3D User Interface design for Virtual Reality applications

Which is better: Naturalism or Magic ?

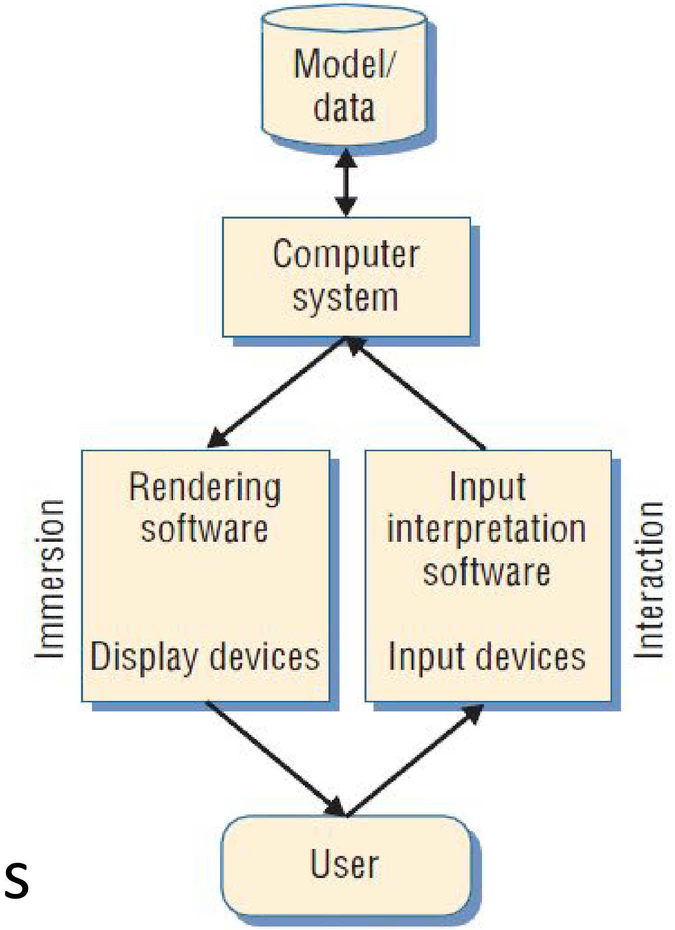
The 3 universal tasks:
Navigation, Selection, Manipulation

Based on [3DUI theory & practice 2nd edition 2017], [A2012],
D. Bowman course notes, Virginia Tech. and [CACM sept. 2012]
J. Jerald, The VR Book, Human_centered design for Virtual Reality, 2016

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

EPFL

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]

[Kongsberg Maritime simulator]

•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, 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) ?


[okanagan college: collision repair department]

• 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.

EPFL IIG

Components of 3D interactions

The three universal tasks:

- **Navigation**
- **Selection**
- **Manipulation**

Other 3DUI components

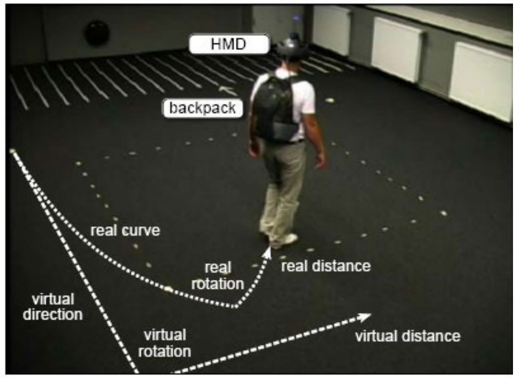
- System control
- Symbolic input
- Constraints
- Passive haptic feedback
- Two-handed interaction

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

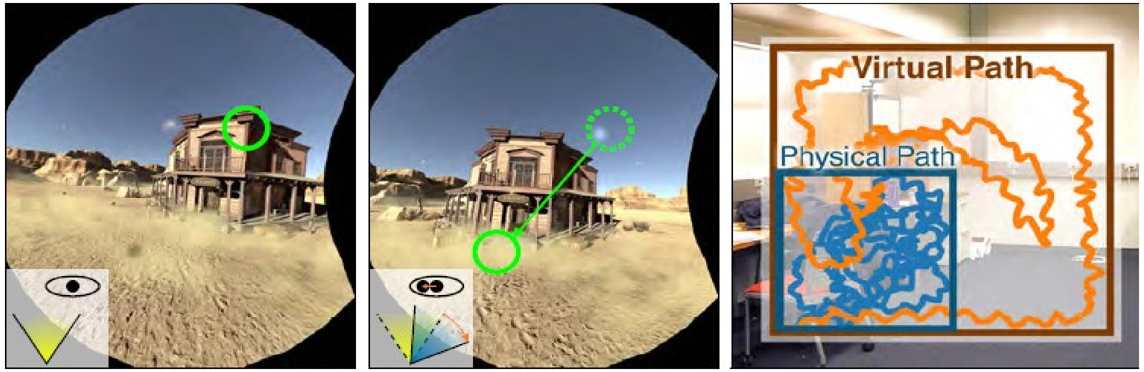
Travel: naturalistic techniques

- 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]
  - 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

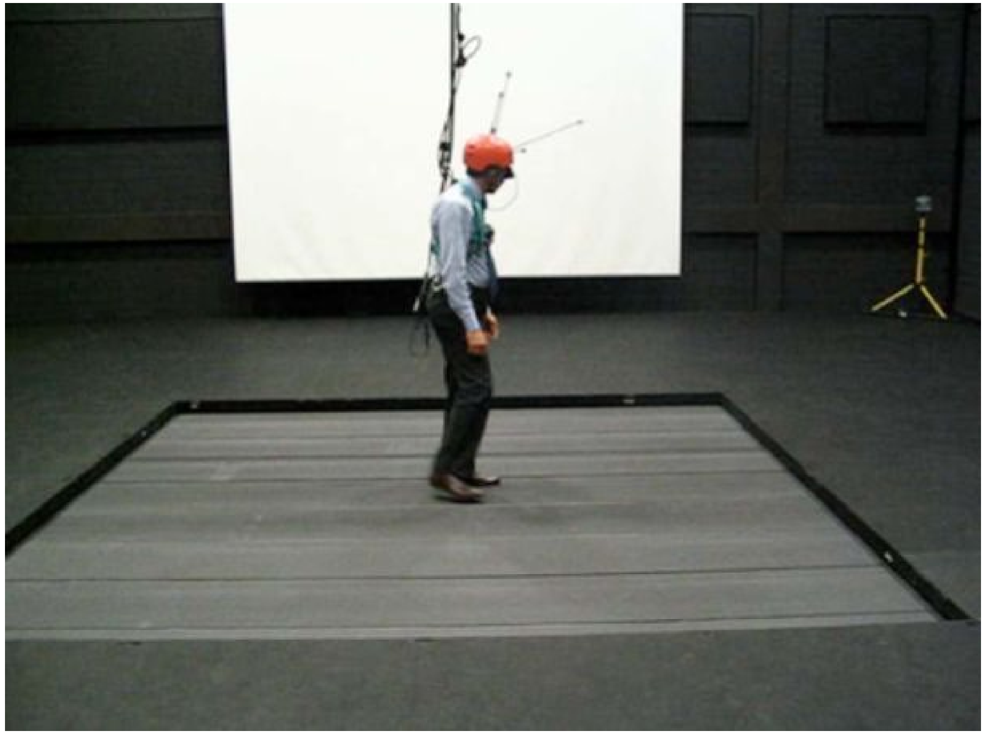
https://youtu.be/eDk4HrEtGrM



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

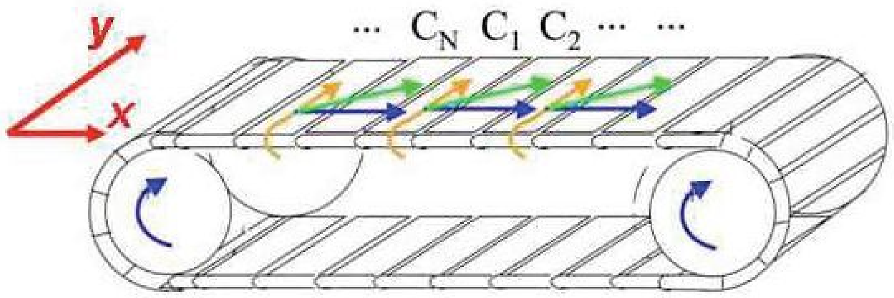
Travel naturalistic interfaces (1)

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



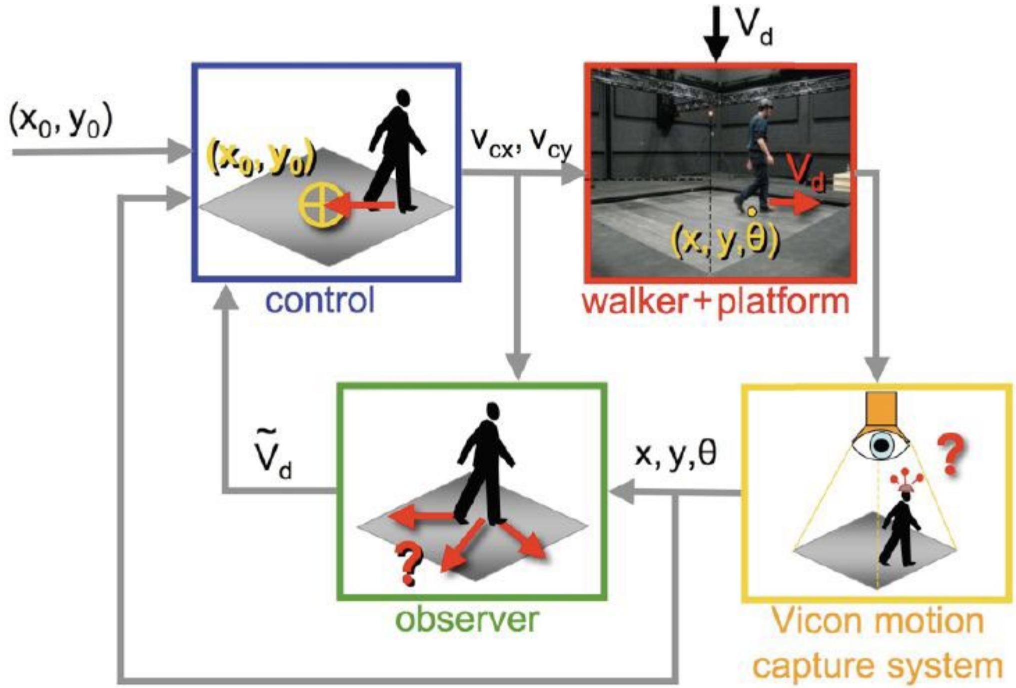
Control Design and Experimental Evaluation of the 2D CyberWalk Platform, De Luca, Mattone & Giordano, Buelthoff, IROS2009 / MPI, TUM, ETHZ, URoma

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)



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.

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

Travel naturalistic interfaces (3)

<u>concept/proto evolving since 2015:</u>

- infinadeck.com
- sold to labs / price range: 40-60 KUSD

<u>Updated tradeoff:</u>

- 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

https://www.youtube.com/watch?v=68YMEmaF0rs&t=2s

- 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

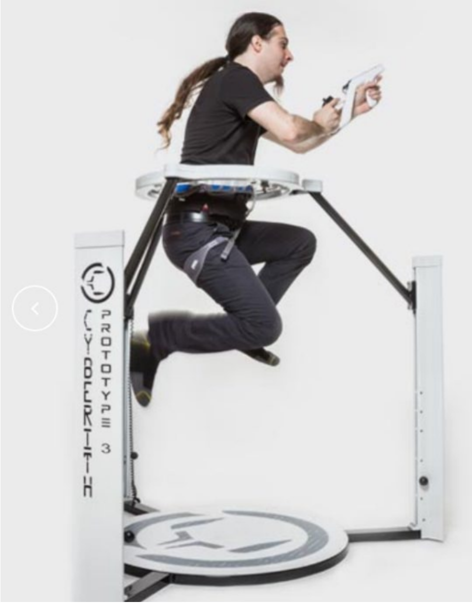
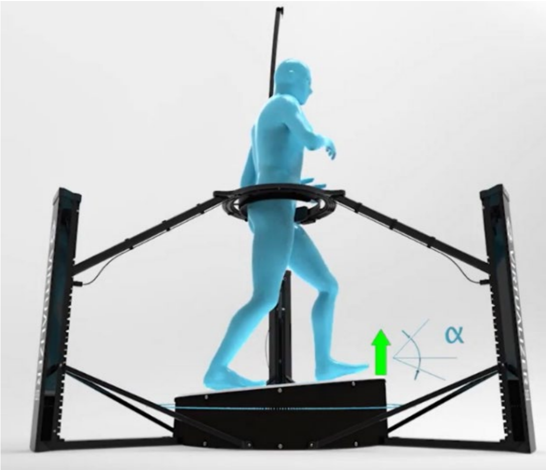
Naturalistic navigation interfaces (4)

- **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)

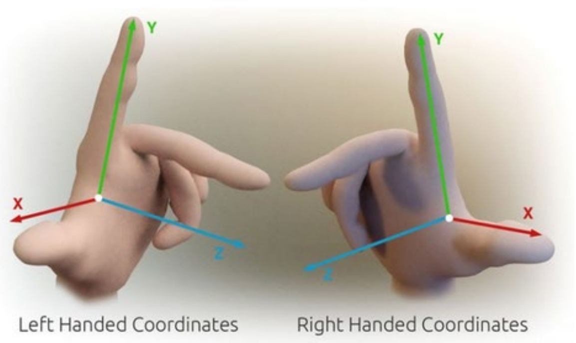
- **Locomotion tracking with Cyberith (Austria)**
  - An omni-directional interface with sensor in the base plate, pillars and ring
  - flat slippery surface => sliding movement
  - Use overshoes
  - Can jump or seat too
  - Price ~6KEURO
  - Cyberirth2 integrates a floor that can automatically tilt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

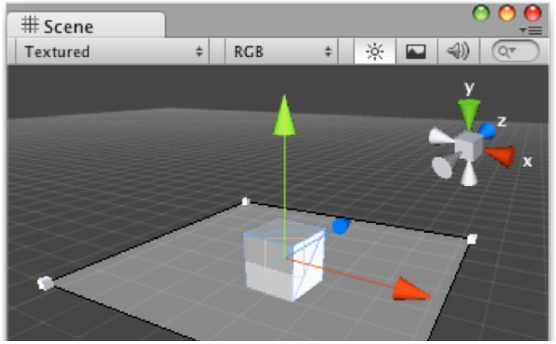





[http://www.cyberith.com/]

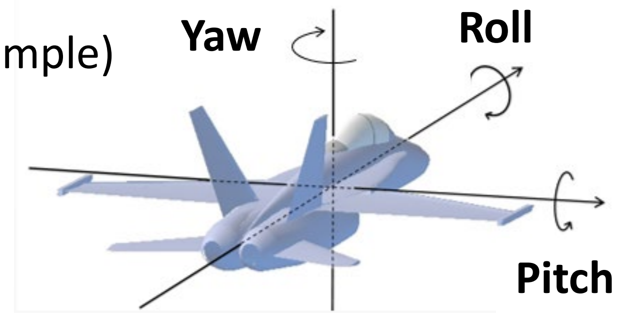
Travel **magic** techniques

- 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)





UNITY convention for 3D coordinate system



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*
    - <u>towards the center of the display</u> vs <u>device pointing direction</u>
    - beneficial to separate *viewing direction* from *travel direction*

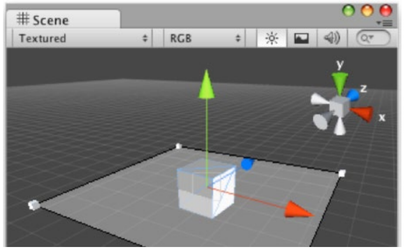
- **Target-based / Teleportation / Dash tranfert**
  - point in 3D with ray & jump (instantaneous or fast blurred movement = dash)
  - specify a point of interest from a list   (easier but constrained if predefined targets)

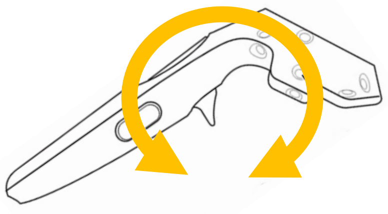
- **Map-based** (with additional 2D map)
  - manipulate user icon on the map

Travel magic techniques: teleportation

The **Yaw** angle
around the vertical axis
defines the radial
Pointing direction

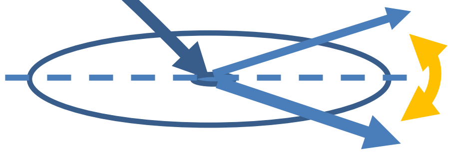
Standard straight line selection metaphor

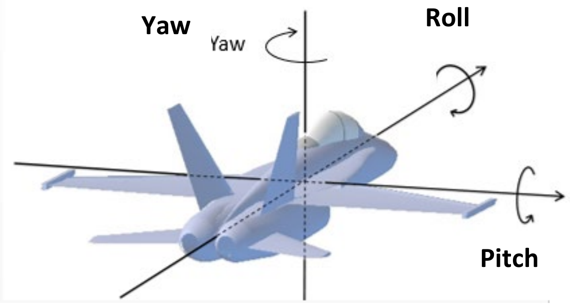




Pitch angle

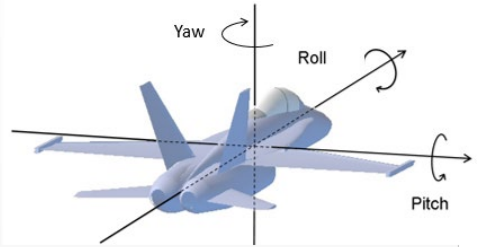
Recent parabolic curve
selection metaphor
-> less fatiguing for pointing
a target location on the floor

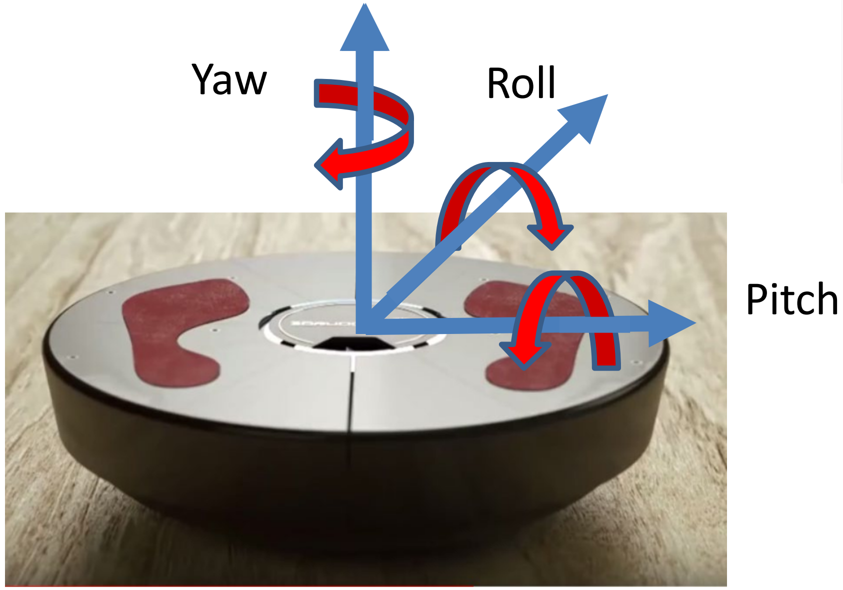




The **Roll** angle
can be used to define
the target radial
Direction [F2019]+video

- 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)

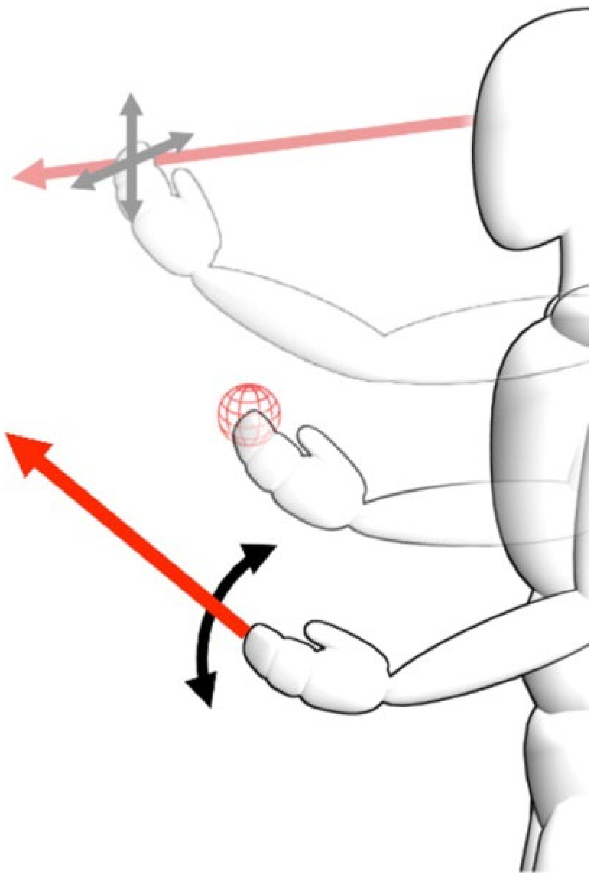
– Naturalistic technique is best if the goal is ***training*** a ***real-world task***, or to <u>increase presence</u>

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

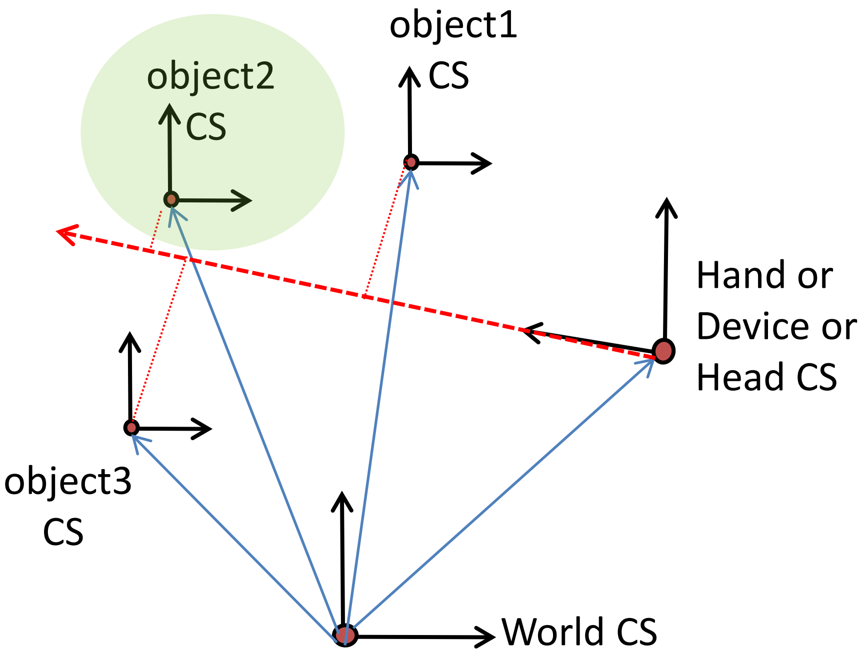
  - *pointing at* with ray/cone casting is still considered natural
    - ray built from hand/device/head orientation
    - or from eye-to-finger direction (Image Plane)



Selection by ray-casting

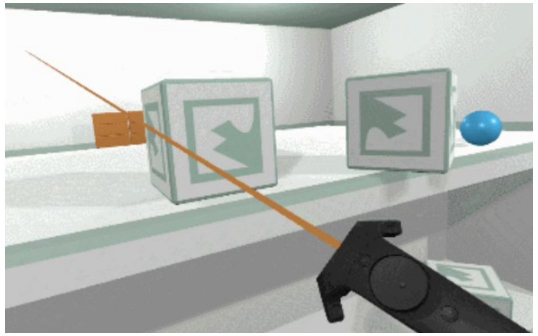
Ray casting technique:

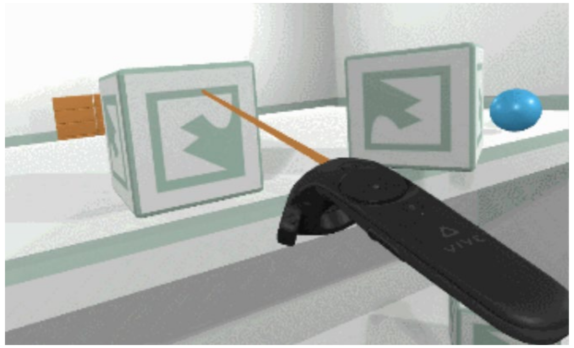
- get world hand/device/head pos & orientation
- compute objects distances to ray segment
- continuously highlight closest *visible* object to ray
- select the closest one when a dedicated event is produced by the user (e.g. *button press on google cardboard HMD or simply a timeout event when an object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

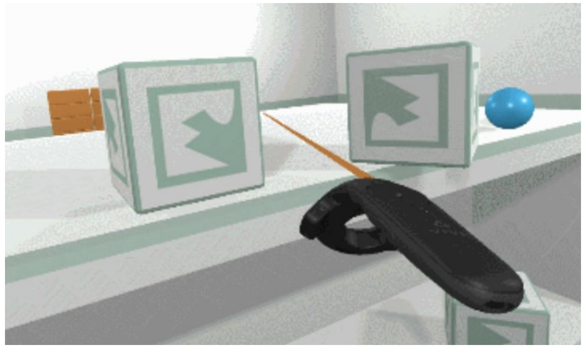


Weakness:

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

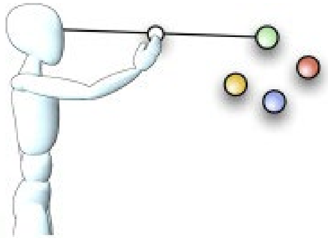


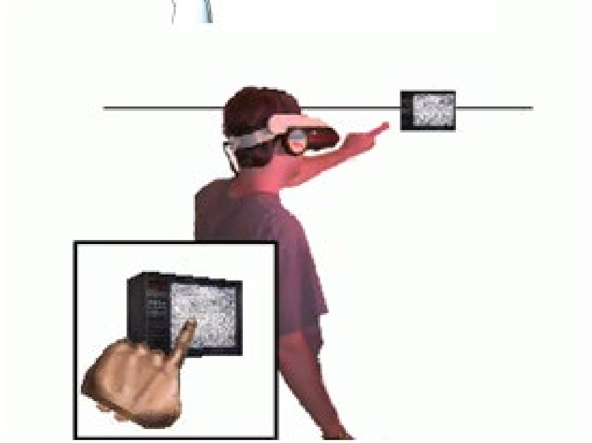




selection by occlusion or framing (image-plane technique)

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



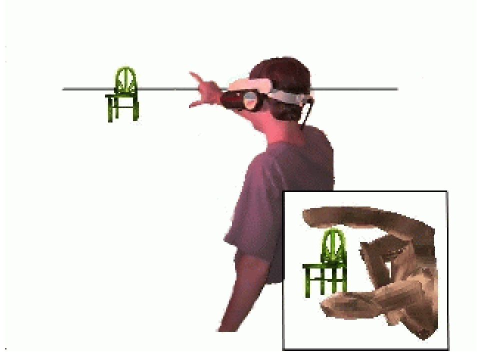


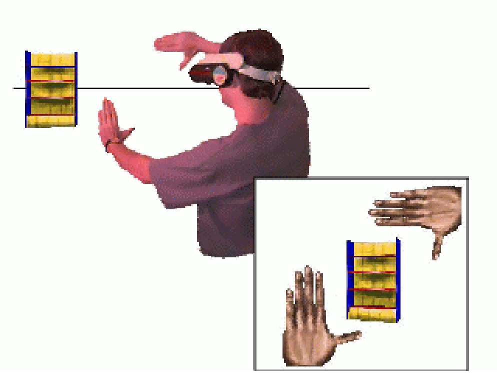
- get world head pos/orient ->eye position
- get hand pos/orient -> finger tip position
- compute objects distances to "eye-through-finger" ray
- highlight/select visible object closest to ray

  <=> the finger tip is occluding the object in the image plane

Alternate approaches:

- use 2 fingers or 2 hands to frame the desired object

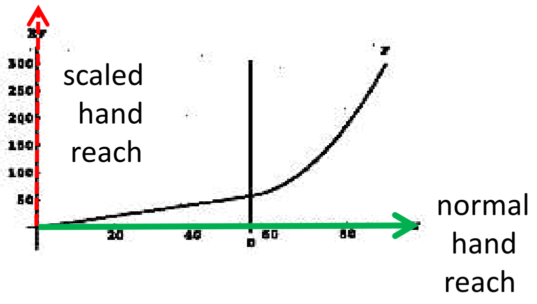


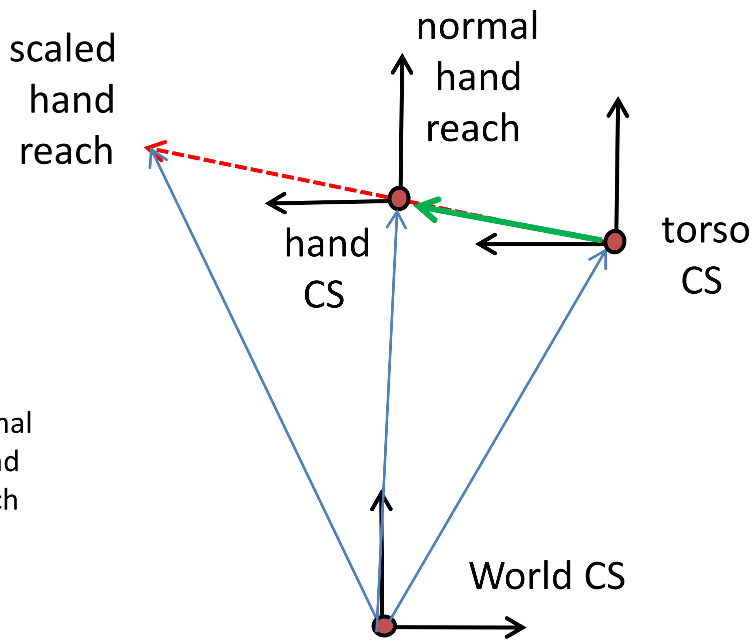


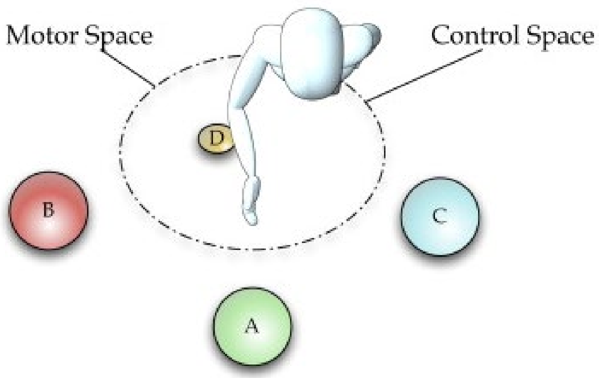
Magic selection technique

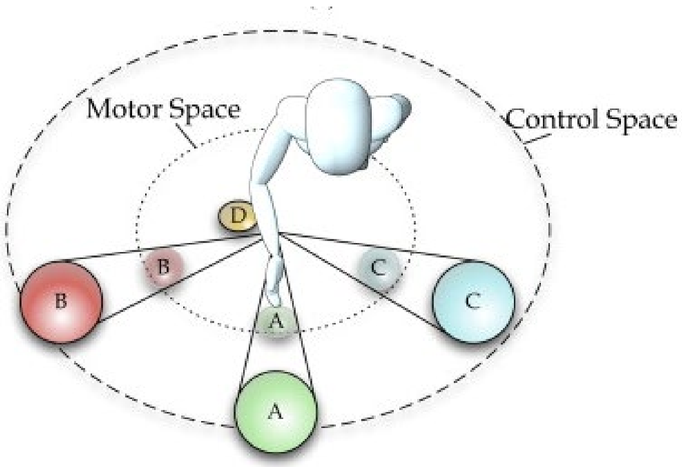
extended "hyper-natural" touching
or pointing metaphors

- 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









Magic selection technique

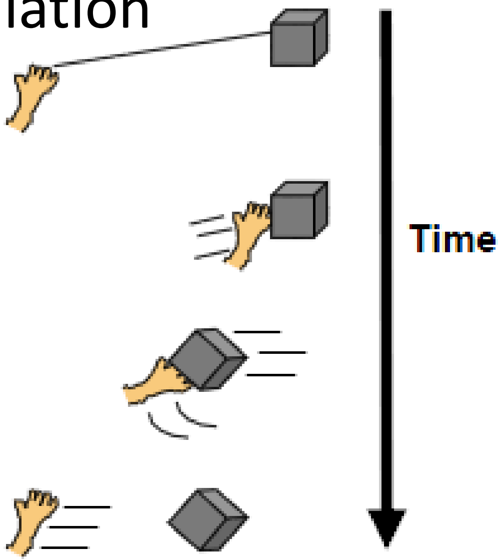
- World in Miniature (WIM)
  - scale-down the model to enhance user reach ability [Stoakley 1995]
  - remove part of the model (cut-aways) to ease the WIM visualization [Andujar 2010]

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

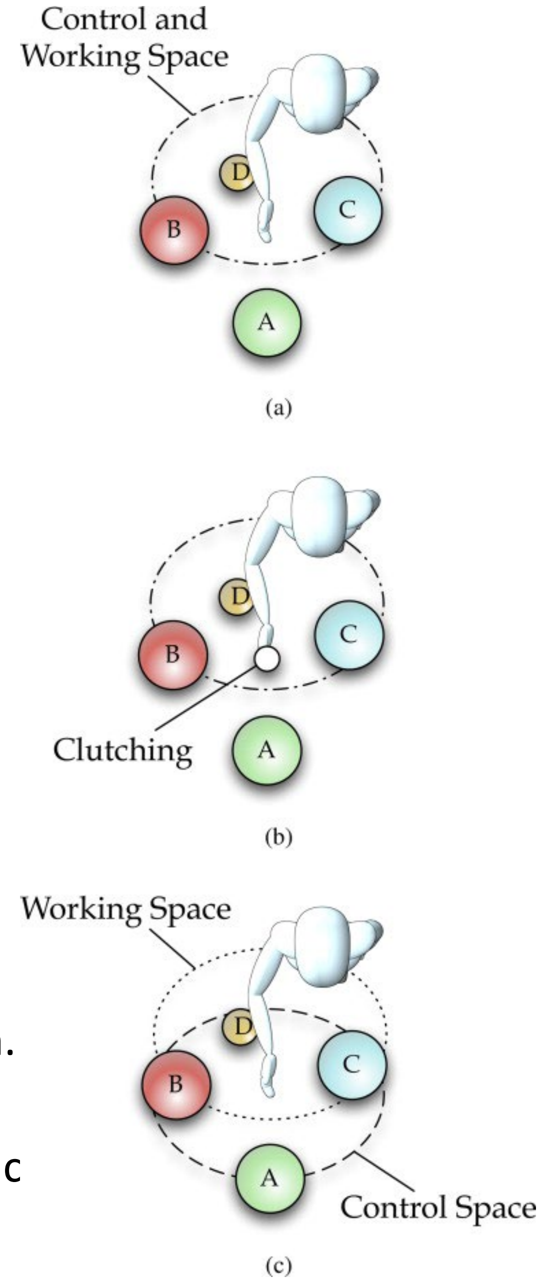
Magic manipulation technique

- 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 spac 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.

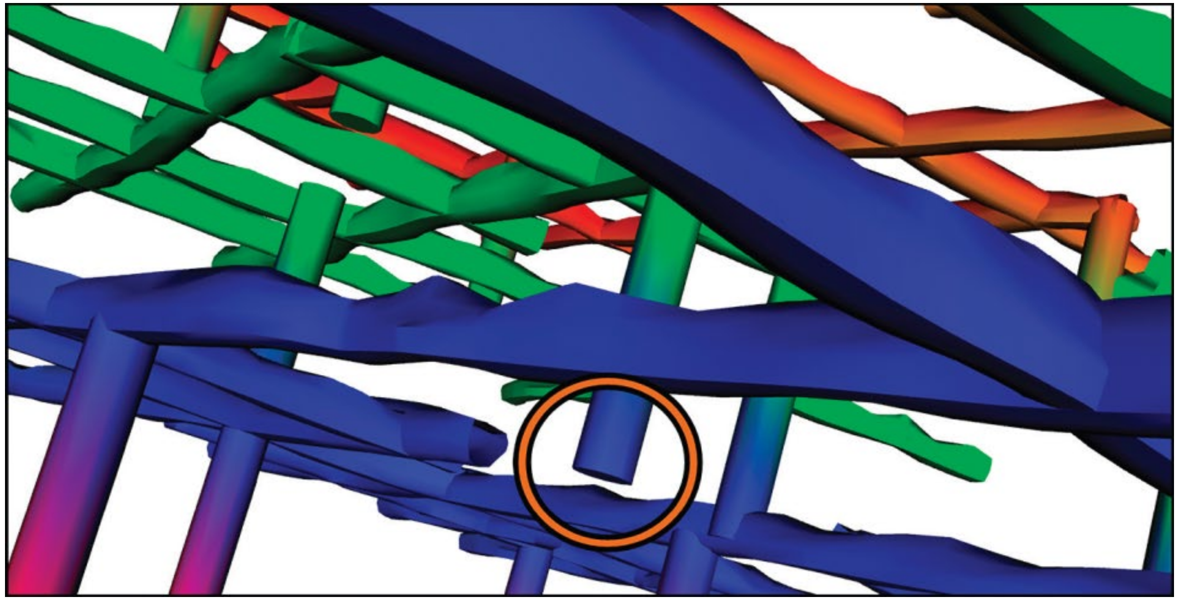
Task	Benefits of naturalism	Limitations of naturalism
Viewpoint rotation	Users prefer physical turning.[32]	Users prefer virtual turning to a combination of physical and virtual turning.[32]
	Natural turning techniques have better performance than virtual turning for visual search.[38]	
Viewpoint translation/travel	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

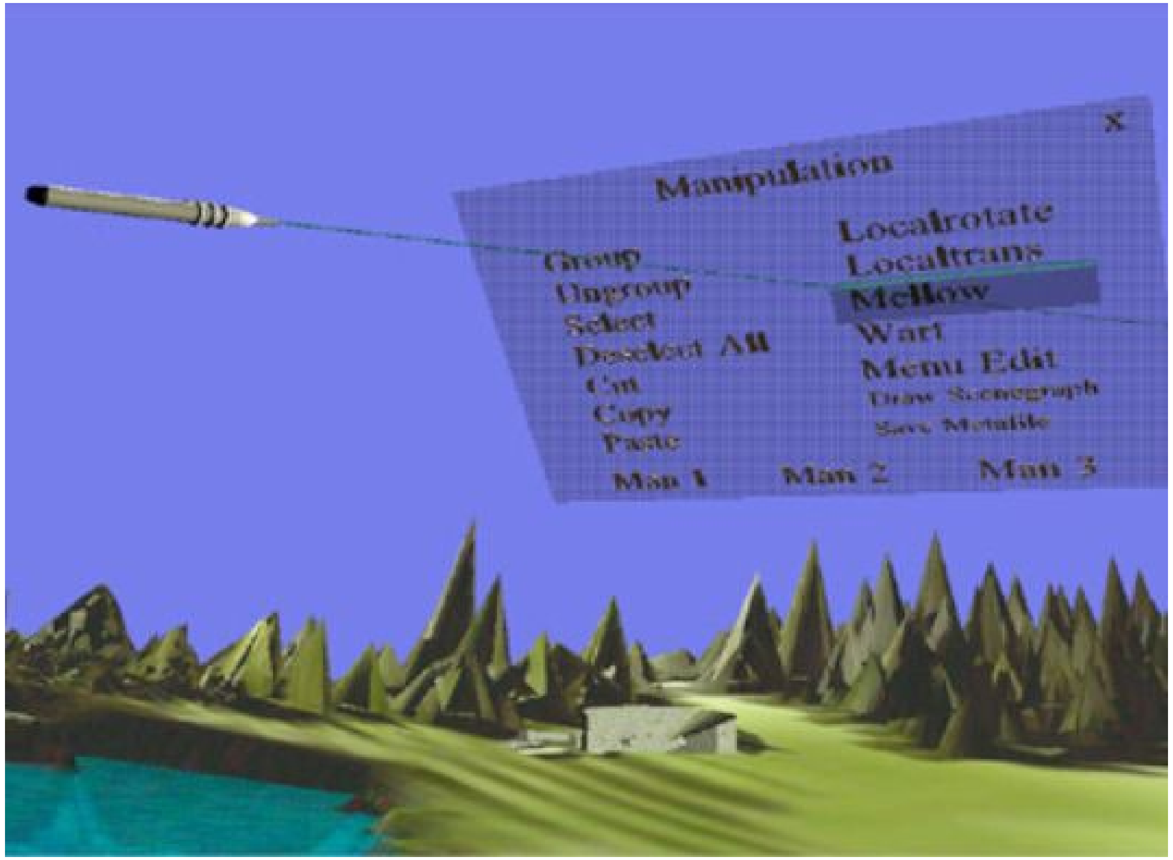
- Sometimes seen as a “catch-all” for 3D interaction techniques other than travel, selection, & manipulation

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

- Broad variety of tasks

Floating menus

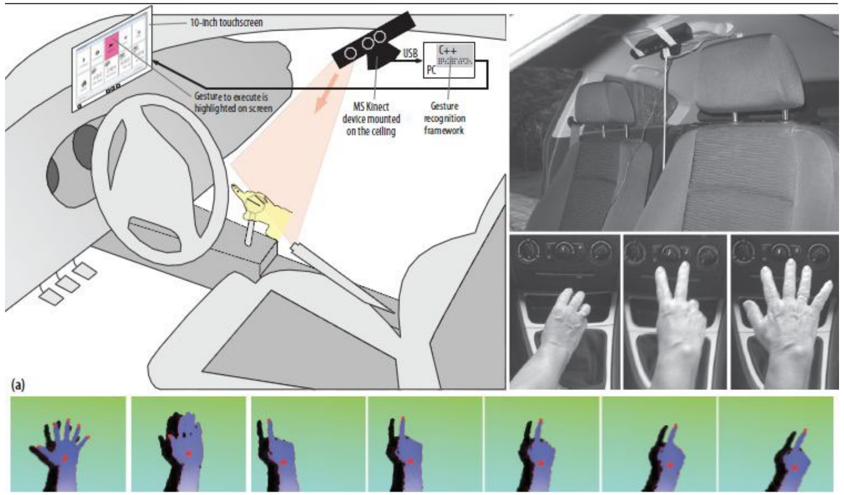
- Can occlude environment
- Using 3D selection for a 1D task



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

- Body-centered enhance usage [Mine97]

Gestural commands



[Andreas Riener IEEE Computer 2012]

- Can be “natural”
- limited vocabulary
- Fuzzy recognition issues
  - HMM [Be2009] & ML
  - 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

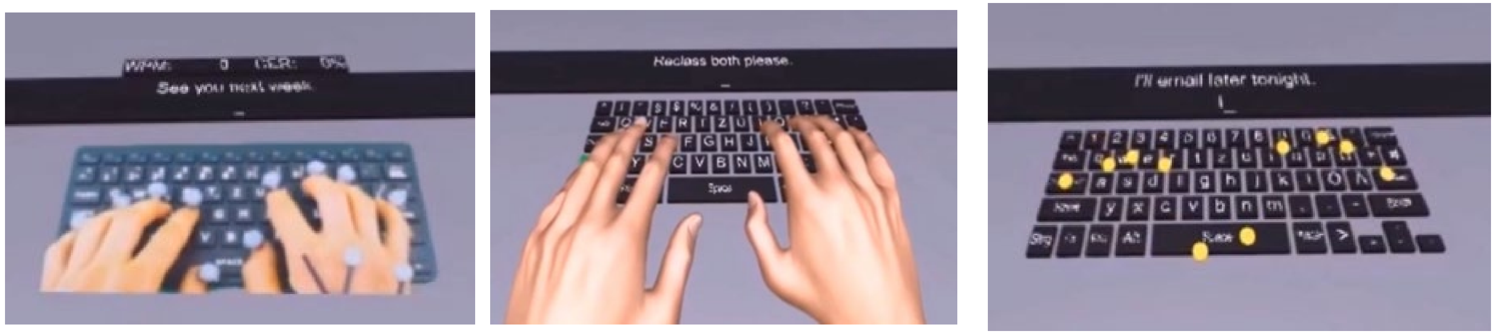
- Don’t disturb flow of action
- Use consistent spatial reference
- Allow multimodal input (redundancy)
- Structure available functions hierarchically
- Prevent mode errors by giving feedback

Symbolic input

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

Meta workrooms Horizon
Cnet evaluation

[Gruber 2018]



Keyboards: miniature, low key-count, tracked, 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)

EPFL

IIG

Passive haptic feedback/Tangible

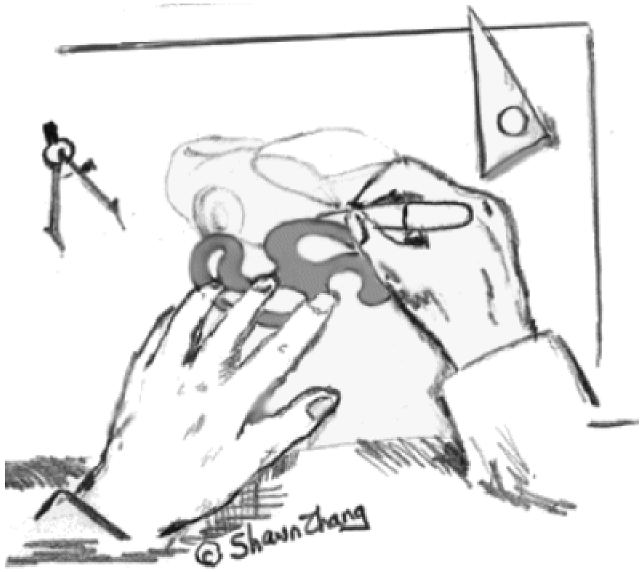
- Tangible interfaces
- Props or “near-field” haptics
- Examples:
  – Flight simulator controls
  – Torch and tomb (above right)
  – Pirates’ steering wheel, cannons =>
- Increase presence
- improve interaction

[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



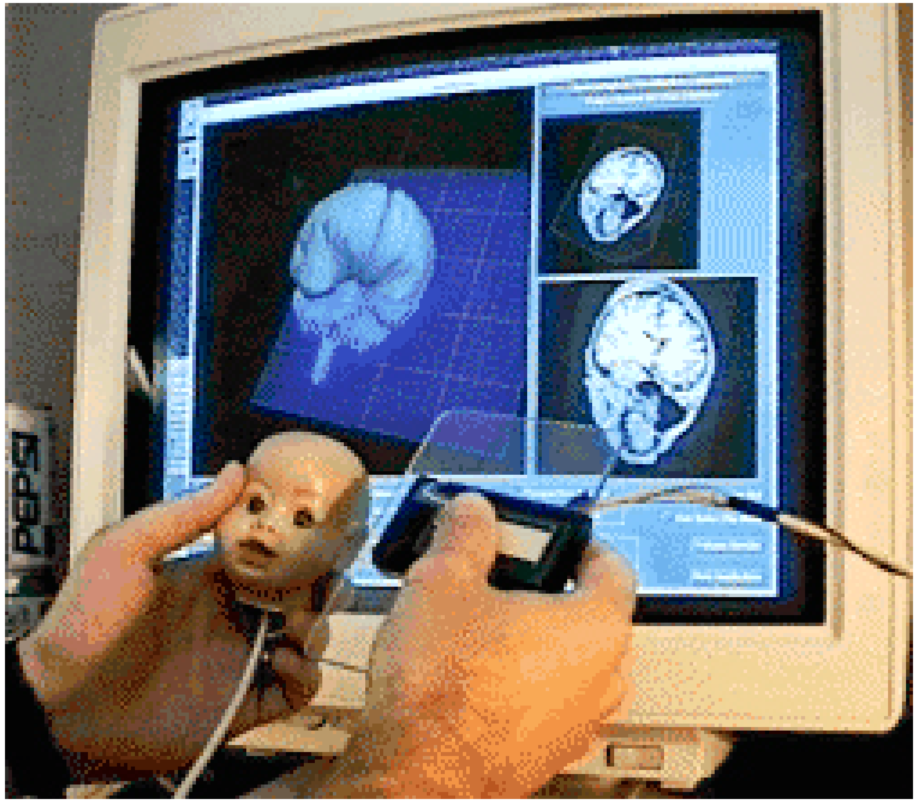
[Scott Mackenzie 2003]

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

EPFL IIG

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