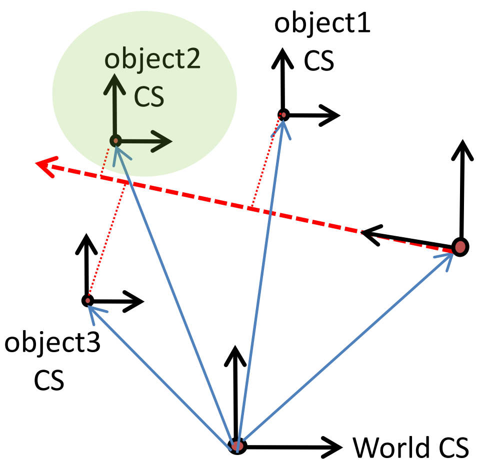
- specifying one or more objects from the environment
- Goal:
  - indicate action on object (e.g. delete, duplicate, etc..)
  - Make object active, travel to object,…

- 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)



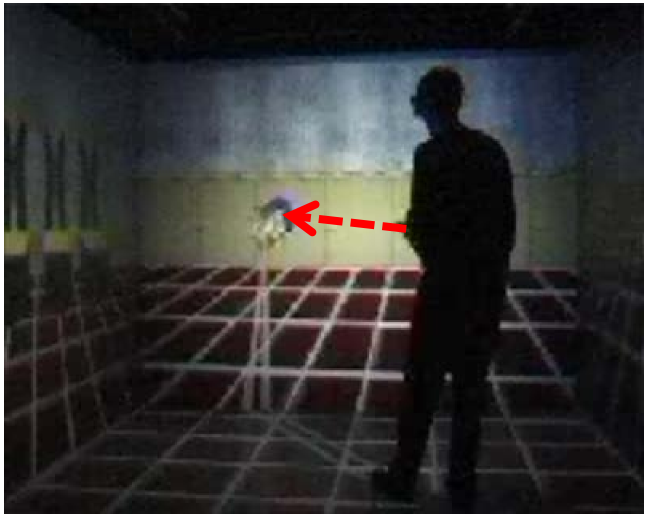
Selection by ray-casting

- Ray casting technique:
  - get world hand/device/head pos & orientation
  - compute objects distances to ray segment
  - continuously highlight closest 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:

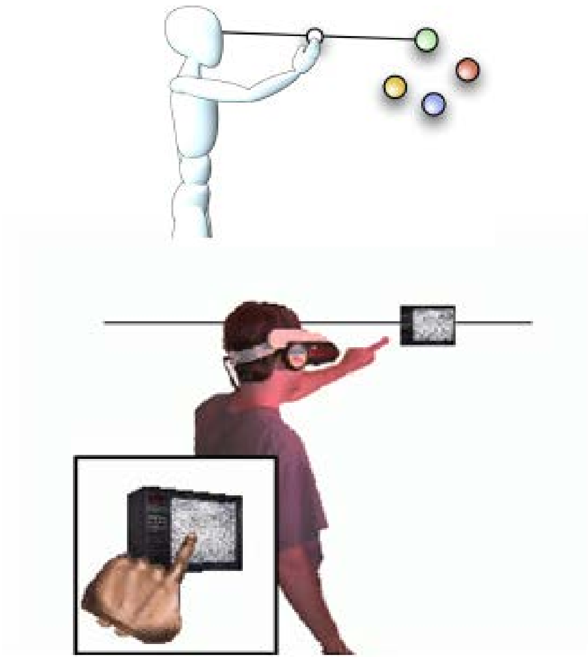
difficult to select small/far objects
target object can be occluded



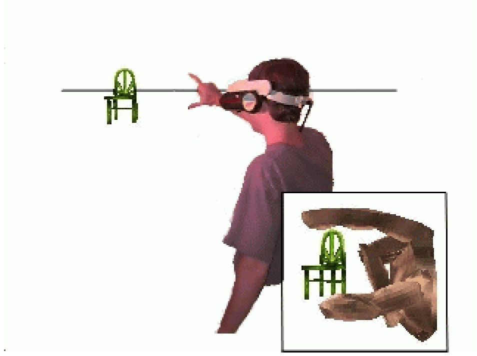
[UCL CAVE ray casting demo]

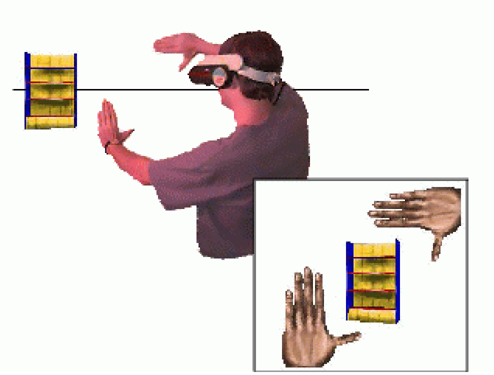
selection by occlusion or framing (image-plane technique)

- 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 closest to ray <=> the finger tip is occluding the object in the image plane



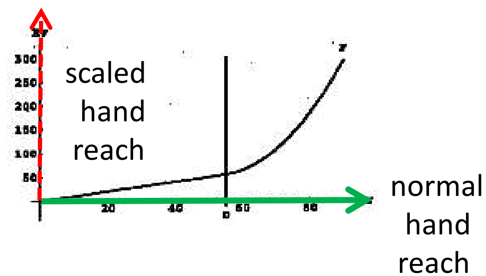
- Alternate approaches:
  - use 2 fingers or 2 hands to frame the desired object



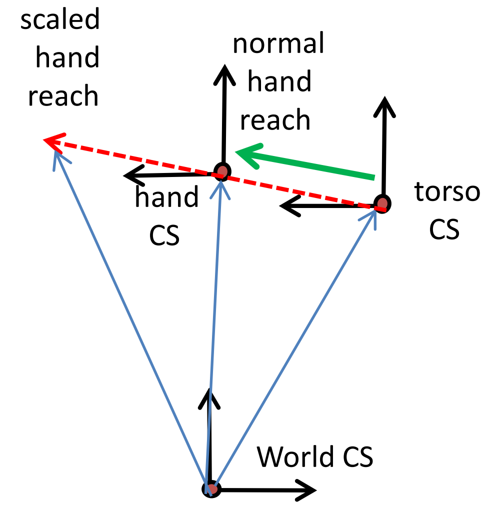


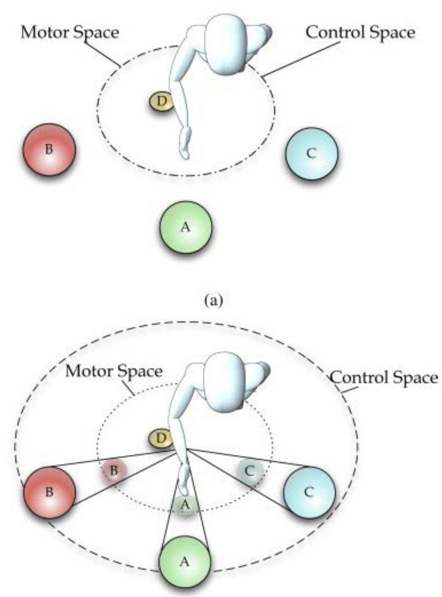
Magic selection technique

- 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



    - once selected the object is attached to the hand and can be manipulated





Magic selection technique

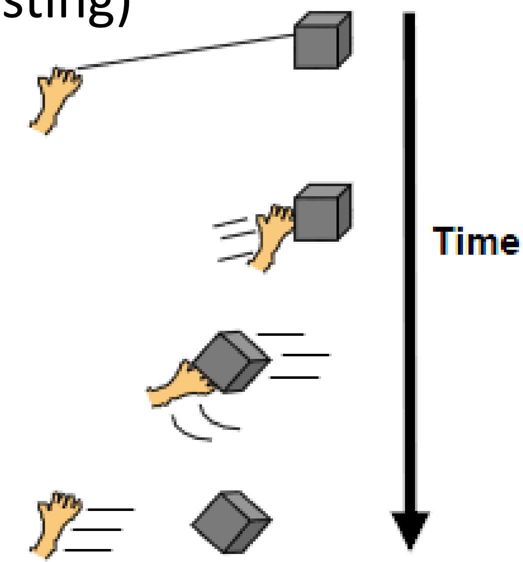
- World in Miniature (WIM)
  - scale-down the model to enhance user reach ability [Stoakley 1995]
  - remove part of the model (cut-aways) to ease the WIM visualization [Andujar 2010]

The Manipulation component

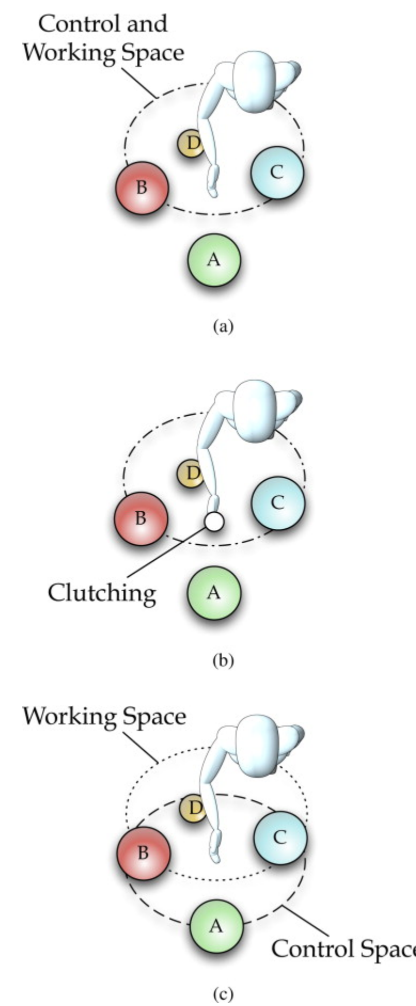
- modify object properties: position, orientation, scale, shape, color, texture, behavior, etc.
  - For positioning: Virtual hand, ray casting, scaling
  - For orienting: the object should be hand-centered
    - apply the hand (re)-orientation to the manipulated object
  - **Haptic** feedback (future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

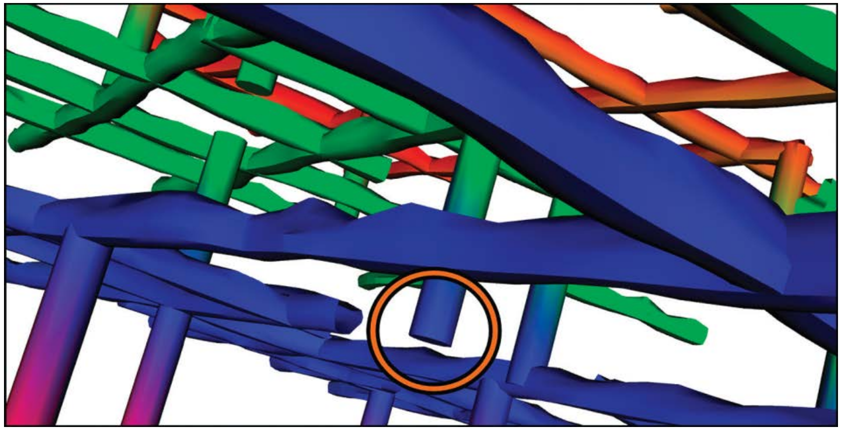
Task	Benefits of naturalism	Limitations of naturalism
Viewpoint rotation	Users prefer physical turning.[32]	Users prefer virtual turning to a combination of physical and virtual turning.[32]
	Natural turning techniques have better performance than virtual turning for visual search.[38]	
Viewpoint translation/travel	Head tracking can improve spatial understanding and detailed spatial judgments.[33]	The benefits of head tracking may depend on other factors, such as stereoscopic display.[33]
		Moderately natural techniques can have poorer performance than traditional techniques.[38]
Manipulation	Natural techniques improve performance of complex manipulation tasks.[34]	Highly natural techniques have limited range.[28]
	Hyper-natural techniques enhance users' abilities.[28]	Hyper-natural techniques often reduce precision.[36]
	It is possible to design hyper-natural techniques that feel natural and have high levels of precision.[36]	
Vehicle steering	Higher levels of interaction fidelity can be more fun for users.[3]	Moderately natural techniques can have poorer performance than traditional techniques.[3]
Aiming	Highly natural aiming techniques can have better performance than mouse-based techniques.[38]	
Multiple tasks	High levels of interaction fidelity, when paired with high display fidelity, can have very good performance.[38]	High levels of naturalism may not be beneficial if the overall interface is unfamiliar.[38]
	Users feel that highly natural techniques are more engaging and induce higher levels of presence.[38]	

Benefits & Limitations of Naturalism (2)

[Bowman, MacMahan, Ragan, CACM Sept 2012]

- 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

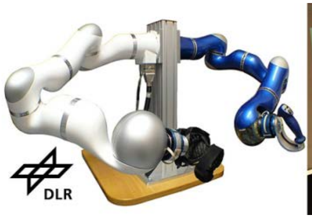
Components of 3D interactions

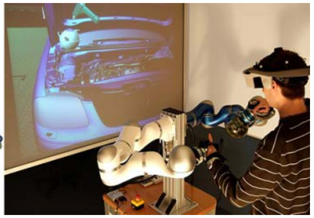
The three universal tasks:

- Navigation
- Selection
- Manipulation

Other 3DUI components

- System control
- Symbolic input
- Constraints
- Passive haptic feedback
- Two-handed interaction





System control

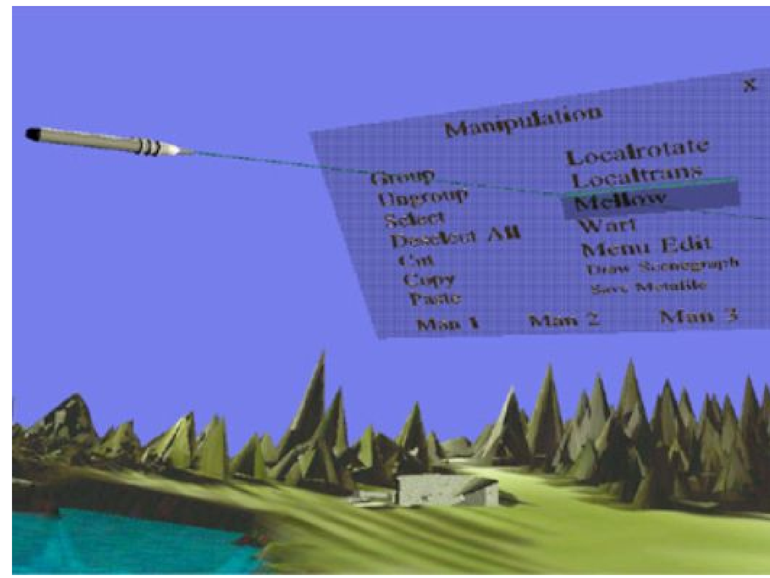
- Sometimes seen as a “catch-all” for 3D interaction techniques other than travel, selection, & manipulation

- Issuing a *command to :*
  - Change the system mode
  - Change the system state

- Often composed of other tasks

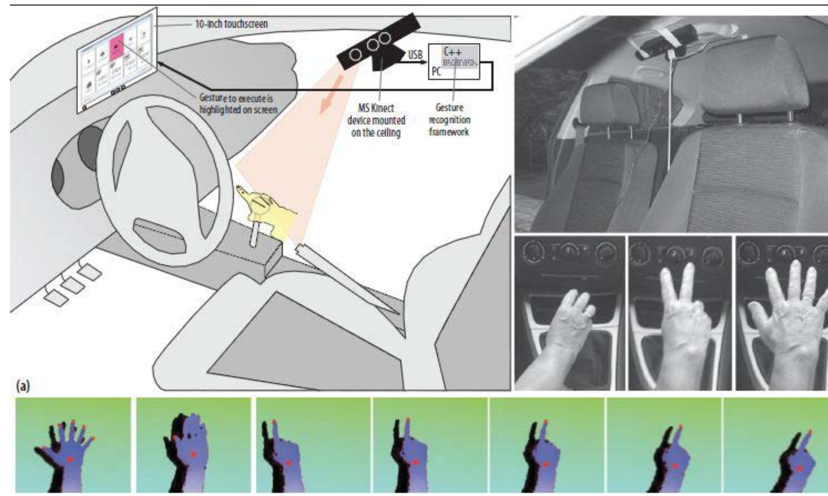
Floating menus

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



- Other types:
  - Rotating menu
  - TULIP (3 items)
- Body-centered enhance usage [Mine97]

Gestural commands



[Andreas Riener IEEE Computer 2012]

- Can be “natural”
- limited vocabulary
- Fuzzy recognition issues
  - Usually HMM [Be2009]
  - toolkit: http://ftm.ircam.fr
- 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

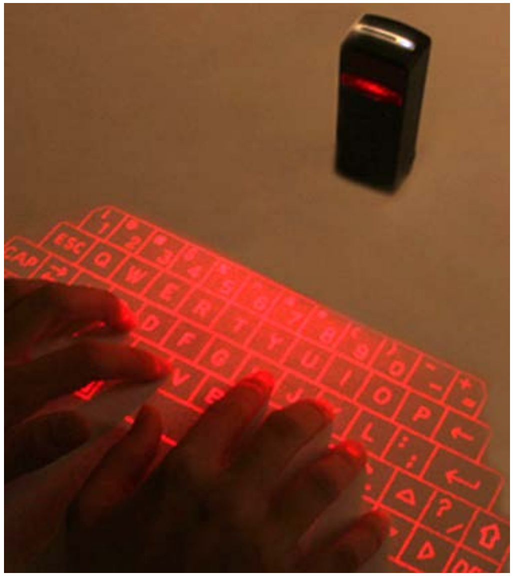
- More appropriate in multimodal interfaces (*provide more than one technique, e.g. voice*)

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?



[Celluon 2010]

Pranav Mistry: The thrilling potential of SixthSense technology

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

Pen-based: pen stroke recognition

Gestures: sign language, numeric, etc

Speech: single char, whole words, general

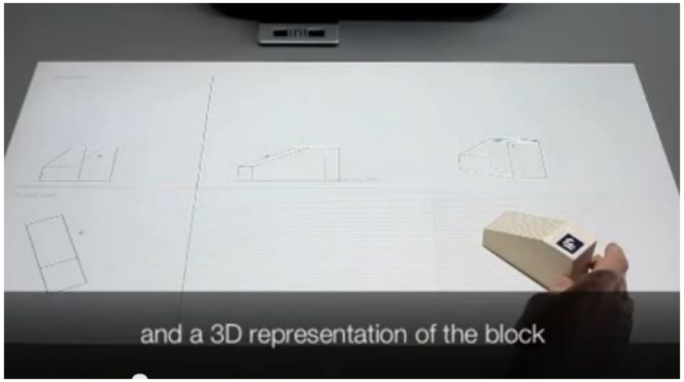
Constraints

- 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
  - Pirates’ steering wheel, cannons
  - Elevator railing
- Increase presence
- improve interaction

(e.g. S. Cuendet 2013)

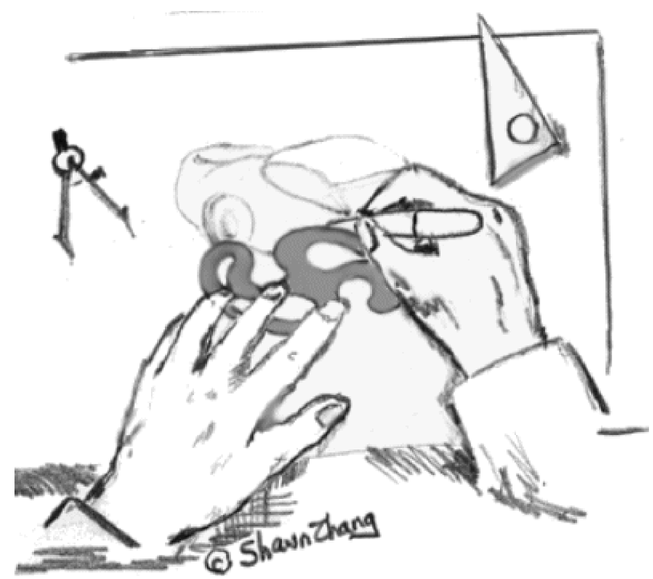


[concept of Tokyo Disney attraction, IEEE Comp. 12]

Two-handed interaction

- Symmetric vs. Asymmetric
- Dominant vs. Non-Dominant hand
- Guiard's principles

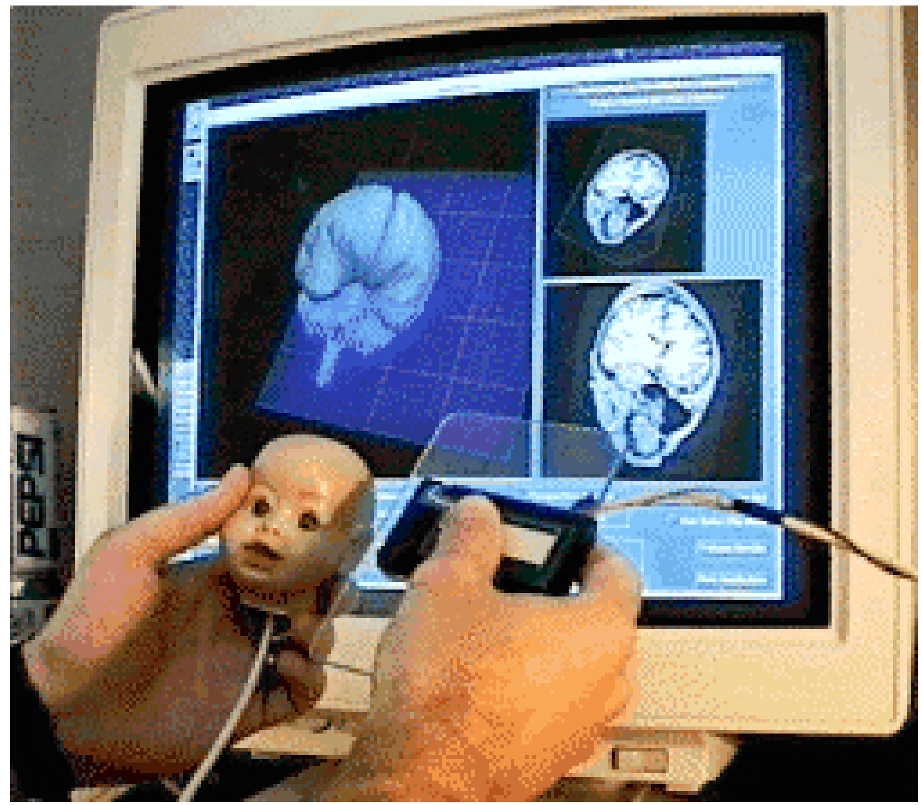
  1) ND hand provides frame of reference



[Scott Mackenzie 2003]

Two-handed interaction (2)

- Guiard's principles
  - 2) ND hand used for coarse tasks, D hand 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

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

- resources: www.3dui.org
- research in VR: http://knowledgebase.cs.vt.edu/

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