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3D User Interfaces for Virtual Reality and Games: 3D Selection, Manipulation, and Spatial Navigation

Siggraph 2018 Course Notes

Bernhard E. Riecke, PhD (Organizer & Speaker)
Associate Professor
School of Interactive Arts and Technology (SIAT), Simon Fraser University

Joseph J. LaViola Jr., PhD (Speaker)
Charles N. Millican Faculty Fellow and Associate Professor
Department of Computer Science, University of Central Florida

Ernst Kruijff, PhD (Speaker)
Interim Professor
Institute of Visual Computing, Bonn-Rhein-Sieg University

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SIGGRAPH '18, August 2018, Vancouver, BC, Canada

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Abstract

In this course, we will take a detailed look at different topics in the field of 3D user interfaces (3DUIs) for Virtual Reality and Gaming. With the advent of Augmented and Virtual Reality in numerous application areas, the need and interest in more effective interfaces becomes prevalent, among others driven forward by improved technologies, increasing application complexity and user experience requirements. Within this course, we highlight key issues in the design of diverse 3DUIs by looking closely into both simple and advanced 3D selection/manipulation and spatial navigation interface design topics. These topics are highly relevant, as they form the basis for most 3DUI-driven application, yet also can cause major issues (performance, usability, experience. motion sickness) when not designed properly as they can be difficult to handle. Within this course, we build on top of a general understanding of 3DUIs to discuss typical pitfalls by looking closely at theoretical and practical aspects of selection, manipulation, and navigation and highlight guidelines for their use.

Keywords

Display, Games, Research, UI/Tools/Systems, VR/AR

Level of Difficulty

Intermediate

Prerequisite

Some background in creating VR and gaming experiences.

Intended Audience

Developers, researchers, psychologists, and user-experience professionals who want to adopt new ways of interacting in Virtual Reality using state of the art 3D User interface design strategies, ranging from 3D selection and manipulation to spatial navigation.

Audience Takeaways

By participating in two consecutive and logically interlinked sessions, participants will acquire necessary skill set to design, develop and validate 3D interfaces and techniques for virtual reality and gaming systems. In summary, the sessions will enable participants to acquire the necessary knowledge and skills through covering spatial navigation and 3D selection/manipulation topics, grouped in the two blocks of the course.

With the increasing availability, quality, and affordability of immersive gaming and virtual/augmented/mixed reality hard- and software, there is an increasing need for improved interfaces that combine high usability and learnability with a more embodied interaction that goes beyond gamepads and mouse/keyboard approaches. This topic is highly relevant, as many application domains benefit from well-performing techniques, from games to 3D design exploration/review and big data exploration scenarios. Furthermore, due to the recent (re)advent of virtual reality, this area has become even more relevant as many users are affected by the (lack of) performance of 3D interfaces and techniques. Hence, we will cover the full range from hand-operated to full-body controlled interfaces, from low-cost to high-end.

Course structure

Both the selection and manipulation and the spatial navigation blocks deal with foundations and practical aspects to create a solid foundation for creating 3D user interfaces. While other 3D user interface tasks such as system control exist, navigation and selection/manipulation form the predominant tasks in most 3D user interfaces, and thus are highly representative.
Both the 3D Selection and Manipulation and the spatial navigation blocks will start by covering the **fundamentals** and applicable usage domains. This includes a classification of different interfaces and techniques (with pros and cons) as well as other issues including adverse effects such as motion sickness and usability issues will be discussed, along with a set of guidelines to alleviate them.
In the subsequent more applied **practice** section of each block, we will provide an overview of the methodologies to design, develop, and validate novel interfaces and interaction techniques, again accompanied with a set of guidelines. Attendees will also be guided through various real-world design examples that highlight the foundations and practical design decisions, development issues, and validation methodologies.

Course Timeline

The structure of the course comprises two main building blocks that represent the two main topics of the course.

Introduction (LaViola, Riecke & Kruijff, 15 min).

Welcome, overview of course and motivation for attending. Speaker Introductions.
This includes an overview of the goals and structure of the course, highlighting the foundational and practical aspects, as well the relevance and contents of the two building blocks 3D selection/manipulation and navigation.

3D Selection and Manipulation (LaViola, 60 Min)

Foundations (10 min)

- 3D Manipulation Tasks
- Classifications for 3D Manipulation

Practice (50 min)

- Grasping Metaphors
    - Simple Virtual Hand
    - Go-Go Interaction
    - Rigid- and Soft-Body Fingers
    - God Fingers
    - 3D bubble cursor
    - PRISM
    - Hook
    - Intent-driven Selection
- Pointing Metaphors
    - Ray Casting
    - Fishing Reel
    - Image-plane Pointing
    - Flashlight

    - Aperture Selection
    - Sphere Casting
    - Bendcast
    - Depth Rays
- Indirect Metaphors
    - Indirect Touch
    - Virtual Interaction Surface
    - Levels-of-Precision Cursor
    - Virtual Pad
    - World in Miniature
    - Voodoo Dolls
- Bimanual Metaphors
    - Spindle
    - iSith
    - Spindle + Wheel
    - Flexible Pointer
- Hybrid Metaphors
    - HOMER
    - Scaled-World Grab
- Other Aspects of 3D Manipulation
    - Nonisomorphism
    - Multiple Object Selection
    - Progressive Refinement
- Design Guidelines

Q&A (LaViola, Riecke & Kruijff, 10 min, followed by break)

< break >

Navigation (Riecke and Kruijff, 90 min)

This session will provide the foundations on top of which the subsequent practical design application session will be built. We will provide an introduction to psychophysical aspects underlying navigation, and an overview and categorization of various navigation techniques, paradigms, and devices reflecting the introduced psychophysics. In detail, this section encompasses the following:

Foundations of navigation (15 min)

- Psychophysics - Wayfinding and self-motion perception
    - The basics of self-motion, interrelationship with cognition/wayfinding aspects
    - Overview of self-motion cues
    - Cognition / wayfinding
- Adverse side effects
    - Cybersickness
    - Disorientation
    - Spatial awareness
    - Design guidelines to minimize adverse side effects

Navigation paradigms and devices (70 min)

- Common VR interface: Controller- and gaze/head-based navigation

- The challenge of VR navigation: Limitations of common VR interfaces
- Navigation devices and techniques
    - Basic overview of navigation paradigms and challenges
    - Device characteristics and mapping
        - How to map inputs to simulated self-motion? (e.g., position/velocity/ acceleration control), psychophysical and user experience aspects
    - Device overview with pros and cons of different approaches
        - Physical Walking
            - Non-negated walking
                - Non-redirected walking
                - redirected walking
                - Walking in place
            - Negated walking
                - Navigation devices such as treadmills
        - Motion cueing interfaces
            - From actuated motion platforms to user-powered low-cost leaning interfaces including case studies
        - Flying interfaces
    - Design guidelines and how to choose a suitable interface

Round-up and Q&A (Riecke, Kruijff, 10 min)

Speaker Biographies

Bernhard Riecke is associate professor in the School of Interactive Arts & Technology (SIAT) at Simon Fraser University. Riecke received his PhD from Tübingen University in 2003 and worked for a decade in the Virtual Reality group (Cyberneum) at the Max Planck Institute for Biological Cybernetics, as well as Vanderbilt and UC Santa Barbara. His work spans theoretical and applied domains and is published in journals including Frontiers, JOV, ACM-TAP, Cognition, and Presence, and conferences including IEEE VR, ACM-CHI, ACM SIGGRAPH, ACM-SUI, ISEA, and Spatial Cognition. Bernhard recently gave a TEDx talk on “Could Virtual Reality make us more Human”.

Joseph J. LaViola Jr. is an associate professor in the Department of Computer Science at the University of Central Florida. He directs the Interactive Computing Experiences Research Cluster of Excellence and is also an adjunct associate research professor in the Computer Science Department at Brown University. He is the lead author on the second edition of "3D User Interfaces: Theory and Practice", the first comprehensive book on 3D user interfaces. Joseph received a Sc.M. in Computer Science in 2000, a Sc.M. in Applied Mathematics in 2001, and a Ph.D. in Computer Science in 2005 from Brown University.

Ernst Kruijff is interim professor at the Institute of Visual Computing, Bonn-Rhein-Sieg University of applied sciences and adjunct professor at Simon Fraser University. His work has been presented at conferences such as IEEE VR, 3DUI and ISMAR, and ACM VRST. Ernst has presented numerous courses about 3DUI topics, including ACM SIGGRAPH, CHI and VRST, and IEEE VR. Ernst is co-author of the standard reference in the field of 3DUIs (LaViola et al. 3D User Interfaces: Theory and Practice, 2017).

Supplementary materials

Some of the course concepts are based on the presenters' book: Joseph J. LaViola Jr, Ernst Kruijff, Ryan P. McMahan, Doug Bowman, and Ivan P. Poupyrev. 2017. 3D User Interfaces: Theory and Practice (2nd ed.). Addison-Wesley.

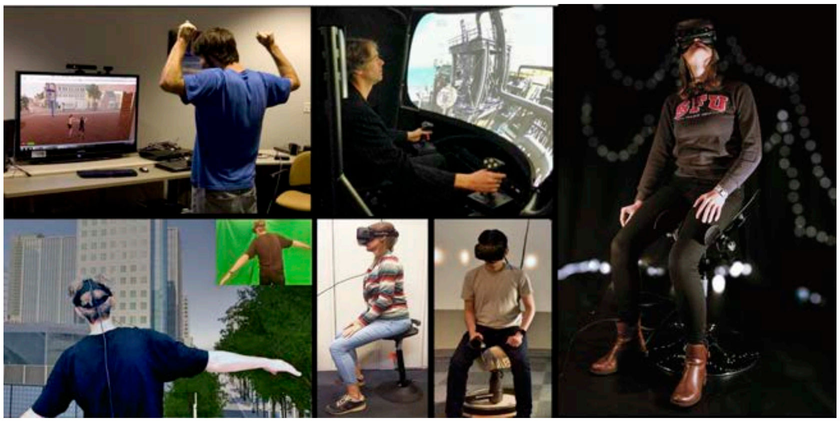
Updated course notes and additional resources will be available at http://iSpaceLab.com/project/3DUI-course/

Welcome & Introduction

3D User Interfaces for Virtual Reality and Games

3D Selection, Manipulation, and Spatial Navigation

Bernhard E. Riecke / Joseph LaViola / Ernst Kruijff



Who are we?

Bernhard Riecke

Associate Professor

School of Interactive Arts and Technology (SIAT)
Simon Fraser University (SFU)
Vancouver area, BC, Canada

Joseph J. LaViola Jr

Charles N. Millican Faculty Fellow and Associate Professor

Department of Computer Science, University of Central Florida, FL, USA

Ernst Kruijff

Interim Professor

Institute of Visual Computing

Bonn-Rhein-Sieg University of Applied Sciences

Sankt Augustin, Germany

Adjunct Professor: School of Interactive Arts and Technology, Simon Fraser University

Goal

- Learn how to design, develop and validate 3D user interfaces and techniques for virtual reality and gaming
- From theory to practice, from simple to advanced 3D selection/manipulation and spatial navigation interface

Timeline

9 – 9:10 Introduction

9:10 – 10:10 3D Selection and Manipulation (LaViola, 60 Min)

- **Foundations**
- **Practice**
  - Grasping Metaphors
  - Pointing Metaphors
  - Indirect Metaphors
  - Bimanual Metaphors
  - Hybrid Metaphors
  - Other Aspects of 3D Manipulation
  - Design Guidelines

10:10 – 10:30 Q&A & break

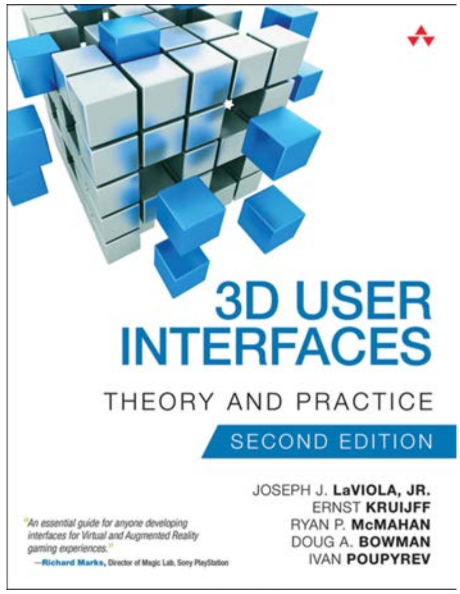
10:30 – 12:00 - Navigation (Riecke & Kruijff, 90 min)

- **Foundations**
  - Psychophysics - Wayfinding and self-motion perception
  - Adverse side effects
- **Navigation paradigms and devices**
  - Common VR interface: Controller- and gaze/head-based navigation
  - The challenge of VR navigation: Limitations of common VR interfaces
  - Navigation devices and techniques
    - Basic overview of navigation paradigms and challenges
    - Device characteristics and mapping
    - Device overview with pros and cons of different approaches
      - Physical Walking, Motion cueing interfaces, Flying interfaces
    - Design guidelines and how to choose a suitable interface

12:00 – 12:15 Round-up and Q&A (Riecke & Kruijff)

sources

Part of this tutorial is based on:



Where to get the slides

http://iSpaceLab.com/project/3dui-course/

If you cite us: see ACM digital library:

Riecke, B. E., LaViola Jr., J. J., & Kruijff, E. (2018). 3D User Interfaces for Virtual Reality and Games: 3D Selection, Manipulation, and Spatial Navigation. In Proceedings of ACM SIGGRAPH 2018 Courses (SIGGRAPH ’18). (half-day course). Vancouver, BC, Canada:

Questions?

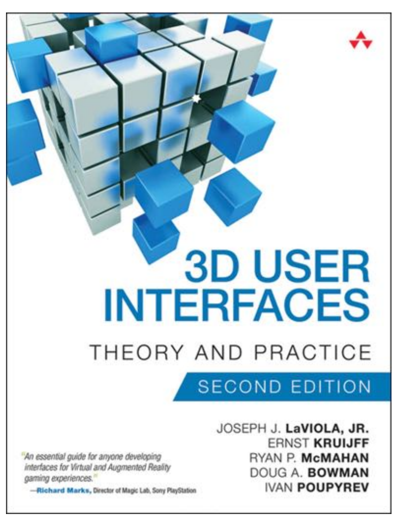
- Please feel free to ask questions during the talks if you have any
  - More complex questions during Q&A and break

3D Selection and Manipulation

Joseph J. LaViola Jr.

Bernhard E. Riecke / Joseph J. LaViola Jr. / Ernst Kruijff

3D User Interfaces: Theory and Practice, Second Edition



3D Interaction Techniques

- Choosing the right input and output devices not sufficient for an effective 3D UI
- Interaction techniques: methods to accomplish a task via the interface
  - hardware components
  - software components: control-display mappings or transfer functions
  - metaphors or concepts
- Universal tasks: selection and manipulation, travel, system control

Overview

- Manipulation: a fundamental task in both physical and virtual environments
- 3D manipulation task types
- Classifications of manipulation techniques
- Techniques classified by metaphor:
  - Grasping
  - Pointing
  - Indirect
  - Bimanual
  - Hybrid

3D Manipulation Tasks

- Broad definition: any act of physically handling objects with one or two hands
- Narrower definition: spatial rigid object manipulation (shape preserving)

3D Manipulation Tasks

Canonical Manipulation Tasks

- *Selection*: acquiring or identifying an object or subset of objects
- *Positioning*: changing object’s 3D position
- *Rotation*: changing object’s 3D orientation
- *Scaling*: uniformly changing the size of an object

3D Manipulation Tasks

Canonical Manipulation Tasks

- Task parameters

Task	Parameters
Selection	Distance and direction to target, target size, density of objects around the target, number of targets to be selected, target occlusion
Positioning	Distance and direction to initial position, distance and direction to target position, translation distance, required precision of positioning
Rotation	Distance to target, initial orientation, final orientation, amount of rotation, required precision of rotation

3D Manipulation Tasks

Application-Specific Manipulation Tasks

- canonical tasks can fail to capture important task properties for real applications
- ex: positioning a medical probe relative to virtual models of internal organs in a VR medical training application
- techniques must capture and replicate minute details of such manipulation tasks

3D Manipulation Tasks

Manipulation Techniques and Input Devices

- number of control dimensions
- integration of control dimensions
  - multiple integrated DOFs typically best for 3D manipulation
- Force vs. position control
  - position control preferred for manipulation
  - force control more suitable for controlling rates

3D Manipulation Tasks

Manipulation Techniques and Input Devices

- Device shape
  - generic vs. task-specific
- Device placement/grasp
  - power grip
  - precision grip
    - use fingers
    - reduce clutching

Image courtesy of Ivan Poupyrev

Classifications for 3D Manipulation

- Isomorphic (realistic) vs. non-isomorphic (magic)
- Task decomposition
- Metaphor

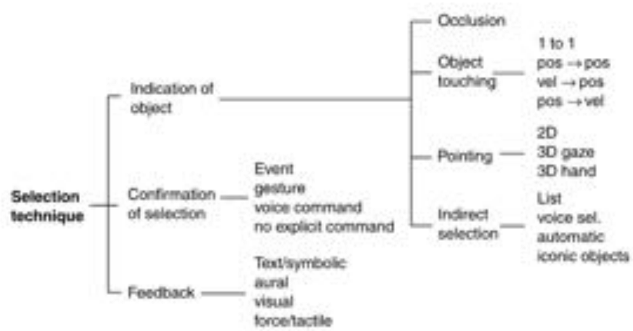
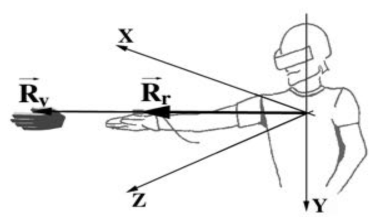


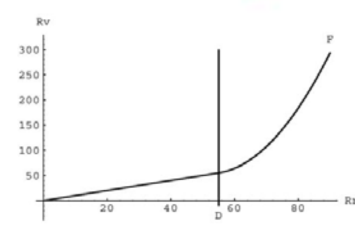
Image curtesy of LaViola et al:
LaViola, J. J., Kruijff, E., McMahan, R. P., Bowman, D., & Poupyrev, I. P. (2017).
3D User Interfaces: Theory and Practice (2nd edition). Addison-Wesley.

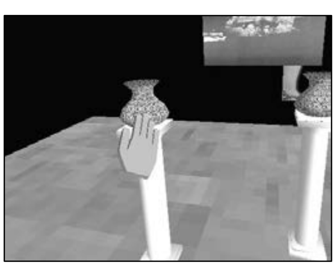
Grasping Metaphors

Hand-Based Grasping

- Simple virtual hand
- Go-Go







$$r_v = F(r_r) = \begin{cases} r_r & if\ r_r \leq D \\ r_r + \alpha(r_r - D)^2 & otherwise \end{cases}$$

$where\ r_r$ = length of $\overrightarrow{\boldsymbol{R}_r}$

r_v = length of $\overrightarrow{\boldsymbol{R}_v}$

D, α are constants

Images courtesy of Ivan Poupyrev

Grasping Metaphors

Finger-Based Grasping

- Rigid-body fingers
- Soft-body fingers
- god fingers

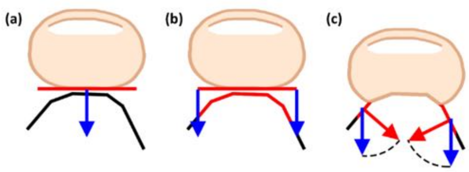


Image adapted from Talvas et al. 2013

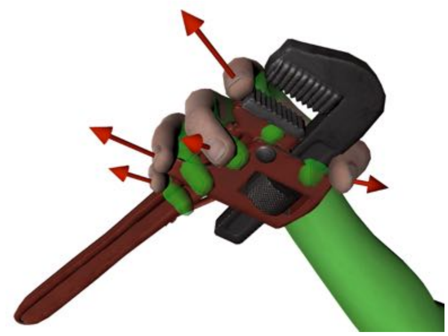


Image adapted from Borst and Indugla 2005

Grasping Metaphors

Rigid-body fingers (Borst and Indugla 2005)

- Need to track the hands and fingers (e.g., bend sensing glove or 3D depth camera)
- Map hand and finger positions to virtual hand and fingers
- Physics-based interactions
  - use virtual torsional and linear spring dampers
  - dynamically influence mapping between real and virtual hands
- Can be “sticky” – difficult to precisely release objects
- Sticky object problem can be reduced with better heuristic-based release functions

Grasping Metaphors

Soft-Body Fingers (Jacobs and Froehlich 2011)

- Use deformable representations for virtual fingers
- Lattice shape matching algorithm
  - deform the pads of virtual fingers to dynamically adapt to shapes of grasped objects
  - when real fingers initially collide with virtual objects, virtual finger pads deform slightly
  - when real fingers penetrate inner space of virtual objects, more points of collision produced for virtual fingers
- Implicit friction model compared to rigid body model

Grasping Metaphors

God Fingers (Talvas et al. 2013)

- god object – a virtual point that adheres to rigid body physics and never penetrates virtual objects (remains on their surface)
  - force direction can be easily calculated
- Goal is to use god-objects for finger grasping and manipulation
  - compute contact area about god-object point as if surface was flat
  - contact area fitted to geometry of the object based on god object force direction
  - odd deformations are prevented by using angular threshold between force directions and surface normals

Enhancements for Grasping Metaphors

- 3D bubble cursor
- PRISM
- Hook
- Intent-driven selection

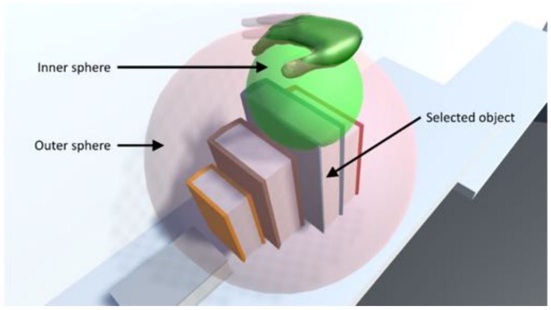


Image adapted from Periverzov and Llies 2015

3D Bubble Cursor (Vanacken et al. 2007)

- Semi-transparent sphere that dynamically resizes itself to encapsulate the nearest virtual object
- Designed for selecting a single object
- When sphere is too large and begins to intersect a nearby object a second semi-transparent sphere is created to encapsulate that object

Grasping Metaphors

PRISM (Frees and Kessler 2005)

- Precise and Rapid Interaction through Scaled Manipulation
- Apply scaled down motion to user's virtual hand when the physical hand is moving below a specified speed
  - decreased control to display gain
  - increased precision
- Causes mismatch between virtual and physical hand location
  - use offset recovery mechanism based on hand speed
  - allows virtual hand to catch up to physical

Grasping Metaphors

Hook (Ortega 2013)

- Supports object selection of moving objects
- Observe relationship between moving objects and the hand to develop tracking heuristics
  - compute distance of hand to each virtual object
  - orders and scores targets based on increasing distance
  - close targets have scores increased, far targets have scores deceased
- When selection is made, target with highest score is selected

Grasping Metaphors

Intent-Driven Selection (Periverzov and Llies 2015)

- Use posture of virtual fingers as confidence level in object selection
- Proximity sphere is positioned within grasp of virtual hand
  - virtual fingers touch the sphere
  - anything within the sphere is selectable
- As hand closes, additional proximity spheres are made to specify a smaller subset of selectable objects until one target is selected

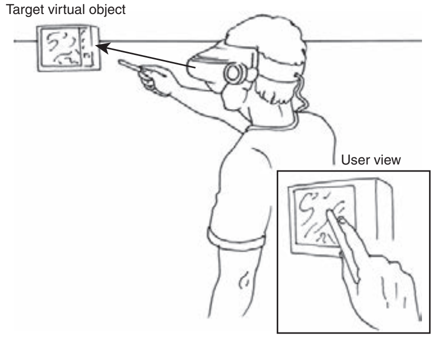
Pointing Metaphors

- Pointing is powerful for selection
  - remote selection
  - fewer DOFs to control
  - less hand movement required
- Pointing is poor for positioning
- Design variables:
  - how pointing direction is defined
  - type of selection calculation

Pointing Metaphors

Vector-Based Pointing Techniques

- Ray-casting
- Fishing reel
- Image-plane pointing



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Pointing Metaphors

Ray-casting

- Simple pointing technique
- Point at object with virtual ray
  – virtual line indicates direction (e.g., laser pointer)
  – size of the virtual line can vary
- Perform ray casting to select desired object
- Precision can be compromised with far away objects

Pointing Metaphors

Fishing Reel

- Additional input mechanism to control the virtual ray
- Select with ray casting and reel the object back and forth using additional input (e.g., slider, gesture)

Pointing Metaphors

Image Plane Pointing (Pierce et al. 1997)

- Image plane techniques simplify object selection by using 2 DOF
  - select and manipulate objects with their 2D projections
  - use virtual image plane in front of user
  - simulate direct touch
- Used to manipulate orientation, not position
- Examples include Head Crusher, Lifting Palms, Sticky Finger, and Framing

Pointing Metaphors

Volume-Based Pointing Techniques

- Flashlight
- Aperture
- Sphere-casting

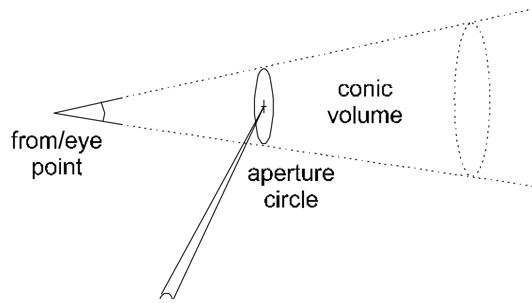


Image courtesy of Andrew Forsberg

Pointing Metaphors

Flashlight

- Provides soft selection and does not require as much precision
- Instead of using a ray, a conic selection volume is used
- Apex of cone is at the input device
- Object does not have to be entirely within the cone
- Must deal with disambiguation issues
  - choose object closer to the centerline

Pointing Metaphors

Aperture Selection (Forsberg et al. 1996)

- Modification of flashlight technique
- User can interactively control the spread of the selection volume
- Pointing direction defined by 3D position of user's viewpoint (tracked head location) and position of a hand sensor
- Moving hand sensor closer or farther away changes aperture

Pointing Metaphors

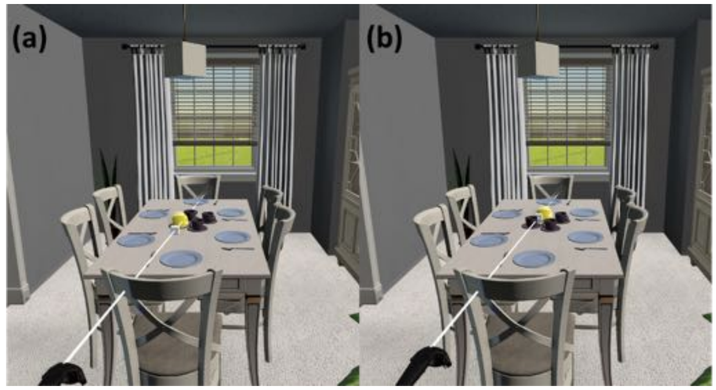
Sphere Casting

- Define position of predefined volume at the intersection of a vector used for pointing and the VE
- Modified version of ray casting
  - casts sphere onto nearest intersected surface

Pointing Metaphors

Enhancements for Pointing Metaphors

- Bendcast
- Depth ray
- Absolute and relative mapping



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Pointing Metaphors

Bendcast (Riege et al. 2006)

- Pointing analog to 3D bubble cursor
- Bends the pointing vector toward object closet to the vector's path
  – point line distance from each selectable object is calculated
  – circular arc used to provide feedback

Pointing Metaphors

Depth Ray (Vanacken et al. 2007)

- Used to disambiguate which object the user intends to select when pointing vector intersects multiple targets
- Uses depth marker along the ray length
- Object closest to the marker is selected
- User can control marker by moving a tracked input device back or forward

Pointing Metaphors

Absolute and Relative Mapping (Kopper et al. 2010)

- Useful in dense environments
- Provides manual control of control to display gain ratio of pointing
  - lets users increase the effective angular width of targets
- Can give user impression of slow motion pointer

Indirect Metaphors

Indirect Control-Space Techniques

- Indirect touch
- Virtual interaction surface
- Levels-of-precision cursor
- Virtual pad

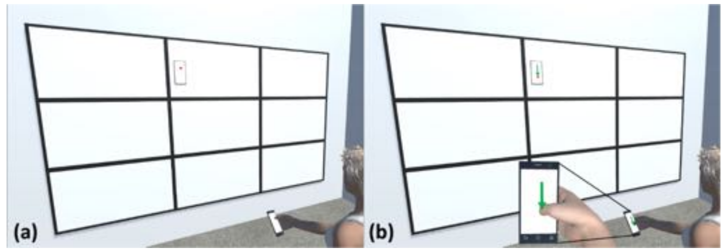


Image adapted from Debarba et al. 2012

Indirect Metaphors

Indirect Touch (Simeone 2016)

- Touch multi-touch surface to control cursor on primary display
- With second finger touch the surface to select an object under the cursor
- Use surface-based techniques for manipulation
- Choice of absolute or relative mapping

Indirect Metaphors

Virtual Interaction Surfaces (Ohnishi et al. 2012)

- Extension of indirect touch
- Mapping of multi-touch surface to nonplanar surfaces in VE
- Allow user to manipulate objects relative to desired paths or other objects
- Supports drawing directly on complex 3D surfaces

Indirect Metaphors

Levels-of-Precision Cursor (Debarba et al. 2012)

- Extends indirect touch with physical 3D interactions
- Uses smartphone
  - affords multi-touch and 3D interaction using inertial sensors and gyroscopes
- Map smaller area of smartphone to larger area of primary display
- Determine orientation for pointing operations

Indirect Metaphors

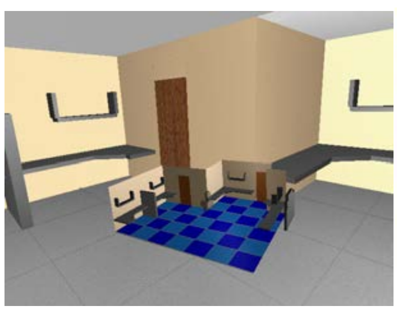
Virtual Pad (Andujar and Argelaguet 2007)

- Does not require multi-touch surface
- Virtual surface within the VE is used
- Similar to image plane methods

Indirect Metaphors

Indirect Proxy Techniques

- World in miniature
- Voodoo Dolls



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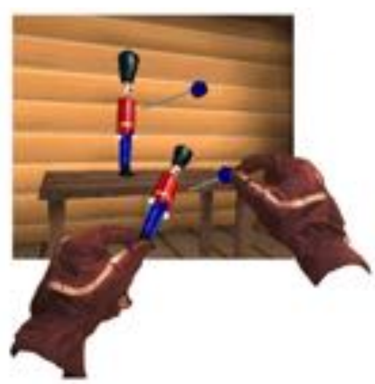


Image courtesy of ACM

Indirect Metaphors

World in Miniature (Stoakley et al. 1995)

- Scale entire world down and bring within user's reach
- Miniature hand held model of the VE (exact copy)
- Manipulating object in WIM indirectly manipulates object in the VE
- Many design decisions for implementation
  - has scaling issues

Indirect Metaphors

Voodoo Dolls (Pierce et al. 1999)

- Builds upon WIM and image plane techniques
- Seamless switching between different reference frames for manipulation
  - manipulate objects indirectly using temporary handheld copies of objects (dolls)
  - user can decide which objects to manipulate by using image plane selection (no scaling issues)
- Two handed technique
  - non-dominant hand represents a stationary reference frame
  - dominant hand defines position and orientation of object relative to stationary reference frame
  - user can pass doll from one hand to the other

Bimanual Metaphors

- Dominant and non-dominant hands
- Symmetric vs. asymmetric
- Synchronous vs. asynchronous
- Examples
  - symmetric-synchronous – each hand performing same movement at same time
  - symmetric-asynchronous – identical hand movements at different times
  - asymmetric-asynchronous – different hand movements at different times

Bimanual Metaphors

Symmetric Bimanual Techniques

- Spindle
- iSith

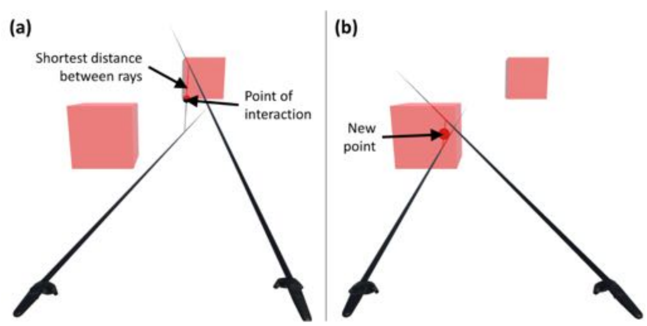


Image adapted from Wyss et al. 2006

Bimanual Metaphors

Spindle (Mapes and Moshell 1995)

- Two 6 DOF controllers used to define a virtual spindle that extends from one controller to another
  - center of spindle represents primary point of interaction
- Translation – move both hands in unison
- Rotation – yaw and roll by rotating hands relative to each other
- Scale – lengthen or shorten distance of hands

Bimanual Metaphors

iSith (Wyss et al. 2006)

- Intersection-based Spatial Interaction for Two Hands
- Two 6 DOF controllers define two separate rays
  - ray-casting with both hands
  - shortest line between two rays is found by crossing two vectors to find vector perpendicular to both
  - known as projected intersection point (point of interaction)

Asymmetric Bimanual Techniques

- Spindle + Wheel
- Flexible pointer

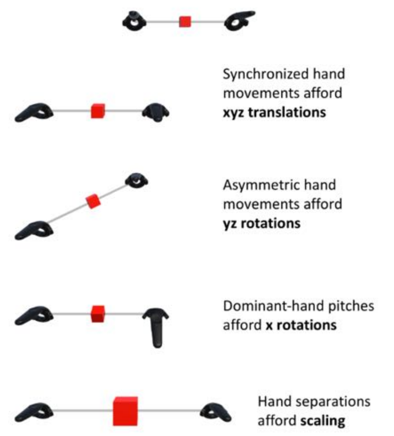


Image courtesy of Ryan McMahan

Spindle + Wheel (Cho and Wartell 2015)

- Extended Spindle to include rotating pitch of virtual object
- Uses virtual wheel collocated with dominant hand cursor
  - twist dominant hand for rotation

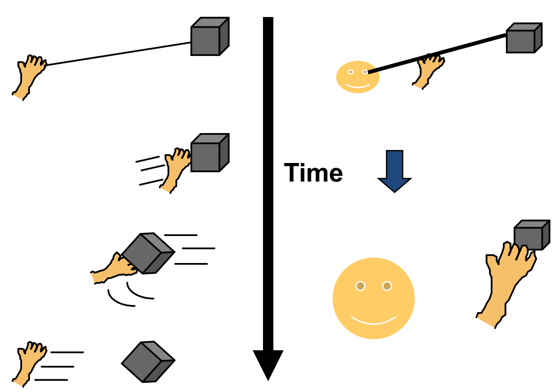
Bimanual Metaphors

Flexible Pointer (Olwal and Feiner 2003)

- Make use of two handed pointing
- Curved ray that can point at partially occluded objects
  - implemented as quadratic Bezier spline

Hybrid Metaphors

- Aggregation of techniques
- Integration of techniques
  - HOMER
  - Scaled-world grab



Hybrid Metaphors

HOMER (Bowman and Hodges 1997)

- Hand-centered Object Manipulation Extended Ray-Casting
- Select object using ray casting
- Users hand then attaches to the object
- User can then manipulate object (position and orientation) with virtual hand

Hybrid Metaphors

Scaled World Grab (Mine et al. 1997)

- User selects object with given selection technique
- Entire VE is scaled down around user's virtual viewpoint
- Scaling is done so object is within user's reach
- If center of scaling point is midway between user's eyes, the user will be unaware of the scaling

Other Aspects of 3D Manipulation

Nonisomorphic 3D rotation

- Amplifying 3D rotations to increase range and decrease clutching
- Slowing down rotation to increase precision
- Absolute vs. relative mappings
  - Absolute mappings can violate *directional compliance*
  - Relative mappings do not preserve *nulling compliance*

Other Aspects of 3D Manipulation

Multiple Object Selection

- Serial selection mode
- Volume-based selection techniques
  - e.g., flashlight, aperture, sphere-casting
- Defining selection volumes
  - e.g., two-corners, lasso on image plane
- Selection-volume widget
  - e.g., PORT

Other Aspects of 3D Manipulation

Progressive Refinement

- Gradually reducing set of objects till only one remains
- Multiple fast selections with low precision requirements
- SQUAD
- Expand
- Double Bubble

Image courtesy of Ryan McMahan

Other Aspects of 3D Manipulation

SQUAD (Kopper et al. 2011)

- Sphere-casting refined by QUAD menu
  - progressive refinement for dense VEs
- User specifies initial subset of environment using sphere cast
- Selectable objects laid out in QUAD menu
- Use ray-casting to select one of the four quadrants
  - selected quadrant is laid out in four quadrants
  - repeat until one object is selected

Other Aspects of 3D Manipulation

Expand (Cashion et al. 2012)

- Similar to SQUAD
- User selects collection of objects
- User's view expands this area and creates clones of the selectable objects (laid out in grid)
- User uses ray-cast to select object

Other Aspects of 3D Manipulation

Double Bubble (Bacim 2015)

- Both SQUAD and Expand suffer from initial selection containing large set of objects
- 3D bubble cursor is used upon initial selection
  – bubble not allowed to shrink beyond a certain size
- Objects laid out in a menu and selected using 3D bubble cursor

Design Guidelines

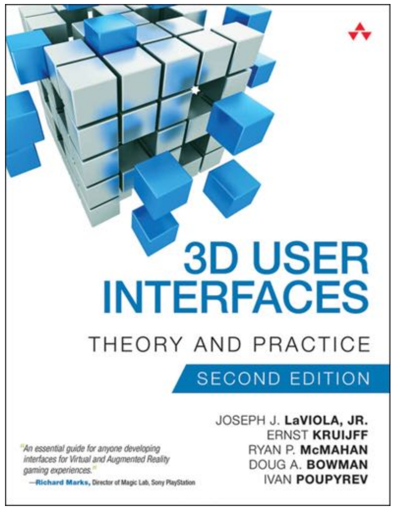
- Use existing manipulation techniques unless a large amount of benefit might be derived from designing a new application-specific technique.
- Use task analysis when choosing a 3D manipulation technique.
- Match the interaction technique to the device.
- Use techniques that can help to reduce clutching.

Design Guidelines

- Nonisomorphic ("magic") techniques are useful and intuitive.
- Use pointing techniques for selection and grasping techniques for manipulation.
- Consider the use of grasp-sensitive object selection.
- Reduce degrees of freedom when possible.
- Consider the trade-off between technique design and environment design.
- There is no single best manipulation technique.

3D User Interfaces: Theory and Practice, Second Edition

Book includes
- Human factors and HCI background
- Input and Output hardware
- Navigation techniques
- System Control
- 3D UI Design



Manipulation not discussed
- 2D and 3D surface metaphors
- 3D widgets
- Case studies on VR and Mobile AR

3D User Interfaces for Virtual Reality and Games
3D Selection, Manipulation, and Spatial Navigation

Foundations of Navigation

Bernhard E. Riecke / Joseph LaViola / Ernst Kruijff

Overview

- Psychophysics
  - Cognition: wayfinding
    - Cognitive mapping
    - Situation awareness
    - Spatial knowledge and reference frames
    - Wayfinding cues
  - Perception: self-motion
    - Principles
    - Cues

Adverse side effects
- Issues
- Design guidelines to minimize effects

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Wayfinding

- **Wayfinding** is the cognitive process of determining and following a route between an origin and a destination (Passini 1981)
  - Cognitive component of navigation - travel is the physical counterpart
  - High-level thinking, planning, and decision-making related to user movement

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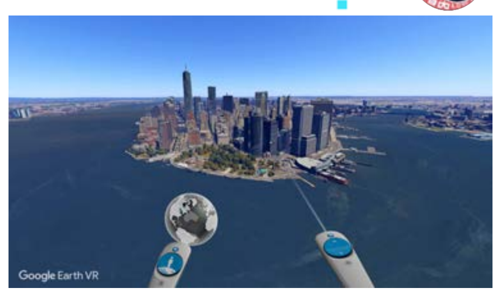
https://commons.wikimedia.org/wiki/File:Oldmexicocity.jpg

Wayfinding

- Wayfinding involves spatial understanding and planning tasks
  - Determining current location within environment
  - Determining a path from current to a goal location
  - Building a cognitive map
- Real-world wayfinding has been researched extensively (Wiener 2003)

- In (large) virtual worlds, wayfinding can be crucial (Darken 1998)
- Travel and wayfinding can be combined (Bowman 1997)
  - Can reduce cognitive load
  - Can reinforce user's spatial knowledge



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https://icdn3.digitaltrends.com/image/google-earth-vr-4.jpg?ver=1

Situation awareness and cognitive mapping

- **Situation awareness:** internalized model of current state of the user's environment (Endsley 2012)
  - Perception of elements in the environment within a volume of time and space
  - Comprehension of their meaning, projection of their status in the near future

- **Spatial orientation:** knowledge of our location and viewing direction

- Environmental information is stored in our long-term memory
  - Referred to as **cognitive map** (Golledge 1999)
  - Mental hierarchical structure of information representing spatial knowledge (exocentric)
  - During wayfinding, we make use of existing spatial knowledge, acquire new spatial knowledge, or use a combination of both (Thorndyke 1982)

Types of spatial knowledge

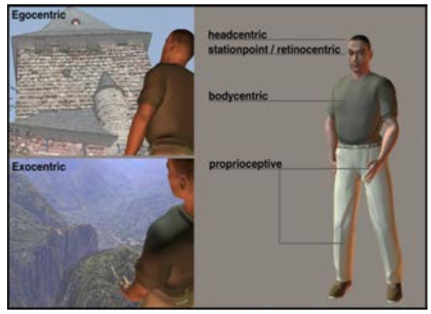
- During wayfinding, people obtain different kinds of spatial knowledge (Thorndyke 1982, Giraudo 1988)
  - Landmark knowledge
  - Procedural knowledge (or route knowledge)
  - Survey knowledge

- Search strategies and movement parameters influence the effectiveness of **spatial knowledge acquisition**

New York Landmark. © Ernst Kruijff

Reference frames

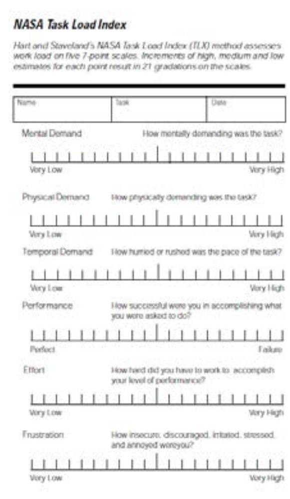
- During real-life motion, we feel as if we are in the center of space (ego/self-motion)
  - During such motion, we need to map ego/exocentric information (Howard 1991)
  - **Egocentric** reference frame is defined relative to a certain part of the human body, provides distance and orientation cues
  - **Exocentric** reference frame is object- or world-relative



Human reference frames (right) and associated views (left). In an egocentric view (top left), the user is inside the environment, while in exocentric view (bottom left), the user is outside the environment, looking in. © Ernst Kruijff (3DUI book)

Cognitive load

- Amount of cognitive work / effort required by a task or situation
  - User abilities and skills can reduce cognitive load
  - Often assessed using subjective measures (Hart 1988)
  - Can greatly influence wayfinding (Spiers & Maguire 2008)



NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?
Very Low — Very High

Physical Demand — How physically demanding was the task?
Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?
Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?
Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?
Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?
Very Low — Very High

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https://en.wikipedia.org/wiki/NASA-TLX#/media/File:NasaTLX.png

Wayfinding - environment-centered cues/support

Effectiveness of wayfinding depends on number and quality of wayfinding **cues** or **aids** provided to users

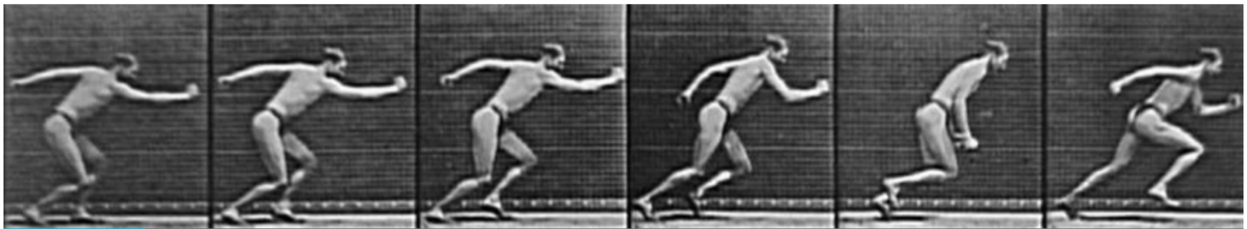
- Use real-world wayfinding principles to built up your environment, supporting spatial knowledge acquisition
  - Design *legible* environments (Lynch 1960)
- Natural environment principles
  - Horizon, atmospheric perspective / fog
- Architectural design principles
  - Lighting, texture, colour, ..
- Artificial cues
  - Signs, trails, maps, compass, grid.. (Darken & Cevik 1998)

Jeffrey Shaw's Legible city. © Jeffrey Shaw.
http://www.jeffreyshawcompendium.com/wpcontent/uploads/2015/03/js44w1989LegibCit1_o018_r.jpg

Wayfinding – user-centered cues

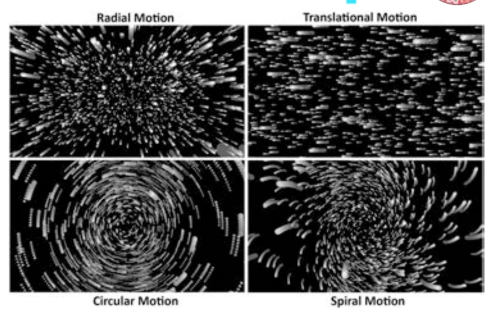
- Navigation in a 3D environment involves the processing of **multiple sources of sensory information** that we receive from the environment and the use of this information to execute a suitable travel trajectory

Photo by Muybridge. © wikimedia commons.
https://static1.squarespace.com/static/556f8d45e4b056e358098f31/t/56d46f51356fb0434a1fdc0b/1456762741525/



Visual cues

- Key to spatial perception
  - Multitude of depth cues, such as motion parallax, shadows, ..
  - Visual patterns can provide strong motion cues (Palmisano et al. 2015)
  - Also specific illusions, like train illusion or waterflow



© Palmisano et al. 2015.
Future challenges for vection research: definitions, functional significance, measures, and neural bases. Front. Psychol., 27 February 2015
http://www.frontiersin.org/files/Articles/129184/fpsyg-06-00193-r2/image_m/fpsyg-06-00193-g007.jpg

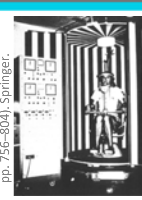
How to induce self-motion illusions (vection)?

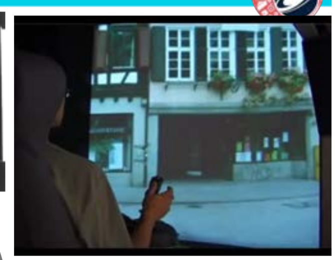
- **Visual** vection (Flowing river; waterfall, train illusion) Mach (1875), Helmholz (1896), Fischer & Kornmüller (1930) Tschermak (1931), Riecke, (2011) "linear/circular Vection"

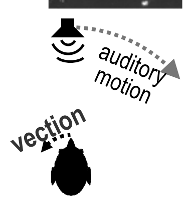
- **Auditory** vection
  - 20-70% *can* perceive auditorily induced vection Dodge, 1923; Hennebert, 1960; Lackner, 1977; Marmekarelse & Bles, 1977; Larsson et al., 2004ff; Väljamäe et al., 2004ff, Riecke et al., 2005ff...
  - But: Much weaker than visual vection

- **Biomechanical** (e.g., stepping around) *circular* vection
  - Most (>90%?) perceive it (e.g., Bles & Kapteyn, 1977, Bles, 1981)
  - Vection onset time: ca. 20s (Becker et al., 2002, Bruggeman et al, 2009)

© Dichgans, J., & Brandt, T. (1978). Perception (Vol. VIII, pp. 756–804). Springer.







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Auditory self-motion illusions ("circular vection") can be facilitated by vibrations and the potential for actual motion. ACM APGV 2008
https://www.youtube.com/watch?v=72jQcYkM_yI

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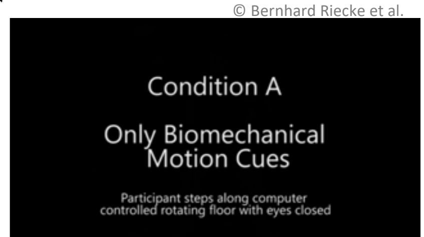


Why care about self-motion illusions (vection)?

Help make VR feel “real”

Convincingness and naturalism (Riecke et al, 2005ff; Stanney, 2002)

Presence & immersion (Prothero, 1995; Riecke et al, 2005ff; Stanney, 2002)

Spatial orientation (Hypothesis by Riecke & von der Heyde, 2003, confirmed: Riecke et al., VR 2012, Frontiers 2015)

Cool: embodied, even indistinguishable from actual self-motion

How to enhance vection? Visual cues & parameters

FOV (Brandt et al, 1973, Dichgans & Brandt, 1978…)

However: little influence of display type (Riecke & Jordan, 2015)

Visual velocity (Allison et al, 1999, Brandt et al, 1973, Dichgans & Brandt, 1978, Schulte-Pelkum et al., 2003…)

Simulated viewpoint or display jitter (Palmisano et al, 2000ff)

Naturalistic stimuli & ecological validity (Schulte-Pelkum et al., 2003; Riecke et al., 2006)

Possibility of actual motion (Lepecq et al., 1995; Wright et al., 2006, Riecke, 2011, Riecke et al, 2009)

Fixation or staring (instead of smooth pursuit) (Fischer & Kornmüller,1930; Becker et al. (2002)

Consistent stereoscopic depth cues (Lowther & Ware, 1996; Palmisano, 1996, 2002; Allison, Ash & Palmisano, 2014)

Perceived background motion (not just physical depth) (Howard & Heckmann, 1989; Ito & Shibata, 2005; Nakamura, 2008; Ohmi & Howard, 1988; Ohmi, Howard, & Landolt, 1987).

Stationary foreground (Brandt et al., 1975; Howard & Howard, 1994; Nakamura, 2006)

- Depth perception: perceived background motion

Cross-modal facilitations: auditory, vibration, subsonic, biomechanical (*circular treadmill, but not linear*) (Väljamäe, et al., 2006 ff; Riecke et al., 2005ff; Schulte-Pelkum et al, 2005ff, Seno et al.; however: Ash et al., 2013)

Interpretation & meaning of stimuli (Larsson et al., 2005; Väljamäe, et al., 2006 ff; Riecke et al., 2005ff; Seno et al.; however: Ash et al., 2013)

Auditory cues

- Auditory cues can provide direction, velocity cues
  - 20-70% *can* perceive auditorily induced vection
    - (Dodge, 1923; Hennebert, 1960; Lackner, 1977; Marmekarelse & Bles, 1977; Larsson et al., 2004ff; Väljamäe et al., 2004ff, Riecke et al., 2005ff…)
  - But: Much weaker than visual vection
- Can be coupled to vibration cues (tactile)

- **Note**: auditory cues can also aid in wayfinding tasks (church bells, train stations)

Auditory vection. © Bernhard Riecke et al.
Auditory self-motion illusions ("circular vection") can be facilitated by vibrations and the potential for actual motion. ACM APGV 2008
https://www.youtube.com/watch?v=72jQcYkM_yI

Vestibular cues

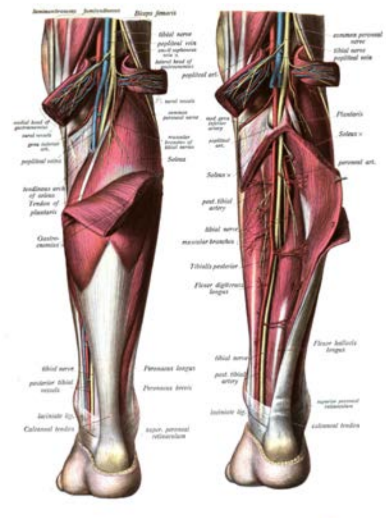
- Balance system
  - Consists of otolith organs (linear movement) and three semicircular ducts (rotational movement)
  - Has affect on cybersickness: minimal cues can help
  - Uses auditory nerve, can be stimulated directly (balance control) (Scinicariello et al. 2001, Aoyama et al. 2015)

© Luca Garelli. https://www.youtube.com/watch?v=rDjYa5LPn5s

Vestibular nerve stimulation.
© GVS/Nippon Telegraph & Telephone Corp
https://www.youtube.com/watch?v=guaiDZdsDjI

Somatosensory cues

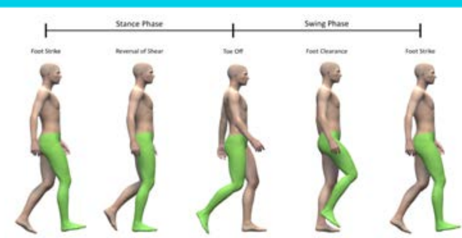
- Handles **haptic** sensations
  - cutaneous (skin) and subcutaneous (below skin)
  - mechanical sensations in the joints and muscles (incl. proprioception)
- Can provide feedback about geometry, roughness (touch), and weight and inertia (force)
  - Some typical cues: ground surface feedback (Kruijff et al. 2016) , feeling of wind (Kruijff et al. 2017), motion of legs / stride length



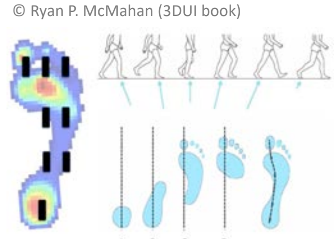
Muscles, tendons, nerves, joints, bones. © wikimedia commons.
https://upload.wikimedia.org/wikipedia/commons/a/a0/Sobo_1909_579-580.png

Somatosensory - human gait

- Bipedal propulsion caused by human limbs
  - Affected by **velocity** and **ground surface**
  - Consists of **stance phase** (foot touches ground) and **swing phase** (leg is moved and foot is airborne)
  - Can differ in both **frequency** and **length**
- **Ground contact** of foot is defined by **roll-off process**
  - Different forces (**pressure**) under foot sole at different stages
  - Amount of ground contact differs with velocity: with increasing velocity airborne phases and (heel) pressure increases



Human gait cycle.
© Ryan P. McMahan (3DUI book)



(A) heel strike, (B) heel strike to foot flat, (C) foot flat to midstance, and (D) midstance to toe off. Left image © wikimedia commons, right image © Ernst Kruijff
https://upload.wikimedia.org/wikipedia/commons/8/85/Example_foot_pressure.png

Sensory system issues

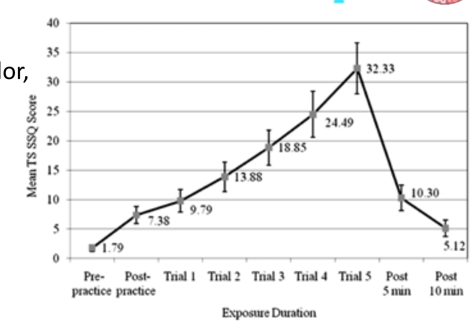
- **Sensory substitution**
  - “Translate” the missing information over another sensory channel
  - Can cover for technical limitations (for example, translate force into vibration)
  - Makes use of the *plasticity of the brain* (Bach-y-Rita 1987)

- **Multisensory processing**
  - Sensory channels may affect each other (Ernst & Bülthoff 2004)
  - Integration of sensory signals in *multimodal association areas* within the brain
  - Many *cross-modal effects* can already be identified (bias, transfer, ..) (Stein & Stanford 2008)

Adverse symptoms

Motion sickness (cybersickness)

- **Nausea**, dizziness, stomach symptoms, cold sweating, pallor, vominting
- Can last > 1h (25%) or even > 6h (Baltzley et al., 1989)
- **Oculomotor** issues, eyestrain, difficulty focussing, blurred vision
- Annoyed/irritated, headache, fullnes of head, difficulty concentrating
- *Sopite syndrome*: difficulty concentrating, drowsiness, fatigue, apathy



© Moss & Muth 2011
Characteristics of head-mounted displays and their effects on simulator sickness. Human Factors, 53 (3), 308-319.
http://tigerprints.clemson.edu/cgi/viewcontent.cgi?article=1214&context=all_dissertations

(Moss & Muth, Human Factors 2011)

Other adverse symptoms include:

- Re-adaptation
- **Disorientation**, confusion
- Reduced performance

Motion sickness & relation to interfaces / navigation

What causes motion sickness?

- Sensory conflict theory (Reason and Brand 1975)
  - → reduce sensory mismatch
    - smooth accelerations/jerks & keep them short
    - Perceived self- vs. object motion (VR vs. CAD)
  - → Design interfaces accordingly
    - HMD rotation not interface should control visual rotations
- Postural instability theory (Riccio and Stoffregen, 1991)
  - → training, practice, predictablity of (self/object)movement, "mental model"
- Eye movement theory (Ebenholtz, 1992)
  - OKN can affect vagal nerve → VIMS
  - → stabilize retinal image & gaze
- Rest frame /stable world hypothesis (Prothero and Parker 2003)
  - → What's perceived as "world" should be perceived as stable
  - → provide world-stable "background"/reset frame
- Evolutionary ("poison") theory (Treisman 1977)
  - → incremental exposure for new users

Motion sickness – is vection (self-motion perception) a cause?

- No direct causality: VIMS can occur without vection, and vection without VIMS (Lawson, HoVE 2014, Keshavarz et al., 2015)
- But: Strong VIMS rare without Perceived self-motion
  - VR vs. CAD: self- vs. object-motion
  - → reduce FOV or other vection-facilitating factors

Findings from the Literature concerning the Relation between Vection and Motion Sickness

Studies	Findings
Crampton and Young (1953)	Some participants got nauseated without reporting vection.
Hettinger et al. (1990)	Nonsignificant correlation between vection and MS ($n = 15$).
Hu et al. (1997)	Most MS in condition that elicited most vection ($n = 100$)[a].
Jones (1998)	Small but significant correlation ($n = 78$)[a].
Webb (2000)	No significant correlation across several studies ($n = 13$–20).
Kleinschmidt et al. (2002)	All participants reported vection; none reported nausea.
Webb and Griffin (2002)	Nonsignificant correlation between vection and MS ($n = 16$).
Muth and Moss (2009)	Positive, significant correlation ($n = 80$)[a].
Lawson (2005)	Maximal vection ratings with little or no MS.
Chen, Chow, and So (2011)	Different MS levels at the same vection velocity rating.
	Conclusion: 3/10 studies found a relation between vection and MS.

[a] Significant findings obtained.

© Lawson, HoVE 2014, p. 564
https://www.researchgate.net/publication/289866392_Motion_Sickness_Symptomatology_and_Origins

Motion sickness – what to do? (guidelines)

- Avoid ship-like frequencies (0.2 Hz)
- Adaptation: Repeated exposure with breaks (2-5 days) (Lawson, HoVE 2014, Watson, 1998)
- Reduce inconsistencies: latencies, lag, distortion, flicker
- Reduce accelerations/jerks
- Head movements (not manual input) should control visual scene motion
- Active navigation control
- Provide (minimal) physical motion cues to minimize motion sickness and enhance spatial perception
- Further infos:
  - E.g., Lawson, HoVE 2014, Keshavarz et al., Frontiers 2015, Jerald, VR book 2016, Oculus guidelines,)

GENERATIONS / VANCOUVER 12-16 AUGUST SIGGRAPH2018

3D User Interfaces for Virtual Reality and Games

3D Selection, Manipulation, and Spatial Navigation

Navigation: Paradigms & Devices

Bernhard E. Riecke / Joseph LaViola / Ernst Kruijff

Using common input devices

2D input	3D input		
			
joypad/stick, keyboard, tablet	gaze-directed steering	hand-directed steering (pointing)	leaning
© xbox https://compass-ssl.xbox.com/assets/99/9f/999f3ab3-ab9a-4628-8554-d5020d112ed6.jpg?n=X1-Wireless-Controller-Adapter-Windows_Gallery_1056x594_02.jpg	© heise https://heise.cloudimg.io/width/700/q75.png-lossy-75.webp-lossy-75.foil1/_www-heise-de_/imgs/18/2/3/9/1/5/5/8/vive-pro_pdp-04-0944b8947e7b77a6.jpeg	© VIVE https://www.vive.com/media/filer_public/43/cf/43cf7a3f-f9f7-48b1-969e-d928a8166a97/vive-hardware-controllers-2.png	© wikimedia https://upload.wikimedia.org/wikipedia/commons/f/f3/Wii_Balance_Board_transparent.png

Using common input devices

- **Joysticks, joypads, keyboards**
  - “Standard” input devices
  - Most users experienced with usage
  - Can be precise
  - Still used often (VR games)
  - However: lack of self-motion cues
- **Steering wheels**
  - Not standard, but used frequently
  - Easy to use
  - Lack of self-motion cues
- **Tablets**
  - Can be used in combination with 3D navigation
  - However:
    - Hard to use with a HMD
    - Again, no self-motion cues

© logitech
https://www.logitechg.com/assets/53683/13/g920-racing-wheel.png

© Hachet et al.
Navidget for Easy 3D Camera Positioning from 2D Inputs. IEEE 3DUI‘18, 2008.
https://www.youtube.com/watch?v=wpaKjLZll80

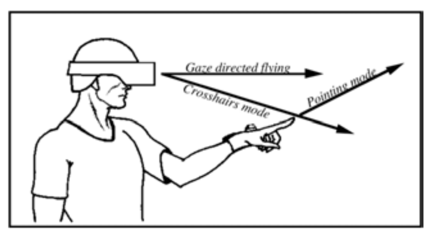
Steering – spatial steering techniques

- Allow user to guide or control the movement of travel by manipulating the orientation of a tracking device
  - Generally easy to understand and provide the highest level of control by user
- Spatial steering techniques:
  - Gaze-directed steering
  - Hand-directed steering (pointing)
  - Torso-directed steering
  - Lean-directed steering

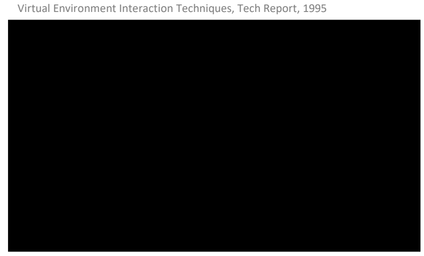
Steering – spatial steering techniques

Gaze-directed steering

- Allows user to move in view direction (Mine 1995)
  - Obtained from head tracker orientation
  - Some have also used eye-tracking
- Can be extended by allowing user to strafe
- Easy to understand and control
  - Decouples navigation from pointing device (manipulation)
- However:
  - Couples gaze direction and travel direction: users cannot look one direction and travel in another
  - Going around curves not natural



© Mark Mine – cross-hair functions as cursor in 2D
Virtual Environment Interaction Techniques, Tech Report, 1995



© Tregillus
Handsfree Omnidirectional VR Navigation using Head Tilt. In Proceedings of ACM CHI'17, 2017
https://www.youtube.com/watch?v=e6fyfnVTAYs

Steering – spatial steering techniques

Hand-directed steering (pointing)

- Uses orientation of hand (or tracked controller) to specify the direction of travel
- More flexible but also more complex than gaze-directed steering (Bowman et al. 1997)
  - Requires control of two orientations simultaneously
  - Can lead to higher cognitive load
  - However, user can look around, promotes acquisition of spatial knowledge

© Schulze
http://www.calit2.net/images/articles/StarCAVE_Schulze_Hallway_350.jpg

Hand-directed steering derivative

Handheld-directed steering (wheeling)

- Uses props to mimic steering
  - Handheld controller in (small) steering wheel form-factor
- Easy to use
- However:
  - Not as precise a real steering wheel: lack of constraints, tracking precision of Wii
  - Fatigue - tiring if held up high in front of body (pose)

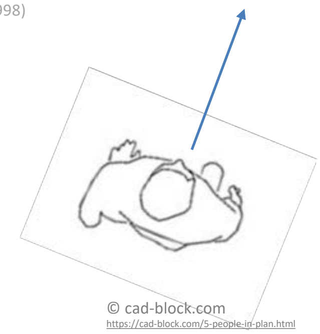
© videojug
https://www.youtube.com/watch?v=Er_hAn6HvXk

steering – spatial steering techniques

Torso-directed steering

- Uses the user's torso to specify the direction of travel (Bowman et al. 1998)
  - People naturally turn their bodies to face walking direction
  - Tracker attached to user's torso, best at waist-level to avoid unwanted rotations
- Decouples user's gaze direction and travel direction

- However:
  - Can only be used on horizontal plane
  - Requires additional tracker next to hand/head



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https://cad-block.com/5-people-in-plan.html

Steering – spatial steering techniques

Lean-directed steering

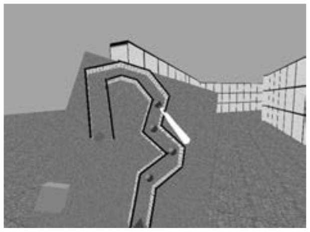
- Interprets leaning direction as direction for travel
  - Similar to Human Joystick techniques
  - Can be done with Wii balance board
- Integrate direction and speed into a single, easy-to-understand movement
  - rely on natural proprioceptive /kinaesthetic senses
  - mostly limited to 2D navigation
  - can be more accurate for traveling than pointing (von Kapri et al. 2011)

© Von Kapri et al.
Comparing Steering-Based Travel Techniques for Search Tasks in a CAVE. IEEE VR'11, 2011
https://www.youtube.com/watch?v=9dz453s7KXw

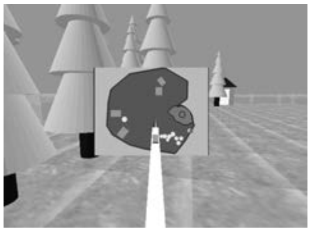
Selection-based travel metaphors

- Depends on user selecting either travel target or path
  - User specifies desired parameters of travel first, travel technique takes care of movement
  - Techniques are not the most natural, but tend to be easy to understand and use

- Different types
  - Target-based
  - Route-planning



Route-planning technique using markers on a 3D map. © Bowman, Davis et al. 1999
Maintaining Spatial Orientation during Travel in an Immersive Virtual Environment. Presence: Teleoperators and Virtual Environments , Volume 8, No. 6 , 1999

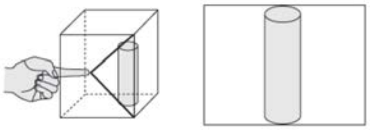


Map-based target specification.
© Bowman, Johnson et al. 1999
Testbed Evaluation of VE Interaction Techniques", in Proceedings of the ACM Symposium on Virtual Reality Software and Technology, 1999, pp. 26-33.

Manipulation-based travel metaphors

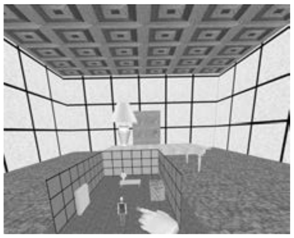
- Cross-task technique using hand-based object manipulation metaphors to manipulate the viewpoint or entire world
  (Mapes & Moshell 1995)
- Should be used in situations where both travel and manipulation tasks are frequent / interspersed

- Different types
  - Viewpoint manipulation
  - World manipulation



Camera-in-hand technique. The user's hand is at a certain position and orientation within the workspace (left), producing a particular view of the environment (right). © 3DUI book

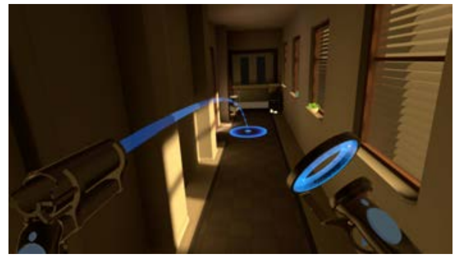
grabbing air with pinch gloves.
© Doug A. Bowman
https://www.researchgate.net/profile/Chadwick_Wingrave/publication/226568577/figure/fig1/AS:302244407857163@1449072090591/User-wearing-Pinch-Gloves-Y.png



© Doug A. Bowman / source: 3DUI book

Manipulation-based travel metaphors

- **Teleportation**
  - Variant of viewpoint manipulation
  - Jumping between locations, move through environment quickly
  - Location selection or through portals
    (Bozgeyikli et al. 2016, Freitag et al. 2014)
  - Works surprisingly well



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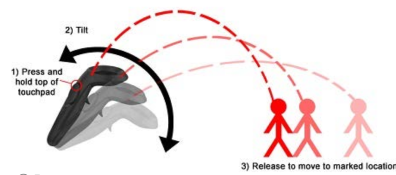
https://o.aolcdn.com/images/dims?quality=100&image_uri=http%3A%2F%2Fo.aolcdn.com%2Fhss%2Fstorage%2Fmidas%2F736a2c6418392731c8c255cbc51f4165%2F204430761%2Fss_5c73165c7fa91e2446342f091ce4a3e5b70969b6.1920x1080-ed.jpg&client=cbc79c14efcebee57402&signature=d6

- However:
  - Can disturb spatial orientation
  - Blink-mode (fast transition) recommended over immediate position change



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http://images.kalloctech.com/Vive_1.jpg

Limitations of common VR navigation interfaces?

- ***Is* there a problem?**
- Usability
  - Accuracy & Precision
  - Smooth movement
  - Learnability
- Missing bodily self-motion cues:
  - Sensory conflict
  - Reduced/no self-motion perception
  - Reduced naturalism & believability
  - Simulator sickness
  - Spatial orientation / spatial awareness deficits
  - Lower fidelity and user experience?
  - Reduced real-world transfer
- Potential „blocking“ of hands
  - simultaneous navigation and selection/manipulation challenging
- Multi-tasking: examples: tourguide; steadicam

© google https://goo.gl/images/yJQmju

© google https://goo.gl/images/adm0Rl

© Oculus: https://goo.gl/images/cPKu9B

Overview – Why travel techniques matter

- Viewpoint or object repositioning is easily the most common and universal interaction task for 3D interfaces
- Travel (and navigation in general) often supports *another* task rather than being an end unto itself
- → what are different travel task & techniques?
- → categorize!

Travel task taxonomy: Exploration, search, maneuvering

- **Exploration** / browsing
  - Often no explicit goal
  - Gathering infos about space/objects, learning environment

  → continuous & direct control, ability to stop
- **Search**
  - Has specific goal/target
  - Might not know how to get there
- **Maneuvering**
  - In local area, involving small & precise movements
    - E.g., position viewpoint to perform task
  - Can be time-consuming and frustrating
  - → provide balance of precision & speed + high usablity
    - E.g., head/body tracking

Travel technique taxonomy: What's being moved?

By what is moved

- **Self-motion**: moving person in world
  - Most 1st person interfaces, incl.
    - Walking & other biomechanical movements
    - Steering; e.g., vehicles, cockpits
    - Selection-based travel (see book: 3D User Interfaces: Theory and Practice (2nd Edition))
    - Manipulation-based travel (see 3DUI book)
      - Gestures & instruments like joystick, gamepad...
- **Object-motion**: moving "world" wrt person
  - E.g., "grab the air"; move world coordinate system
- **Viewpoint-motion**: move camera in 3rd person view
  - E.g., camera on map or "world-in-miniature" (WIM)

Travel technique taxonomy: Continuity

By continuity of self-motion in VR

- **Continuous**
- **Partially** continuous/intermittent
  - E.g., google street view
- **Discontinuous**
  - E.g., teleporting

Travel technique taxonomy: Interactivity

By interactivity

- **active** travel: user directly controls the movement of the viewpoint
  - **Continuous**
    - E.g., Joystick, gamepad, steering wheel, gas pedal, walking, …

  a) position control – mouse, trackpad, …

  b) rate/velocity control – joystick, steering wheel, …

  c) Acceleration (force) control – helicopter, rockets, bicycles…
  - **Discrete** (quasi-real-time)
    - E.g., key press, "go here" click
    - teleporting, path following, self-driving car
    - Useful when goal, not specific path matters
- **passive** travel: the viewpoint's movement is controlled by the system
  - Programmed (not real-time)
    - E.g., passive pre-defined motions (iMax, fun rides)
    - program/tell system what to do/where to go in advance

Travel technique taxonomy: Self-motion cues

Amount of physical & vestibular self-motion cues

- **full** motion cues: 1:1 physical travel
  - the user's body physically translates or rotates in order to translate or rotate the viewpoint
    - E.g., free-space walking
- **Some** physical & vestibular self-motion cues
  - Motion platforms, motion cueing, treadmills
- **No/minimal** physical & vestibular self-motion cues: virtual travel
  - the user's body primarily remains stationary even though the virtual viewpoint moves
    - E.g., joystick, gamepad, mouse, keyboard, fishtank VR,

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How to design travel techniques?

- Goal/ideal: Free roaming in large virtual spaces/games
  - Overall high usability & suitable user experience
  - Unencumbered
  - Intuitive & effortless (“second nature”)
  - Believable
    - Compelling sensation of self- motion
  - Natural → beyond visual cues
    - Proprioceptive, Vestibular, Tactile/haptic, Auditory…
- Note: Travel/navigation is often secondary task
  → Allow for interactions (hands-free locomotion?)
- Constraint: limited physical space, $$, technical complexity, setup…
- Solutions?

How to analyse and decide between all the different options?

Determine **requirements**:
What should users be able to **DO** with the interface? → **functional** requirements
What should they “**feel”/experience** → **non-functional** requirements

Interface	Details	Evaluation / rating (functional & non-					cues provided					
		usability / user experience	Naturalism / realism	technical complexity/effort	safety	cost	visual	auditory	vestibular	proprioceptive	tactile/haptic	exertion
details on interface												
walking, full gait	free-space walking, redirected walking											
walking, partial gait	Walking in place WIP											
walking, gait negation	Linear treadmills											
	omnidirectional treadmills,											
	a) with motion cueing											
	b) without motion cueing											
	c) low-cost, Virtuix...											
1-5 DOF motion platform												
6DOF motion platforms	small envelope											
	large envelope											
	with linear track											
manual motion cueing	seated leaning											
	standing leaning											
classic interfaces (e.g., rate control)	Joystick, gamepad etc.											
6 DOF hand-held controllers	e.g., Oculus Touch											

Walking interfaces – full gait walking ("free space")

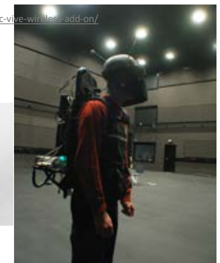
"Natural" full-gait walking & bodily motion cues

- **real walking** (VR & AR)
  - + involving full gait cycle with all biomechanics
    - natural, provides vestibular cues, and promotes spatial understanding
    - useful for both virtual reality and augmented reality
- **redirected walking**
- **scaled walking**

- issues:
  - cables/backpack, tracking, weight, confined to physical space, surface simulation
  - effort (virtual travel often preferred)

© Engadget
https://www.engadget.com/2016/11/10/220-htc-vive-wireless-add-on/

© Oculus
https://www.wired.com/2015/06/oculus-touch-virtual-reality/



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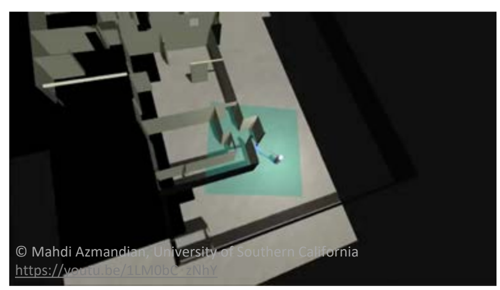
Redirected walking with HMD – approaches

Challenge: unlimited walking in limited space
Idea: redirect user away from boundaries

- **Stop and go**: rotational gain during stationary rotations
  - (e.g., Razzaque et al., Eurographics (2001), Bruder et al. 2015)
  - Challenge: get user to stop & rotate
    - location-oriented tasks (Kohli et al. 2005)
    - visual distractors (Peck et al. 2009)
    - verbal instructions (Hodgson et al. 2014)



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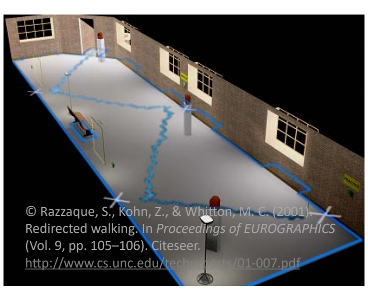
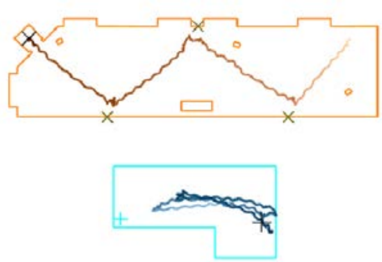
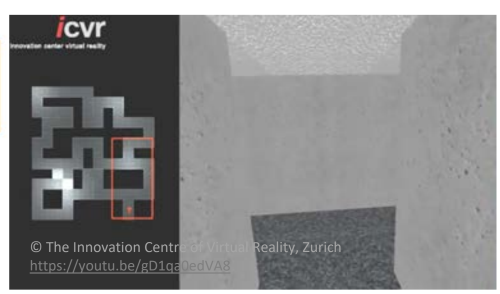


© Razzaque, S., Kohn, Z., & Whitton, M. C. (2001). Redirected walking. In *Proceedings of EUROGRAPHICS* (Vol. 9, pp. 105–106). Citeseer. http://www.cs.unc.edu/techreports/01-007.pdf





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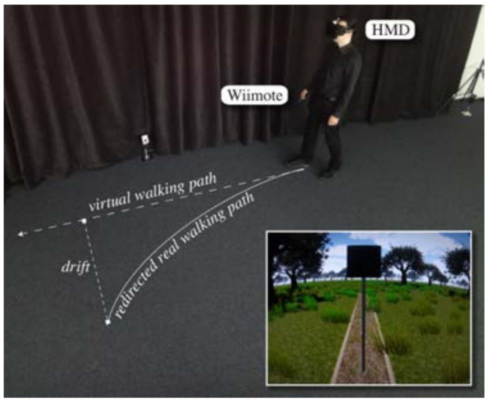
https://youtu.be/gD1qa0edVA8

Redirected walking with HMD – approaches

- **Continuous redirection** while walking (Bruder et al. 2015)
  + small enough rotations are imperceptible to user

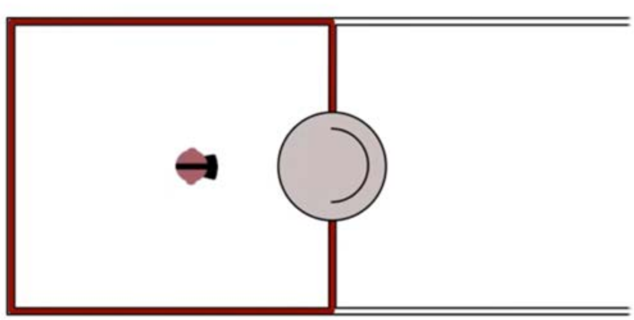


© Bruder, G., Lubas, P., & Steinicke, F. (2015).
Cognitive resource demands of redirected walking. *IEEE Transactions on Visualization and Computer Graphics*, *21*(4), 539–544.
https://basilic.informatik.uni-hamburg.de/Publications/2015/BLS15/cognitive_demands.png

© Bruder et al., IEEE VR 2012 https://youtu.be/0kXZ4pTgiu0

Redirected walking with HMD – implementation guidelines

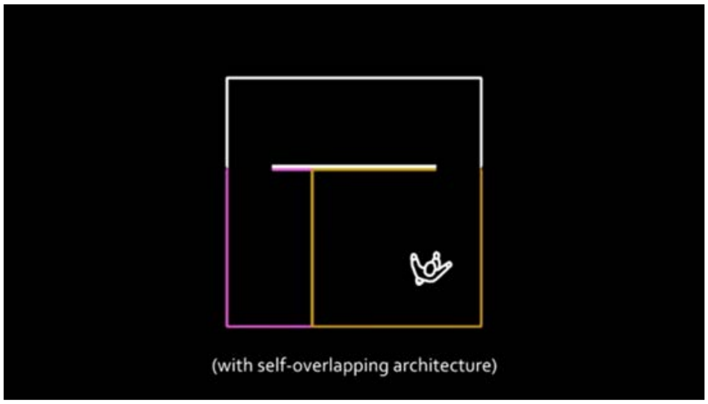
- Employ metaphors for re-direction:
  - E.g., **rotation** metaphors: virtual rotating bookshelf, revolving door, physical props,
  - **Teleport** paradigms: beaming, holodeck, “bird” carrying around user, teleportation, elevator, escalators



Bookshelf and Bird: Enabling Real Walking in Large VR Spaces through Cell-Based Redirection
© Run Yu, Wallace S. Lages, Mahdi Nabiyouni, Brandon Ray, Navyaram Kondur, Vikram Chandrashekar, and Doug A. Bowman *(Virginia Tech, USA) 3DUI 2017* https://youtu.be/AS65-h_CvVs

Redirected walking with HMD – implementation guidelines

- Instead of rotating user: **modify scene**
  - **Impossible spaces** w/ Overlapping rooms (Suma et al. 2012)
  - Dynamically generate corridors between rooms (Vasylevska et al 2013)



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Redirected walking with HMD – implementation guidelines

Avoid perceptual conflicts (Steinicke et al 2010)

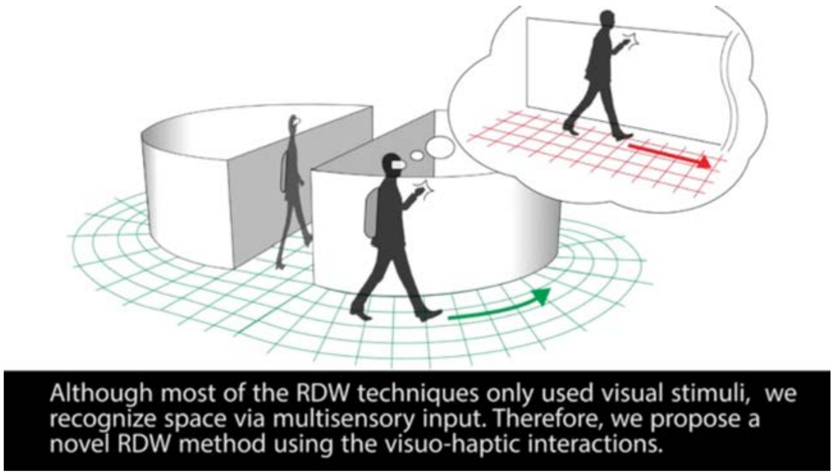
- Avoid re-direction/orientation changes
- users could be physically turned about 49% more or 20% less than a displayed virtual rotation
- users can also be physically translated 14% more or 26% less than a displayed virtual translation
- users will perceive themselves walking straight in the virtual environment while being continuously redirected on a circular arc if the arc's radius is greater than 22 meters

Limitations of redirected walking

- continuous redirected walking requires a large tracking space to be imperceptible: using smaller spaces is not very effective
- even in large tracking spaces, users can still walk outside of the space if they decide to ignore visual cues, tasks, and distractors
- redirected walking with small arcs demands more cognitive resources than with larger arcs (Bruder et al 2015)

Redirected walking with HMD – beyond visual re-direction

- Haptic & visual re-direction (Matsumoto et al., Siggraph 2016: Unlimited corridor)



© Matsumoto et al., Siggraph 2016 Unlimited corridor: redirected walking techniques using visuo haptic interaction https://youtu.be/THk92rev1VA

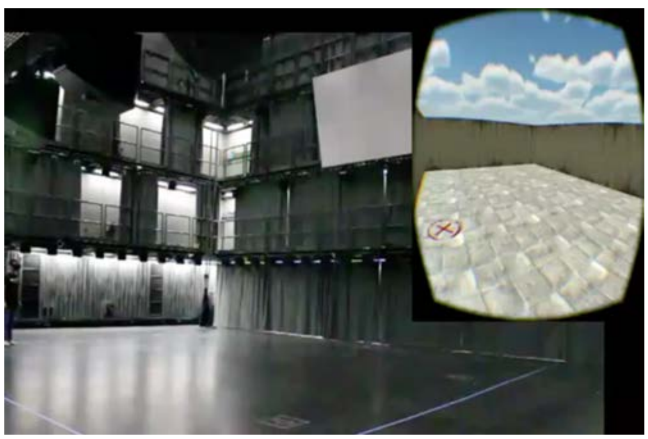
Full gait – scaled walking

Idea: virtual step >> actual step length

- Basic approach: gain factor for horizontal HMD tracking

  + Full gait cycle
  - increases motion sickness
  - less natural and easy to use than real walking (Interrante et al 2007)

- Improvements: "7 league boots"
  - Scale only intended travel direction (larger horiz. speeds)
  - Head bobbing/swaying remains natural
- Limitations
  - Unnatural
  - Perceptible if gain> 1.35 (Steinicke et al 2010)
  - Area still limited → combine w/ other techniques for larger areas



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Walking – partial gait techniques – WIP

Uses subset of gait cycle

- Most common: **Walking-in-place (WIP)**
  - Typical: **marching gesture**
  - Others: **wiping** or **tapping**: less strenuous (Nilsson et al. 2013)

+ Keeps exertion, removes size limitation, enhances presence

- Unnatural, no real movement sensation, (reduced presence?)

- More exertion than real walking

- Less effective and natural than real walking (Usoh et al, Siggraph 1999)

© Human Lab, University of Nevada
Tregillus & Folmer, VR-STEP: Walking-in-Place using Inertial Sensing for Hands Free Navigation in Mobile VR Environments, ACM CHI'16, 2016.
https://youtu.be/dfsToyLs41o

Walking – partial gait techniques

- Distance & direction from center determines motion direction and velocity ("**human mouse**") (Wells et al. 1996)

+ Can enhance presence over virtual travel (McMahan et al. 2012)

- less effective than keyboard/mouse (McMahan et al. 2011)

- artificial, less realistic & naturalistic than real walking

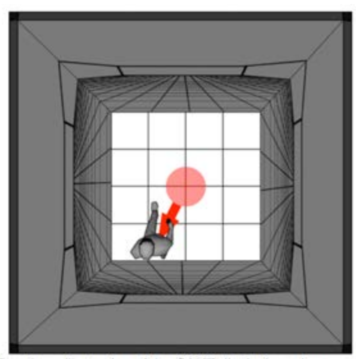


Fig. 2. Top-down illustration of the CAVE displaying a large-scale virtual environment. The human joystick technique utilizes the user's tracked head position from the center of the CAVE for virtual locomotion, as a joystick's 2D vector would be used.

© McMahan et al., Evaluating Display Fidelity and Interaction Fidelity in a Virtual Reality Game," *IEEE Transactions on Visualization and Computer Graphics*, vol. 18, iss. 4, pp. 626-633, 2012.

Walking – gait negation techniques

Almost natural gait without getting anywhere: system moves you back sooner or later

- Linear Treadmills
- Omnidirectional treadmills
  - Passive
  - active
- Low-friction surfaces
- Step-based devices

© CyberWalk http://www.cyberwalk-project.org/
https://www.youtube.com/watch?v=moq1Dclza90

walking – gait negation techniques – Linear treadmills

- But how to turn?
  - Joystick
  - Rotating whole treadmill
- How to Sidestep?
- How to simulate walking up/downhill?

© wikimedia commons

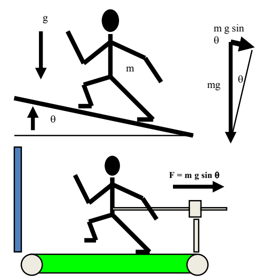
Low-gravity walking: NASA ZLS treadmill. ©NASA.
https://www.nasa.gov/mission_pages/station/research/e2LS_treadmill_010306.html

ATLAS system. ATR (© Miyasoto 2001)

Walking uphill? Tiltable tethered linear treadmill

- Sarcos Treadport 2
  + Tether force can simulate gravity and slope
- Limitations
  - Tilt mechanism is rather slow
  - Fast slope transients cannot be displayed by tilt
  - Tilting complicates ground & wall projection

© John Hollerbach et al., School of Computing, Salt Lake City, Utah, http://www.cs.utah.edu/~jmh/Locomotion.html)



walking – gait negation techniques

active omnidirectional treadmills

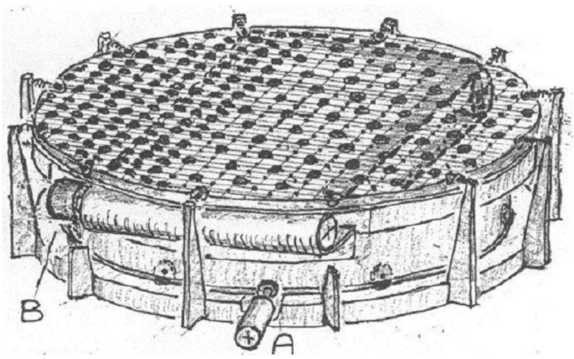
- detect the user's walking motions and move to negate them
  - belt-based treadmills
    - Keep users on treadmill!
  - conveyor rollers

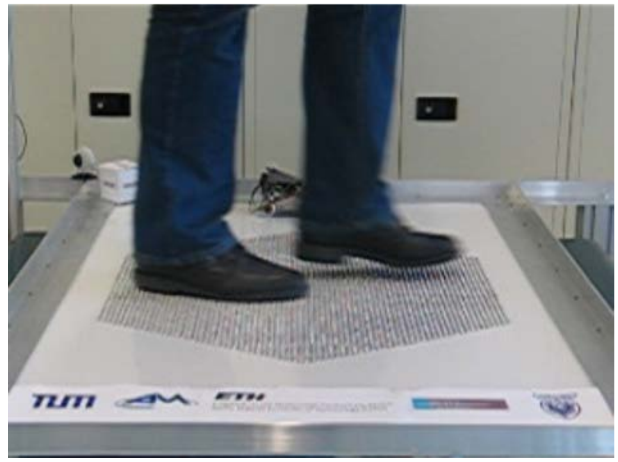
passive omnidirectional treadmills

- No external actuation
  - E.g., weight/force-driven

Active omnidirectional treadmills

- Cyberwalk project
  - Roller balls on treadmill

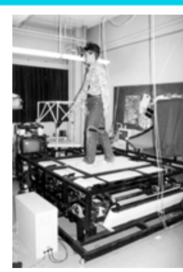


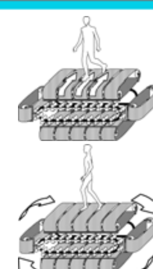


© CyberWalk
http://www.cyberwalk-project.org/
http://www.cyberwalk-project.org/img/Media/CyberWalk-o_ton.mp4

Active omnidirectional treadmills

- Torus treadmill
  - Iwata: IEEE VR 1999 & recent updates
    - 12 rotating treadmills
    - 1x1m, v<1.2m/s, magnetic foot tracking



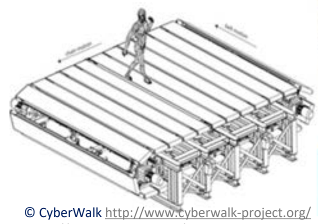


©VRLab, University of Tsukuba, Japan
http://intron.kz.tsukuba.ac.jp/torustreadmill/torustreadmill_e.html

http://intron.kz.tsukuba.ac.jp/wp-vrlab/locomotions/

Active omnidirectional treadmills

- Cyberwalk project

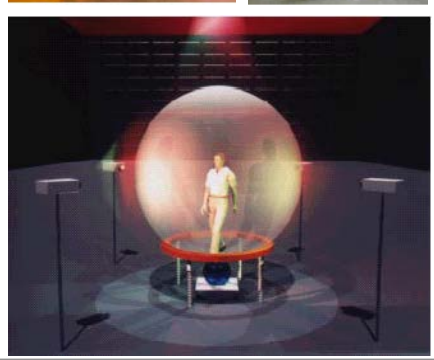


© CyberWalk http://www.cyberwalk-project.org/
https://www.youtube.com/watch?v=moq1DcIza90

Passive omnidirectional treadmills – hamster balls

CyberSphere (1998) & VirtuSphere

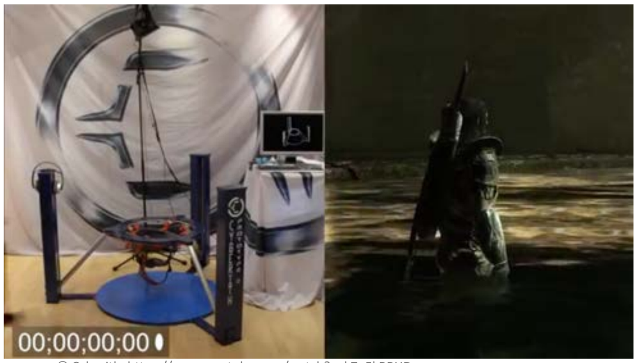
© Virtual Sphere Inc
http://www.virtusphere.com/ https://youtu.be/5PSFCnrk0GI?t=41s



Walking – gait negation techniques – low friction surfaces

low friction surfaces: Walking on slippery ground

+ affordable, omnidirectional
- require slippery/specialized shoes/socks
- Walking not natural - feels like sliding/skatin on ice
- Require some learning & trust



© Cyberith https://www.youtube.com/watch?v=k7n5kRRHDpw

https://commons.wikimedia.org/w/index.php?curid=31353460

Walking – gait negation techniques – low friction surfaces

KatVR

© KatVR http://www.katvr.com

Virtuix Omni

© Virtuix http://www.virtuix.com/
https://en.wikipedia.org/wiki/Virtuix_Omni

Omnidirectional walking - Rollershoes

- Virtual Perampulator: Tracked rollershoes with toe brake
  - Hiroo Iwata, University of Tsukuba/ATR Media Information Research Labs [IEEE VR 1999]




© Hiroo Iwata, University of Tsukuba, Japan
http://intron.kz.tsukuba.ac.jp/wp-vrlab/locomotions/

http://intron.kz.tsukuba.ac.jp/oldreseach/walkthrough/txt-j.html

Omnidirectional walking – step-based devices

Programmable per-Foot motion platforms

GaitMaster 1: Omni-directional

- 3DoF/foot + spring-loaded yaw joint
- Yaw turntable underneath

© Hiroo Iwata, University of Tsukuba, Japan https://youtu.be/RDDH1iqoDzU?t=11s

© Hiroo Iwata, University of Tsukuba, Japan
http://intron.kz.tsukuba.ac.jp/gaitmaster/gaitmaster_e.html

GaitMaster 2: UniDirectional

© Hiroo Iwata & Yoshida (1999), University of Tsukuba/ATR Media Information Research Labs

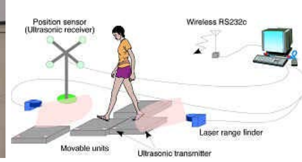
Omnidirectional walking – step-based devices

CirculaFloor: Omnidirectionally moveable floor tiles, holonomic drive, re-centering (motion cueing)

Step-based devices:

+ virtually unlimited omnidirectional walking, compact

- safety, cost, susceptibility to mechanical/software failures, slow, walking unnatural

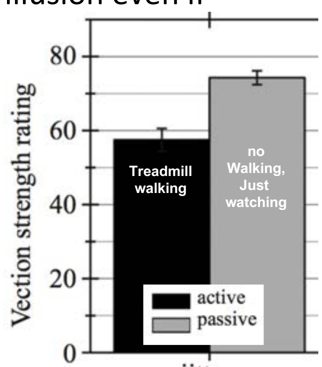


© Hiroo Iwata, University of Tsukuba/ATR Media Information Research Labs [Siggraph 2004 ET]

http://intron.kz.tsukuba.ac.jp/CirculaFloor/CirculaFloor_j.htm

Walking interfaces – do they actually help?

- Do treadmills enhance sensation of self-motion?
- No (Ash et al., 2012, 2013; Kitazaki et al., 2010)
- Linear treadmill walking can *reduce* visually-induced self-motion illusion even if velocity is matched

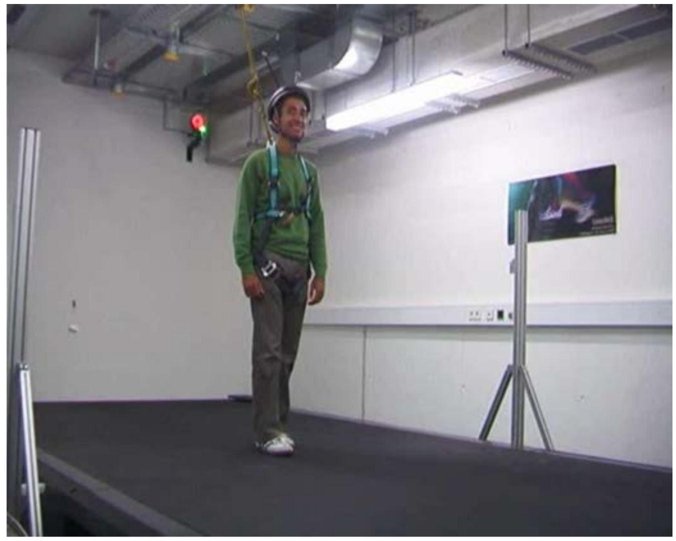


© Steve Palmisano, University of Wollongong

Ash, A., Palmisano, S., Apthorp, D., & Allison, R. S. (2013). Vection in depth during treadmill walking. *Perception*, *42*(5), 562 – 576. http://dx.doi.org/10.1068/p7449

What's missing for treadmills?

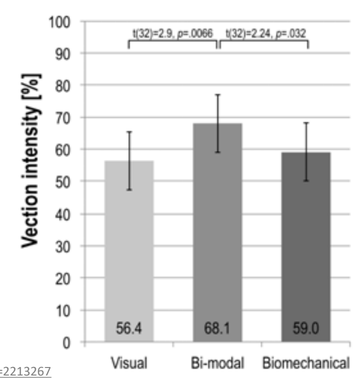
- Vestibular cues? Motion cueing?

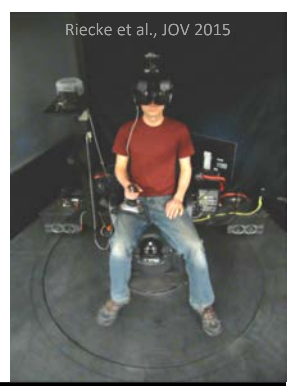


© Betty Mohler & Bernhard Riecke, MPI for Biological Cybernetics

Walking interfaces – do they actually help?

- Circular treadmill walking can
  - Induce self-motion illusion ("vection") by itself (if blindfolded) (Bles & Kapteyn, 1977, Bles, 1981)
  - Enhance visually-induced self-motion illusion (Riecke et al., JOV 2015)
- Linear treadmill walking does not (Ash et al., 2012, 2013; Kitazaki et al., 2010)





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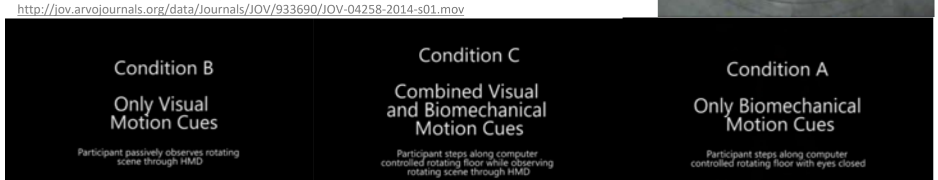
http://ispace.iat.sfu.ca/project/ispacemecha/
http://ispace.iat.sfu.ca/project/vection/
http://jov.arvojournals.org/article.aspx?articleid=2213267
http://jov.arvojournals.org/data/Journals/JOV/933690/JOV-04258-2014-s01.mov



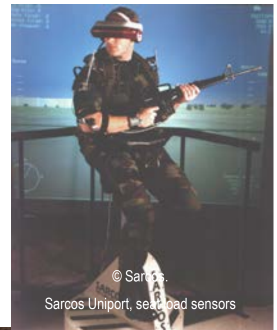
Why walk if you can cycle?

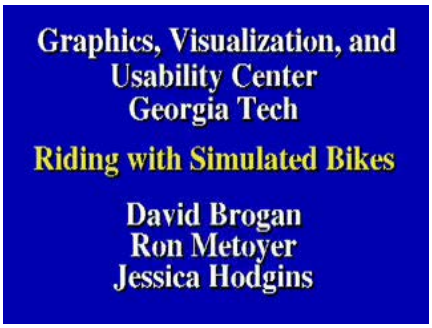
Pro:

- Cyclic motion per def.
- Mechanically simple
- Intuitive
- No walls to walk into
- Lower exertion

challenges:

- Pedaling resistance
  - Friction break
  - Inertia → flywheel
- Viscosity
- Centrifugal force
- Slope
- Acceleration/motion cueing missing



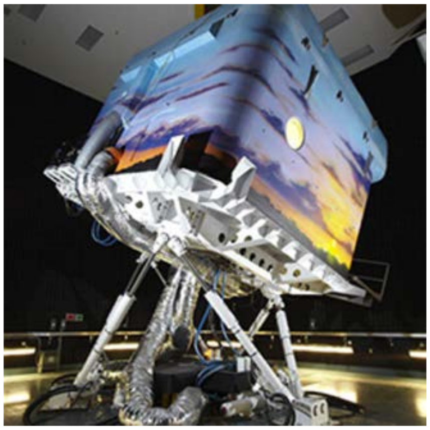


© Animation Lab, Georgia Institute of Technology, USA http://www.cc.gatech.edu/gvu/people/student/David.Rodriguez/bike.html

How to provide more vestibular motion cues?

6DOF motion platforms - Stewart

- Hexapod design



© Toronto Rehabilitation Institute, ON, Canada
http://www.uhn.ca/TorontoRehab/Research/Rehab_Research_Future/Pages/default.aspx

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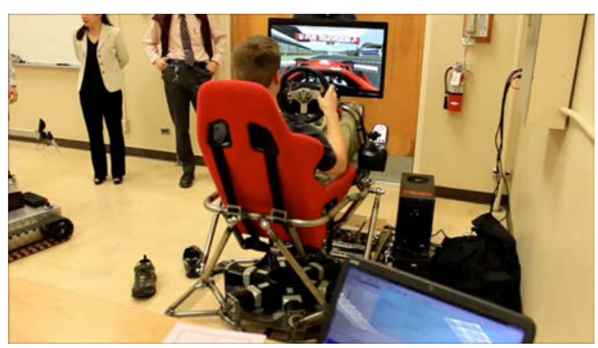
6DOF motion platforms – Stewart, low-cost/DIY

- DIY motion simulators

© Motion Dynamics, San Jose State University, CA, USA http://www.x-sim.de/forum/portal.php

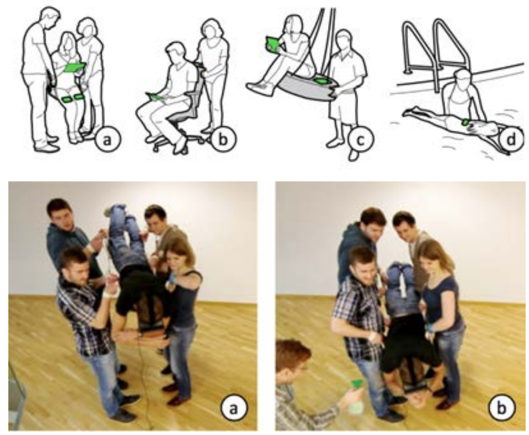


© Motion Dynamics, San Jose State University, CA, USA https://fullmotiondynamics.com/

Ultra-low-cost: Manual motion platforms

- "Haptic Turk": other-human-powered motion platform

© Hasso-Plattner-Institut, University of Postdam, Germany https://hpi.de/baudisch/projects/haptic-turk.html https://youtu.be/FG7qoFubf04



© Cheng, LP, Lühne, P., Lopes, P., Sterz, C. and Baudisch, P. .Haptic Turk: a Motion Platform Based on People. In *Proceedings of CHI 2014*, pp.3463-3472.

6DOF motion platforms – Stewart on rails

© Toyota; Toyota's Higashi Fuji Technical Center in Shizuoka, Japan http://www.transportationtechnologyventures.com/simwiki/index.php?title=Other_Simulators

6DOF motion platforms - Centrifuge

- Desdemona Simulator (TNO)

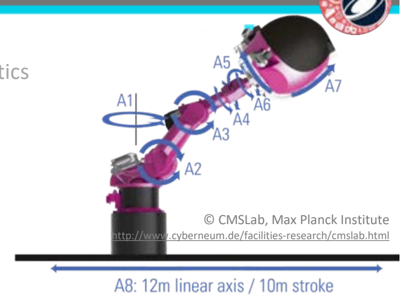
© Desdemona https://youtu.be/YyMQlALrX80?t=16s

© Valente Pais, A. R., Wentink, M., van Paassen, M. M., & Mulder, M. (2009). Comparison of Three Motion Cueing Algorithms for Curve Driving in an Urban Environment. *Presence: Teleoperators and Virtual Environments*, *18*(3), 200–221.
https://www.researchgate.net/profile/Max_Mulder/publication/220089770

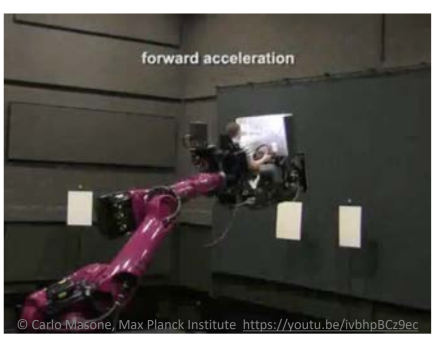
© Desdemona http://www.desdemona.eu/products.html#

6DOF motion platforms – Robot arm

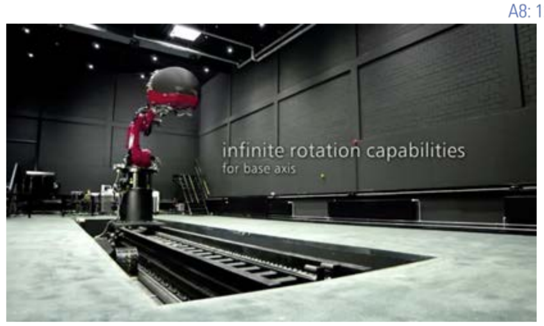
- CyberMotion Simulator, Max Planck Institute for Biological Cybernetics



© CMSLab, Max Planck Institute
http://www.cyberneum.de/facilities-research/cmslab.html



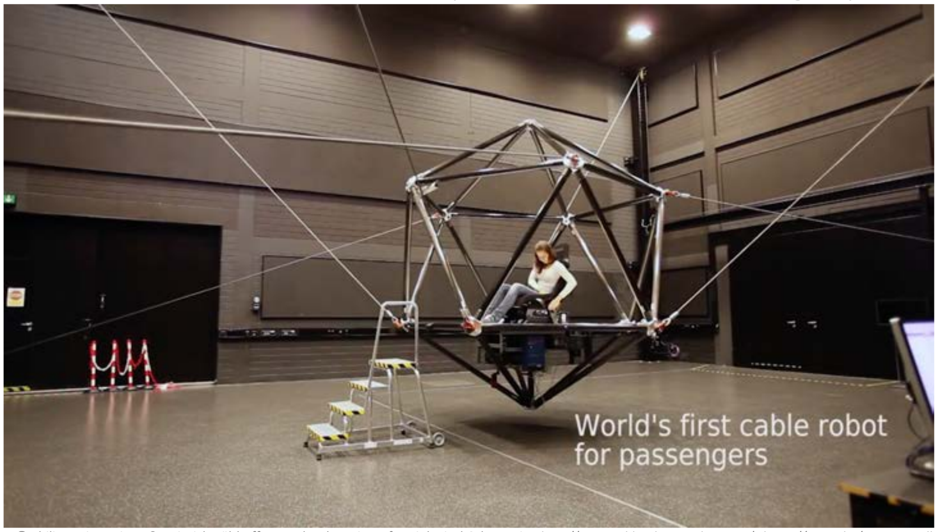
© Carlo Masone, Max Planck Institute https://youtu.be/ivbhpBCz9ec



© Heinrich Bülthoff, Klenkfilm gmbh https://youtu.be/ThkymYRP1g8?t=49s

6DOF motion platform – cable simulator

- MPI CableRobot-Simulator Cyberneum, Max Planck Institute for Biological Cybernetics



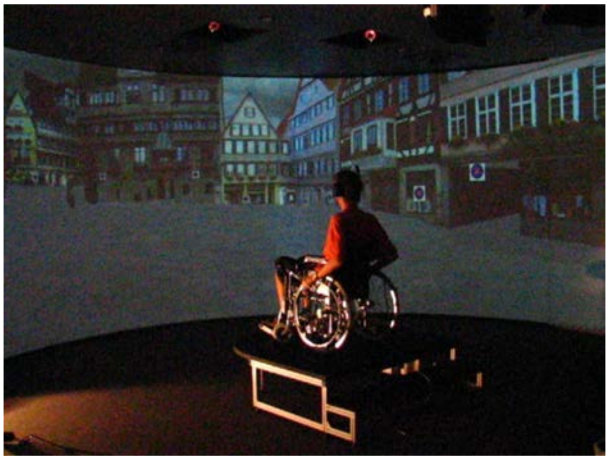
© Philipp Miermeister & Heinrich Bülthoff, Max Planck Institute for Biological Cybernetics, http://www.cablerobotsimulator.org/ https://youtu.be/cJCsomGwdk0?t=10s

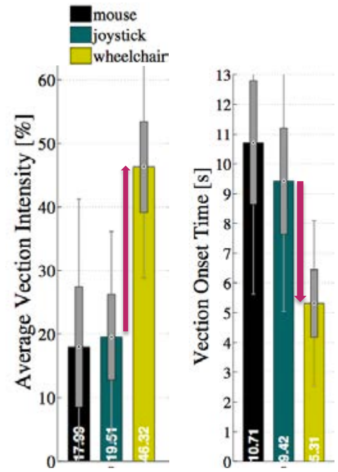
What to do if resources are limited?

- Could we ask users to provide and power their own motion cueing?

Seated motion cueing interface - Wheelchair

- Idea: Participants provide themselves with minimal motion cueing → lean & elegant (Riecke, VRST 2006)

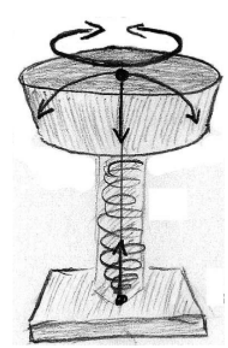




© Bernhard Riecke, VRST 2006 http://ispace.iat.sfu.ca/wp-content/plugins/zotpress/lib/request/rss.file.php?api_user_id=37904&download=NA9EIIG4

Seated leaning interfaces - Leaning Stool

- ChairIO (based on Swopper stool)
  - Beckhaus et al., 2005ff, Usability studies
- NaviChair
  - Kitson et al. (ACM SUI, 2015), Freiberg (MSc thesis, 2015) Usability & navigation studies



© Steffi Beckhaus, ChairIO, im.ve Lab, University of Hamburg
https://imve.informatik.uni-hamburg.de/projects/chairio

But do such leaning interfaces ”work”

- “Lean-based navigation seems **stunningly effective as a navigation** paradigm for reasonably complex physical spaces. Users typically overshoot the first time they try it, but after saying “wow” and rocking back and forth they grasp the concept extremely fast.”
  - Fairchild et al., IEEE VR 1993
- Little formal evaluation, though

Seated leaning interfaces: Gyroxus

- Whole-body seated leaning using user-powered motion cueing (Gyroxus gaming chair) enhances self-motion illusion (vection)
  - Feuereissen & Riecke, 2012
- Clear usability & control issues w/ Gyroxus

© Bernhard Riecke, Riecke et al., ACM SAP 2012,
https://youtu.be/ubmtXfEqT1o

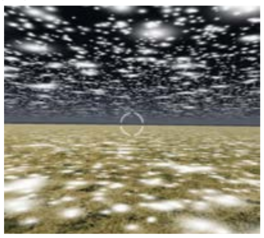
© Gyroxus, 4th Motion, LLC

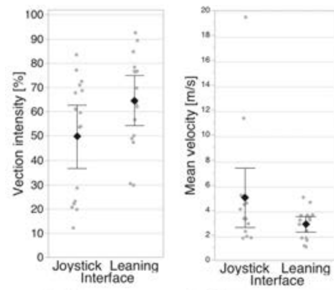
Seated leaning interface: “human joystick”

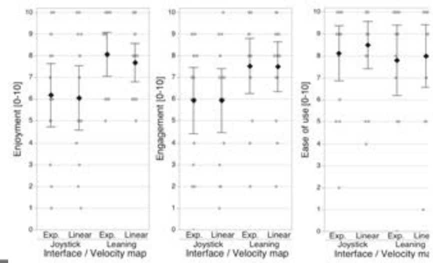
Idea: Upper body leaning as input (low-cost)

- “Human joystick” can enhance self-motion perception
- Also: higher levels of engagement, involvement, attentional capture, enjoyment, as well as reduced distance overshooting,
- Joystick rate higher for comfort of posture

© Riecke, Kruijff et al, in preparation







Standing leaning interfaces

© Wang, J., & Lindeman, R. W. (2012, March). Comparing isometric and elastic surfboard interfaces for leaning-based travel in 3D virtual environments. In *3D User Interfaces (3DUI), 2012 IEEE Symposium on* (pp. 31-38). IEEE.

© de Haan, G., Griffith, E. J., & Post, F. H. (2008). Using the Wii Balance Board™ As a Low-cost VR Interaction Device. In *Proceedings of the 2008 ACM Symposium on Virtual Reality Software and Technology* (pp. 289–290). New York, NY, USA: ACM. https://graphics.tudelft.nl/~eric/publications/wii08.pdf

© J. Wang & R. Lindemann, 3DUI 2012
https://www.semanticscholar.org/paper/Isometric-versus-Elastic-Surfboard-Interfaces-for-Wang-Lindeman/9e6de91b100f1ea968ee4bd947a41365c8c08461

https://pdfs.semanticscholar.org/6cbb/e6156fb6fa27ee3f1d2771fa1e34e7643a25.pdf

Standing leaning interfaces: Joyman

- Leaning on trampoline

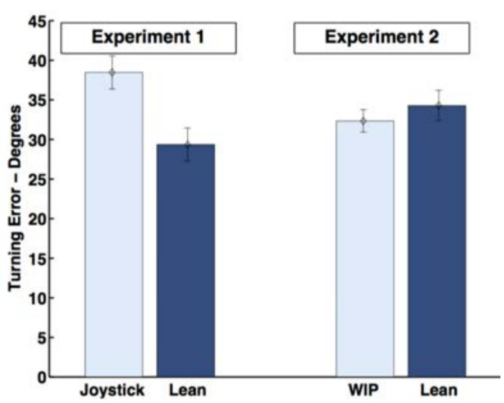
- whole-body leaning (Joyman) vs. joystick:
  - higher ratings for Fun, presence, rotation realism,
  - but less intuitive, accurate, and also slower and more fatiguing


© Maud Marchal, Julien Pettré, Anatole Lécuer. Joyman: a Human-Scale Joystick for Navigating in Virtual Worlds, IEEE Symposium on 3D User Interfaces 2011 (3DUI), Mar 2011, Singapour, Singapore. 2011

https://hal.archives-ouvertes.fr/inria-00567437/PDF/joyman-cameraReady.pdf

Standing leaning interfaces: Wii Balance Board

- Leaning on force plate (Wii balance board) for large-scale navigation
- Wii-leaning and walking in place (WIP) reduced spatial orientation errors compared to joystick (complete-turn-to-face-target task)




© Harris, A., Nguyen, K., Wilson, P. T., Jackoski, M., & Williams, B. (2014, November). Human joystick: Wii-leaning to translate in large virtual environments. In *Proceedings of the 13th ACM SIGGRAPH International Conference on Virtual-Reality Continuum and its Applications in Industry* (pp. 231-234). ACM.
http://dl.acm.org/citation.cfm?id=2670512&dl=ACM&coll=DL&CFID=765619277&CFTOKEN=64154620

How much physical motion (translation) is needed?

Task: Navigational search

Controller

- **Trackpad**-based
- No translational body-based sensory information

NaviChair

- Leaning-based
- Translational information from **upper-body leaning**

NaviBoard

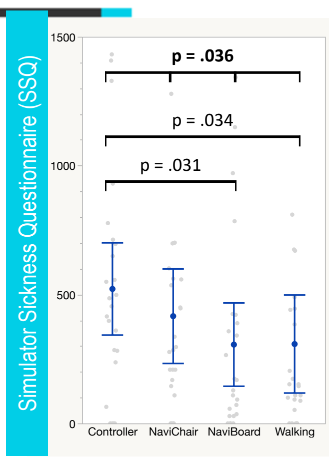
- Leaning-based
- Translational information from the **whole body leaning/stepping**

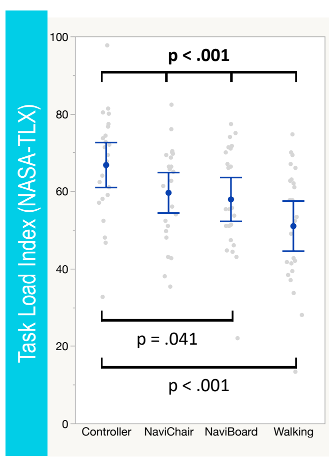
Walking

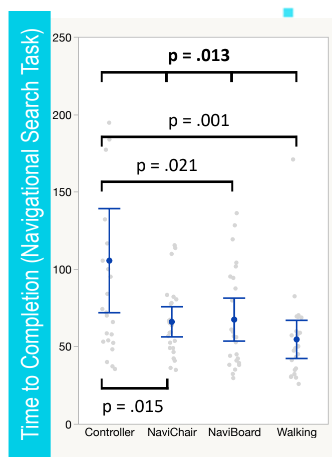
- Actual **walking**
- Full translational body-based sensory information

© Riecke et al:
Nguyen-Vo, T., Riecke, B. E., Stuerzlinger, W., Pham, D.-M., & Kruijff, E. (2018). Do We Need Actual Walking in VR? Leaning with Actual Rotation Might Suffice for Efficient Locomotion. Submitted to Spatial Cognition 2018

How much physical motion (translation) is needed?







- Controller (trackpad): highest sickness, task difficult & completion times
- Body-based information from a leaning interface might suffice for a cost-effective alternative to actual walking

© Riecke et al: Nguyen-Vo, T., Riecke, B. E., Stuerzlinger, W., Pham, D.-M., & Kruijff, E. (2018). Do We Need Actual Walking in VR? Leaning with Actual Rotation Might Suffice for Efficient Locomotion. Submitted to Spatial Cognition 2018

Flying interfaces - issues

Introduce different kinds of flying interfaces, focusing on:

- Different system approaches, up to highly affordable
- Different (vection) cues and system implications

Perception

- Motion range, feedback mapping and compliance
- Additional cues
- Pose: kind / support
- Exertion / bodily involvement
- Presence, experience

System

- Setup complexity and cost
- Getting into the setup (mounting, calibrating)

© Image/industry tap
http://www.industrytap.com/humans-flying-over-225-mph-inches-above-trees-and-cliffs/3477

Traditional flying interfaces

Flight simulators

Perception

- Motion: restricted motion range (unless 360 system is used), mostly compliant
- Additional cues: can be combined with wind, vibration
- Pose: seated, mostly vehicle based
- Exertion: none
- Presence: can be highly realistic, nice experience

System

- Often costly
- Can be difficult to maintain

©Mila Patek,
https://www.youtube.com/watch?v=uUQnZxWqnPE

Birdly

From flight simulator to complex self-motion: birdly (Rheiner 2014)

Perception

- Motion: restricted, but mostly compliant
- Additional cues: wind
- Pose: correct pose, but body supported instead of free-fall
- Exertion: weight balancing and hands, actuation by system
- Presence: semi-realistic bird experience

System

- Rather easy to get in
- However: not truly cheap

Tested.com https://www.youtube.com/watch?v=gWLHIusLWOc

© somniacs.

image: http://birdlyvr.com/wp-content/uploads/2017/03/151026_BHP-2922_03.jpg

From the ceiling

From Birdly to Birdman

Perception

- Motion: restricted by cables, but compliant if constrained in application
- Additional cues: wind
- Pose: flat, hanging (“weightless”)
- Exertion: weight balancing, arm movements
- Presence: fun, involvement

System

- Classical, affordable cable solution widely used
- Takes time to get in

© VR Scout

https://www.youtube.com/watch?v=vTABfNoCF_c

© ARS Electronica

http://www.aec.at/futurelab/en/project/humphrey-ii/

Let's swim

A side step: from birdman to swimming

- Quick step due to similar pose: use similar system for other types of movement
  - Swimming across ocean (Sid Fels)
  - Scuba diving (Jain et al. 2016)

Scuba diving. © Jain et al.
Jain et al. Immersive Scuba Diving Simulator Using Virtual Reality, ACM UIST 2016.
https://www.youtube.com/watch?v=5ZXlkv5tJOQ

Ryanair – flying on a shoestring

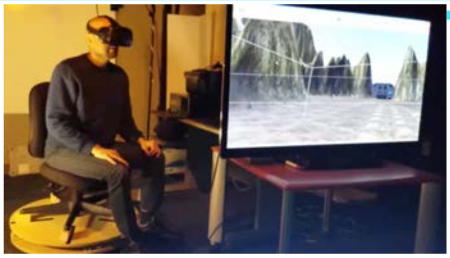
From birdman to anyChair

Perception

- Motion: constrained, but can rotate at spot
- Additional cues: none yet
- Pose: flat
- Exertion: weight balancing
- Presence: funny

System

- Affordable
- Can be combined with many other kinds of interfaces
- Easy to get into



© Bernhard Riecke

Human joystick

Human body as joystick

Perception

- Motion: on spot, but free
- Additional cues: none yet
- Pose: standing / leaning
- Exertion: leaning
- Presence: bodily involved

System

- Affordable
- Can be combined with many other kinds of interfaces
- Easy to get into

TEDxEastVan 2017: “Could Virtual Reality make us more human?”
© Bernhard Riecke
https://youtu.be/cMGOftEi4UU

Hang’n fly

From birdman to different flying metaphor

Perception

- Motion: restricted, mostly upper body, no actuation necessarily, not fully compliant
- Additional cues: wind
- Pose: carried, hanging
- Exertion: weight balancing, arm movement
- Presence: nice experience

System

- Somewhat easier to setup and maintain due to fewer cables
- Still rather affordable

© Okan Köse
https://www.youtube.com/watch?v=uN5YiVIAZ34

From birdman to jumpman (Eidenberg & Mossel, 2015)

Perception

- Motion: constrained, but extended towards multi-pose, compliant if constrained in application
- Additional cues: wind
- Pose: standing and flat
- Exertion: jumping and weight balancing
- Presence: improved presence / UX due to jump stage

System

- more complex physical setup, but nice experience
- issues with getting in

© Eidenberg & Mossel.
Indoor Skydiving in Immersive Virtual Reality with Embedded Storytelling, ACM VRST 2015.
Video: acquired from authors.

No cables please

From jumpman to freefall

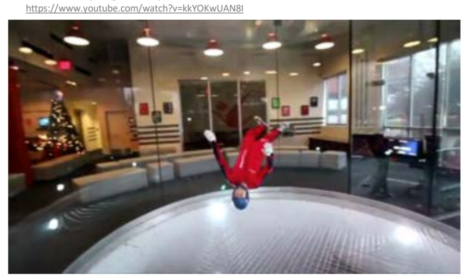
Perception

- Motion: “unconstrained” and “weightless”
- Additional cues: strong (!) wind
- Pose: any, but most likely flat
- Exertion: quite high, due to active balancing
- Presence: can be very realistic while cableless, free movement, wind

System

- Loud
- Back to the start: not really affordable
- Requires training

Indoor flying © Ifly
https://www.youtube.com/watch?v=kkYOKwUAN8I



TunnelFlight. © IBA
https://www.youtube.com/watch?v=4PK3MUjNzc4

Qualitative vs. quantitative research methods

	Qualitative	Quantitative
Method & approach	inductive, bottom-up Coming up w/ new hypotheses + Often "unexpected" findings – issues not asked/intended for can surface	deductive or top-down Hypothesis testing + Can be compared, summarized & quantified easily; Generalizability can be assessed
Typical goals	Goals: Answers exploratory "WHY" questions, description, exploration, discovery…	Goals: Experimental & scientific method: attribute causality, prediction, description, explanation
Focus	"wide-angle", investigating depth & breadth of phenomenon	"narrow or close": testing specific hypotheses
Setting	Naturalistic setting, context of interest	Tightly controlled and reproducible conditions
Interested in	Subjective, personal, socially constructed reality	"objective" or inter-subjective: generalizability
Kind of data collected	e.g., Interviews, observations, text/media analysis; "rich" Includes f2f / non-verbal cues Researcher is primary data collection instrument	"Measurements", incl., behavioral, (neuro)phyisological, introspective (using structured/validated methods, rating scales…)
Results	Particularistic, viewpoint-specific (unclear generalizability)	Generalizable (can miss individual viewpoints/aspects)
Presentation format	Narrative, contextual, quotations	Descriptive (plots…) & inferential (p-values…) statistics
Disadvantages	Generalizability unclear; Limited predictive power Often small N; limited /no hypothesis testing Subjectivity: Prone to biases, Experimenter demand Data analysis (transcription/coding) time-consuming	Can be limited by fixed questions Larger N → can be time consuming Sometimes limited ecological validity

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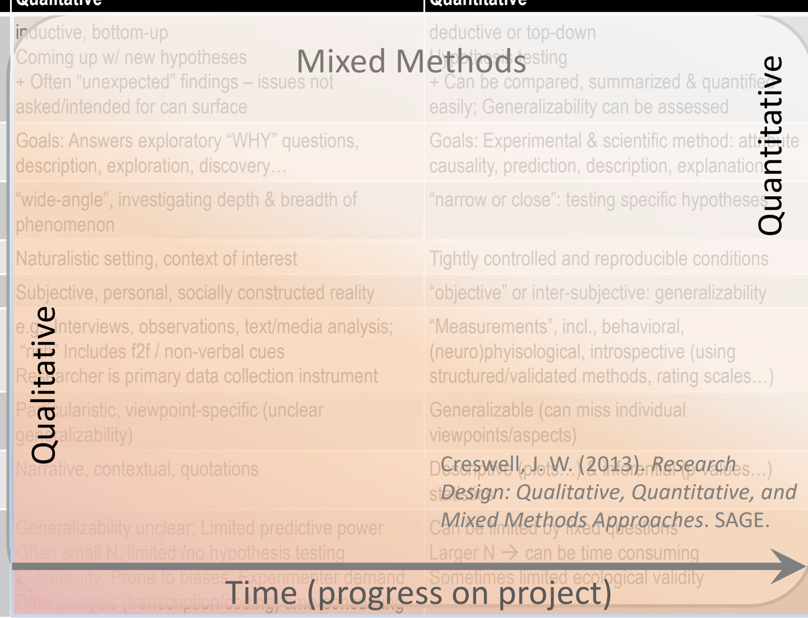

Creswell, J. W. (2013). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. SAGE.

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So which interface should I choose? How to evaluate my interface?

Determine **requirements**:
What should users be able to **DO** with the interface? → **functional** requirements
What should they "**feel"/experience** → **non-functional** requirements

Interface	Details	usability / user experience	Naturalism / realism	technical complexity/effort	safety	cost	visual	auditory	vestibular	proprioceptive	tactile/haptic	exertion
		Evaluation / rating (functional & non-					cues provided					
details on interface												
walking, full gait	free-space walking, redirected walking											
walking, partial gait	Walking in place WIP											
walking, gait negation	Linear treadmills											
	omnidirectional treadmills, a) with motion cueing											
	b) without motion cueing											
	c) low-cost, Virtuix...											
1-5 DOF motion platform												
6DOF motion platforms	small envelope											
	large envelope											
	with linear track											
manual motion cueing	seated leaning											
	standing leaning											
classic interfaces (e.g., rate control)	Joystick, gamepad etc.											
6 DOF hand-held controllers	e.g., Oculus Touch											

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Interface	Details	usability / user experience	Naturalism / realism	technical complexity/effort	safety	cost	visual	auditory	vestibular	proprioceptive	tactile/haptic	exertion
		Evaluation / rating (functional & non-					cues provided					
details on interface												
walking, full gait	free-space walking, redirected walking	3	3	2	1	1	2	2	3	3	3	3
walking, partial gait	Walking in place WIP	2	1	2	1	0	2	2	0	-1	0	0
walking, gait negation	Linear treadmills	1	0	2	1		2	2	0	1	1	1
	omnidirectional treadmills, a) with motion cueing	3	3	-3	-2	-3	2	2	2	3	3	3
	b) without motion cueing	1	2	-2	-1	-2	2	2	0	2	2	3
	c) low-cost, Virtuix...	-1	-1	2	0	1	2	2	-1	0	0	2
1-5 DOF motion platform		1	1	-1	-1	-1	2	2	0	-1	0	-2
6DOF motion platforms	small envelope	1	2	-2	-1	-1	2	2	1	-1	0	-2
	large envelope	2	3	-2	-2	-2	2	2	2	-1	0	-2
	with linear track	3	3	-3	-2	-3	2	2	3	-1	0	-2
manual motion cueing	seated leaning	2	2	3	3	2	2	2	1	1	1	0
	standing leaning	1	2	3	1	2	2	2	1	1	1	0
classic interfaces (e.g., rate control)	Joystick, gamepad etc.	0	-3	3	3	3	2	2	-3	-3	-3	-3
6 DOF hand-held controllers	e.g., Oculus Touch	2	1	2	2	2	2	2	-2	2	2	2
your-own-interface…												

There's a lot of room for your creativity…

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Where to get the slides?

Slides can be downloaded from:
http://iSpaceLab.com/project/3dui-course/

If you cite us: see ACM digital library: Riecke, B. E., LaViola Jr., J. J., & Kruijff, E. (2018). 3D User Interfaces for Virtual Reality and Games: 3D Selection, Manipulation, and Spatial Navigation. In *Proceedings of ACM SIGGRAPH 2018 Courses (SIGGRAPH '18).* (half-day course). Vancouver, BC, Canada:

Related course on navigation interfaces: CHI '18
https://dl-acm-org.proxy.lib.sfu.ca/citation.cfm?id=3170643


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Navigation Interfaces for Virtual Reality and Gaming: Theory and Practice

Full Text: PDF

Authors: Ernst Kruijff — Bonn-Rhein-Sieg University of Applied Sciences, Sankt Augustin, Germany
Bernhard E. Riecke — Simon Fraser University, Surrey, BC, Canada

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Last but not least: Have **fun** & get **creative** while designing, developing and validating 3D user interfaces!

Thanks for coming!

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