Module IN 2018

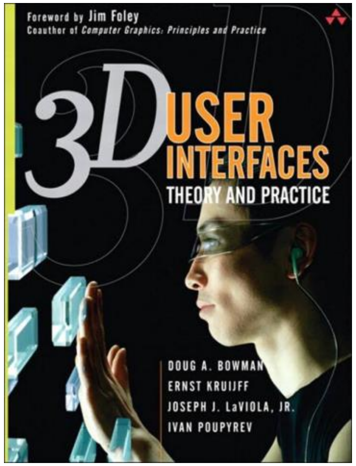
3D User Interfaces
- Dreidimensionale Nutzerschnittstellen -

Prof. Gudrun Klinker

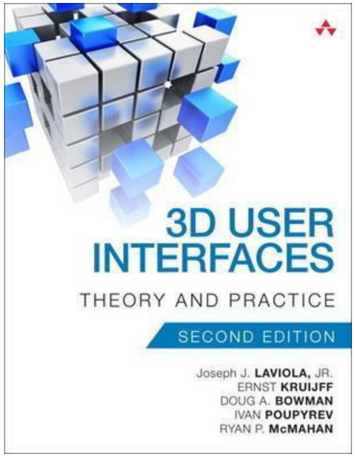
Selection and Manipulation
SS 2023

Literature

- *3D User Interfaces – Theory and Practice. 2nd edition*
  D. Bowman, E. Kruiff, J. LaViola, I. Poupyrev.
  Addison-Wesley Pearson Education, 2005.



- *3D User Interfaces – Theory and Practice. 2nd edition*
  J. LaViola, E. Kruiff, D. Bowman, I. Poupyrev, R. McMahan.
  Addison-Wesley Pearson Education, 2017.
  https://www.pearson.com/us/higher-education/program/La-Viola-3-D-User-Interfaces-Theory-and-Practice-2nd-Edition/PGM101825.html



Agenda

1. 3D Selection and Manipulation Tasks
2. Interaction Techniques and Input Devices
3. Interaction Techniques for 3D Manipulation
4. Design Guidelines

1. 3D Selection and Manipulation Tasks

→ 1.1 Canonical Selection and Manipulation Tasks

1.2 Application-Specific Selection and Manipulation Tasks

1.1 Canonical Selection and Manipulation Tasks

- Parameters associated with specific manipulation tasks
  - Application goals
  - Object sizes
  - Object shapes
  - Distance from objects to user
  - Characteristics of the physical environment
  - Physical and psychological states of the user

- Try to find repeating „basic“ tasks across many applications

1.1 Canonical Selection and Manipulation Tasks

Basic manipulation tasks:

- Selection
  (Real world: Picking an object with a hand)
- Positioning
  (Real world: Moving an object from A to B)
- Rotation
  (Real world: Rotating an object from one pose into another)
- (Scaling)

1.1 Canonical Selection and Manipulation Tasks

Parameter spaces (of individual tasks)

- Task space
- Each task parameter defines a design dimension

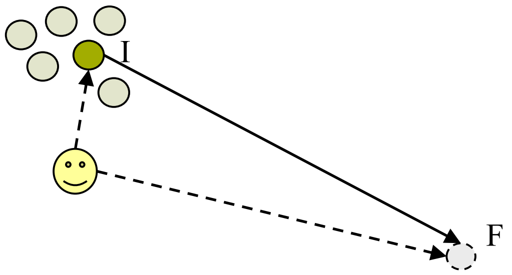
Parameters associated with specific manipulation tasks

- *Application goals*
- *Object sizes*
- *Object shapes*
- *Distance from objects to user*
- *Characteristics of the physical environment*
- *Physical and psychological states of the user*

1.1 Canonical Selection and Manipulation Tasks

Parameter spaces for **basic, recurring tasks**

- Selection
  - Distance, direction to target
  - Target size
  - 密度 Density of objects around target
  - Number of targets to be selected
  - Target occlusion
- Positioning (Google Map)
  - Distance, direction to initial position (I)
  - Distance, direction to final position (F)
  - Translation distance
  - Required precision of positioning 精度
- Rotation
  - Distance to target
  - Initial orientation
  - Final orientation
  - Amount of rotation
  - Required precision of rotation



1. 3D Selection and Manipulation Tasks

1.1 Canonical Selection and Manipulation Tasks

→ 1.2 Application-Specific Selection and Manipulation Tasks

1.2 Application-Specific Selection and Manipulation Tasks

- *Parameters associated with specific manipulation tasks*
  - *Application goals*
  - *Object sizes*
  - *Object shapes*
  - *Distance from objects to user*
  - *Characteristics of the physical environment*
  - *Physical and psychological states of the user*
- Select a representative subset of requirements for a specific task, e.g. for
  - VR medical training: positioning a medical probe in virtual patient models
  - Flight simulator: landing a plane

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重心：Input.

2. Interaction Techniques and Input Devices

→ 2.1 Input-Control-Mapping

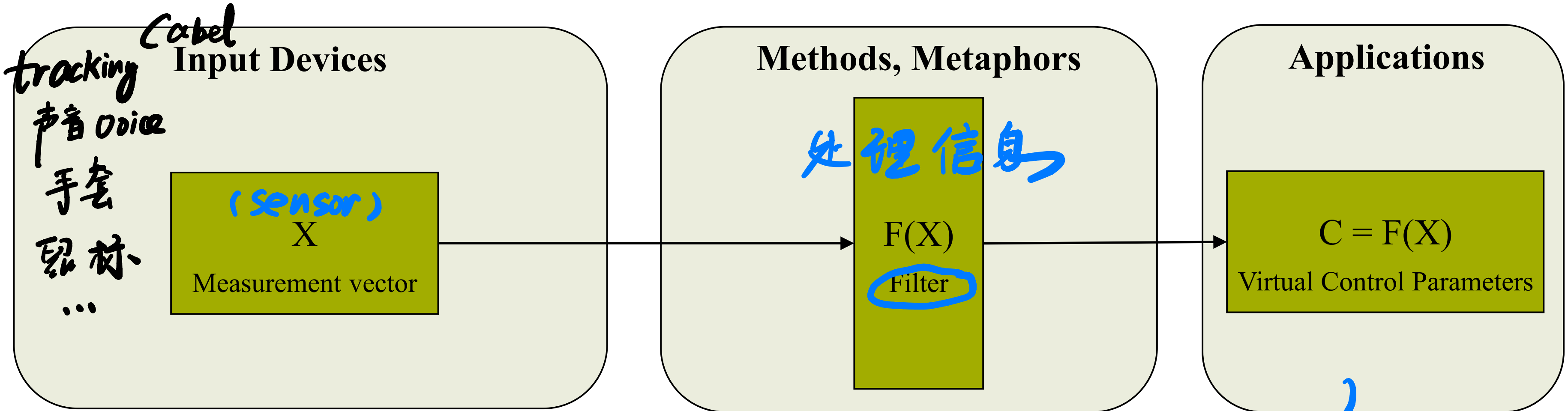
2.2 Control Dimensions and Integrated Control in 3D Manipulation

2.3 Force versus Position Control

Remarks:

- Here: restricted to input devices
- More on this also in a subsequent class on input devices

2.1 Input-Control-Mapping

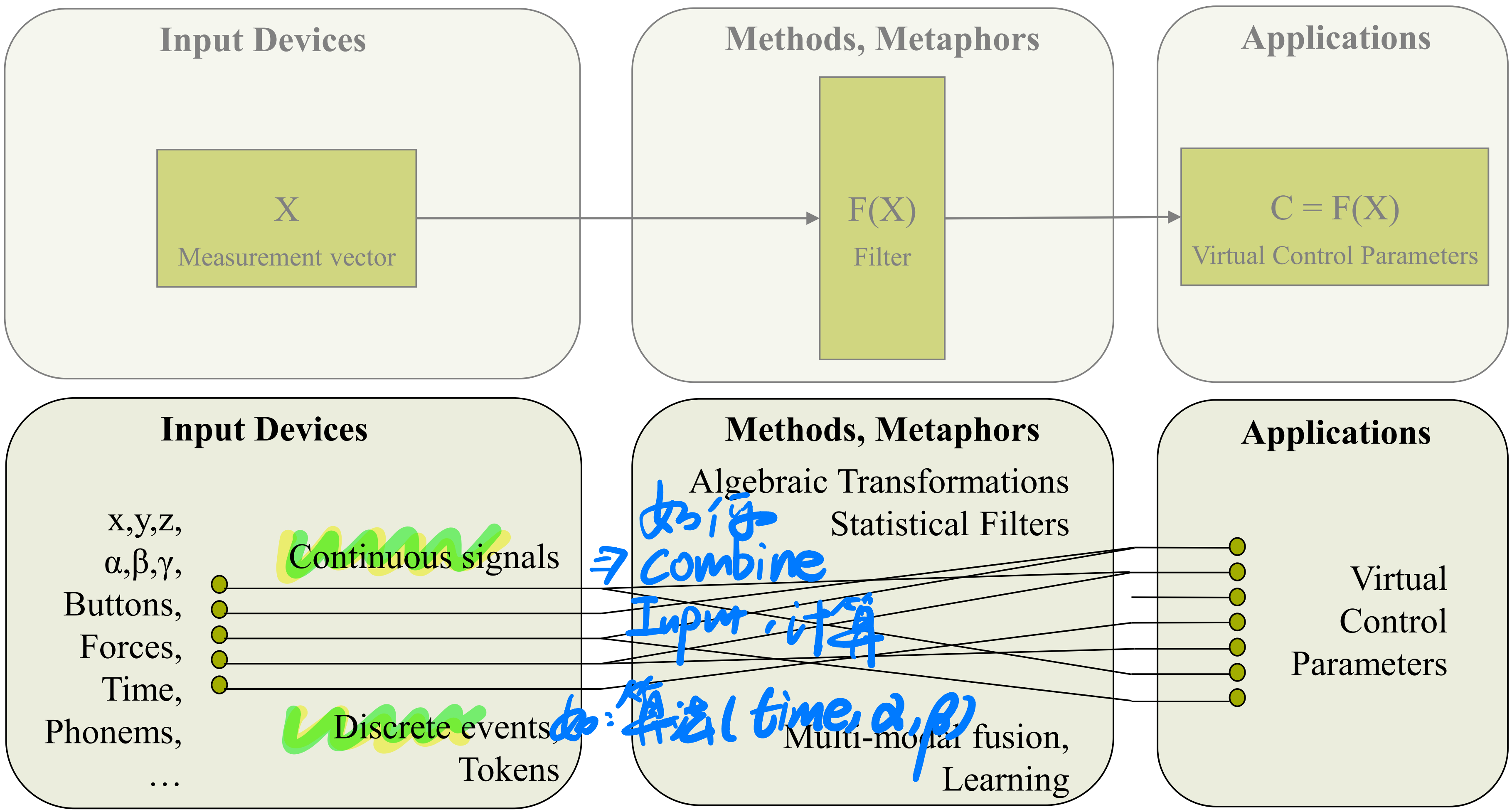


Input-Control Mapping

- Object selection, picking
- Object manipulation
- Travel, camera control

基本 action 的 mapping

2.1 Input-Control-Mapping



2. Interaction Techniques and Input Devices

2.1 Input-Control-Mapping

→ 2.2 Control Dimensions and Integrated Control in 3D Manipulation

2.3 Force versus Position Control

2.2 Control Dimensions and Integrated Control

- Key parameters
  - Number of control dimensions (DOFs) Degrees of Freedom
  - Level of integration (simultaneous control of DOFs)
- Examples
  - Desktop mouse: 2 DOFs
  - Trackers (magnetic, optical): ≤ 6 DOFs
  - Game controllers: ≥ 4 DOFs (2+2 for each hand)
- Issues
  - Cost
  - Availability
  - Ease of maintenance
  - Targeted user population

2. Interaction Techniques and Input Devices

2.1 Input-Control-Mapping

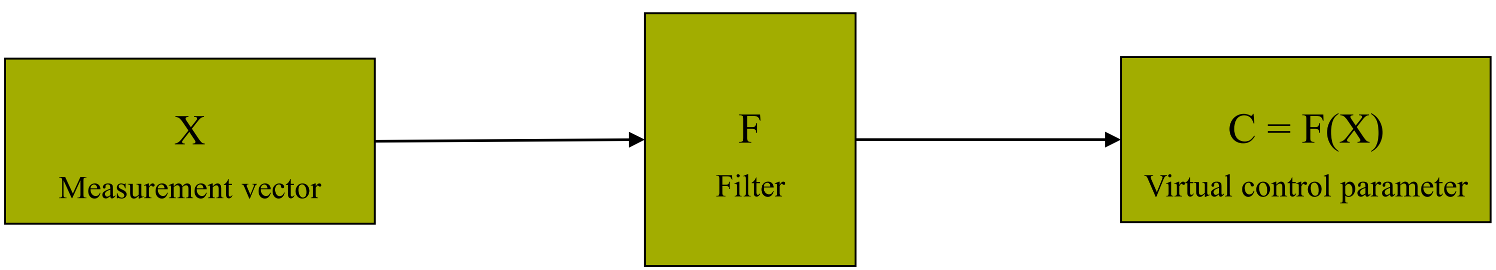
2.2 Control Dimensions and Integrated Control in 3D Manipulation

→ 2.3 Force versus Position Control

2.3 Force versus Position Control

- *Isomorphic control*:
  - Absolute or relative **position** of the human hand (mouse, trackers, etc)
- *Non-isomorphic (*either *isometric* or *isotonic) control*:
  - 力 Force applied to a device, speed of motion (**rate** of position changes) (joy stick)
    速度
  - …

- For 6-DOF manipulation tasks: Position control usually better than force control [Zhai and Milgram 93]
- Force control better at controlling rates (speed of navigation).



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3. Interaction Techniques for 3D Selection and Manipulation

- 3.1 Classifications of Selection and Manipulation Techniques
- 3.2 Interacting by Pointing
- 3.3 Direct Manipulation: Virtual Hand Techniques
- 3.4 World-in-Miniature
- 3.5 Combining Techniques
- 3.6 Nonisomorphic 3D Rotation
- 3.7 Desktop 3D Manipulation

3.1 Classifications

Isomorphism in selection and manipulation techniques

- *Isomorphic* view → 比例调整x、y、z 对人而言自然
  - Strict, geometrical 1-to-1 mapping (one to one mapping)
  - Pro: Very natural
  - Con:
    - Impractical due to constraints on input devices
    - Impractical due to human limitations

    stuck in physical world
- *Non-isomorphic* view:
  - „Better reality“, specifically taylored to 3D environments
  - „Magic“ virtual tools (laser beams, rubber arms, voodoo dolls)

↓

非 geometrical 的 1 to 1

3.1 Classifications

Classification

- By task decomposition
- By metaphor

Input

3.1 Classifications

按一个事件描述Input方式

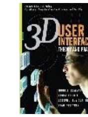
By **task decomposition** 整个Input过程

- All selection and manipulation techniques consist of the same basic components that serve similar purposes
- Interaction „building blocks“:

Example:

- selection technique
  - indication of object 选
    - occlusion
    - object touching
      - list
      - voice sel.
      - automatic
      - iconic objects
    - 所有可能
    - pointing
      - 2D
      - 3D gaze
      - 3D hand
    - indirect selection
      - 1 to 1
      - pos → pos
      - vel → pos
      - pos → vel
  - confirmation of selection 确定吗?
    - event
    - gesture
    - voice command
    - no explicit command
  - feedback
    - text/symbolic
    - aural
    - visual
    - force/tactile

Input程序结果



3.1 Classifications 更自然的学习法

By **metaphor**: Fundamental mental model of a technique

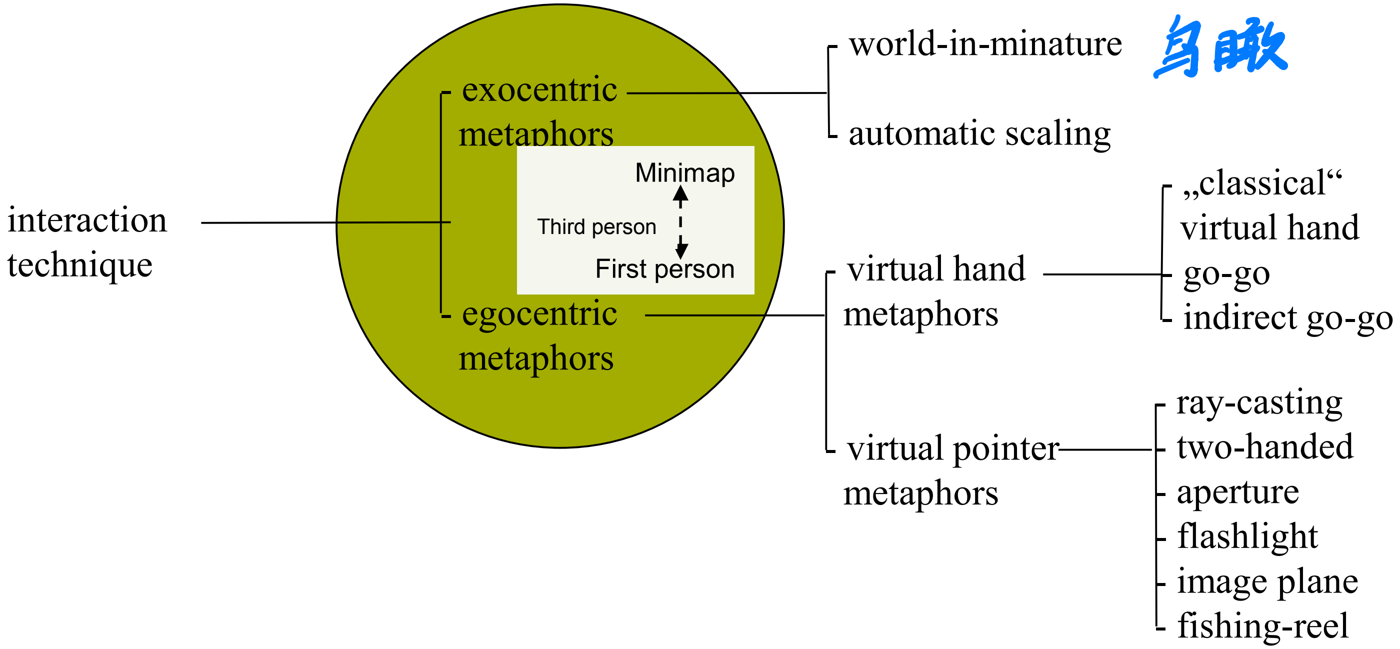
- *Affordances*: what users can do by using a technique
- *Constraints*: what users cannot do with a technique

- interaction technique
  - 向外 exocentric metaphors
    - world-in-minature
    - automatic scaling
  - 中心主义 egocentric metaphors
    - virtual hand metaphors
      - „classical“ virtual hand
      - go-go
      - indirect go-go
    - virtual pointer metaphors
      - ray-casting
      - two-handed
      - aperture
      - flashlight
      - image plane
      - fishing-reel

3.1 Classifications

By metaphor

- Exocentric metaphors: bird‘s eye view
- Egocentric metaphors: through the user‘s eyes



3. Interaction Techniques for 3D Selection and Manipulation

3.1 Classifications of Selection and Manipulation Techniques

→ 3.2 Interacting by Pointing

3.3 Direct Manipulation: Virtual Hand Techniques

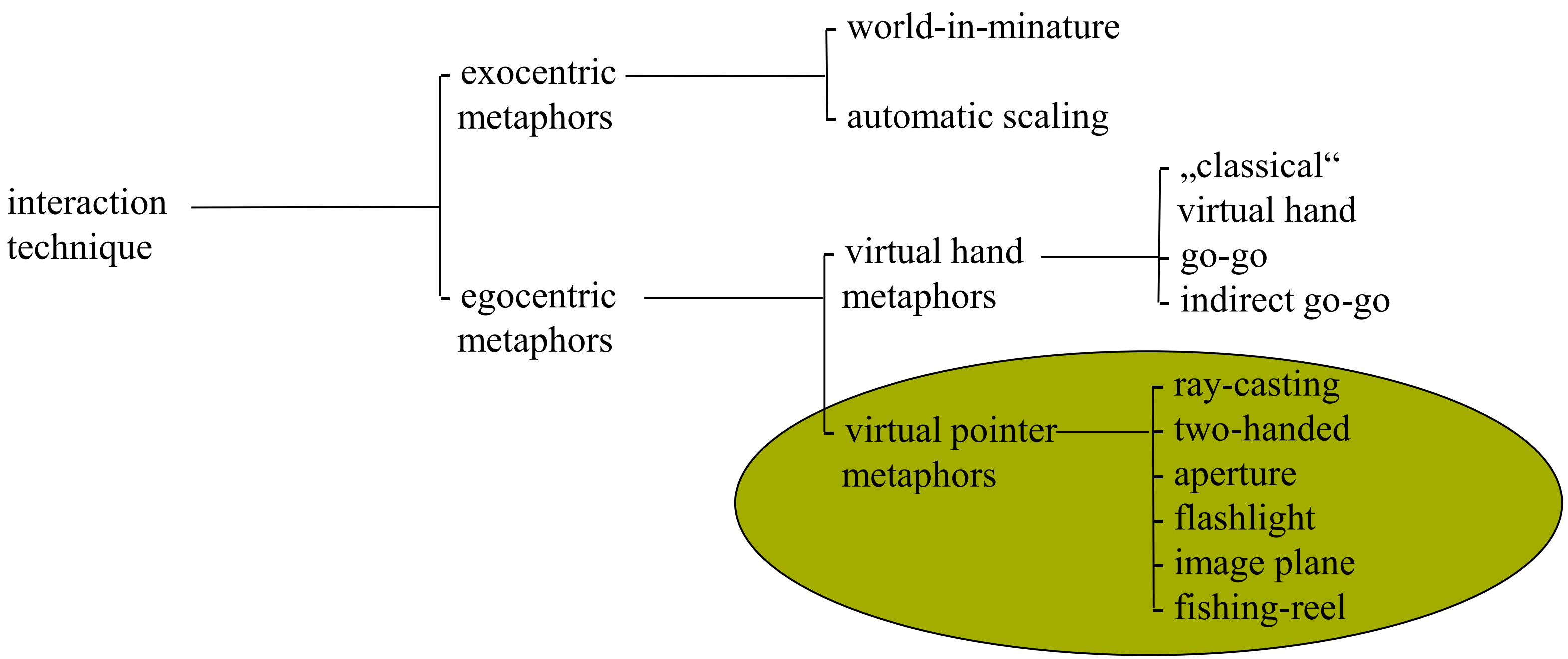
3.4 World-in-Miniature

3.5 Combining Techniques

3.6 Nonisomorphic 3D Rotation

3.7 Desktop 3D Manipulation

3.2 Interacting by Pointing



3.2 Interacting by Pointing

- Goal:
  - Select and manipulate objects **beyond** area of reach
- Sequence of actions:
  - Pointing direction = 3D vector
  - Object selection = intersection (vector, virtual object)
  - Confirmation = triggering event
- Further steps:
  - Attach selected object to end of vector (for manipulation)
- Pro:
  - Better selection performance than hand-based techniques (little physical hand movement)
- Con:
  - Very poor positioning technique (only radial movements around the user)
  - Rotations only around one axis (pointing direction)

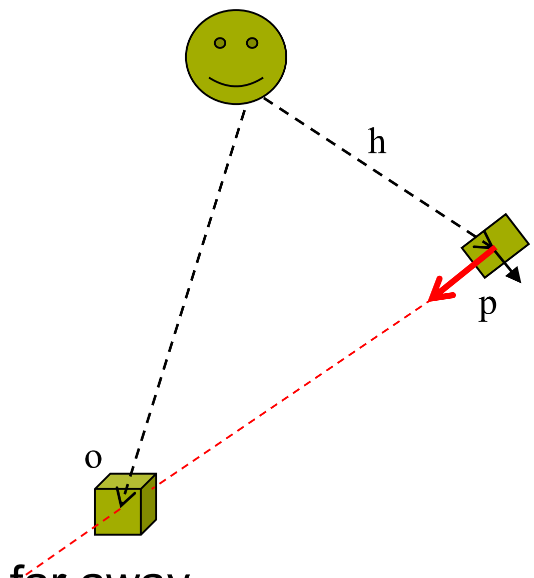
3.2 Interacting by Pointing

→ 3.2.1 Ray-casting
3.2.2 Two-handed pointing
3.2.3 Flashlight and aperture techniques
3.2.4 Image plane techniques
3.2.5 Fishing-reel techniques

3.2.1 Ray-Casting

- Hand position **h** and direction **p**
  - VEs: 6 DOF tracker
  - Desktop environment: 3D widget (WIMP)
- Object position **o**(α) = **h** + α**p**

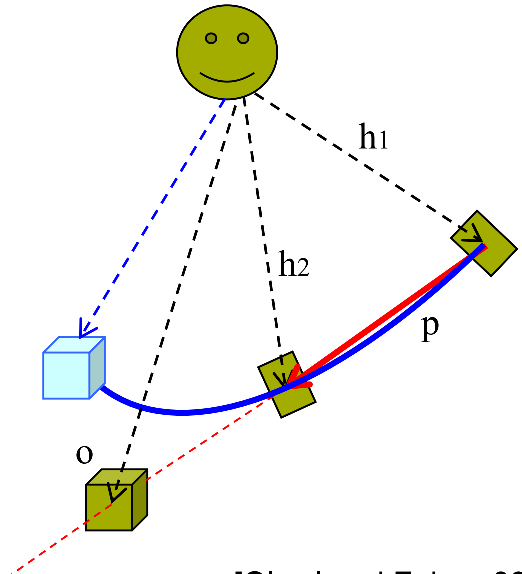
- Shape of ray
  - Short line segment (fixed length)
  - Infinite ray



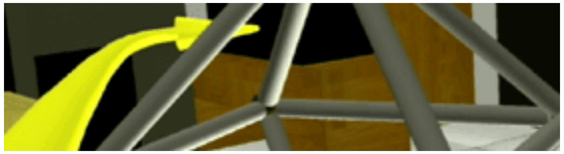
- Powerful technique, if object is not too small or too far away

3.2.2 Two-Handed Pointing

- Hand positions $\mathbf{h_1}$, $\mathbf{h_2}$
- Ray direction $\mathbf{p} = \mathbf{h_2} - \mathbf{h_1}$
- Object position $\mathbf{o}(\alpha) = \mathbf{h_1} + \alpha(\mathbf{h_2} - \mathbf{h_1})$



[Olwal and Feiner 03]

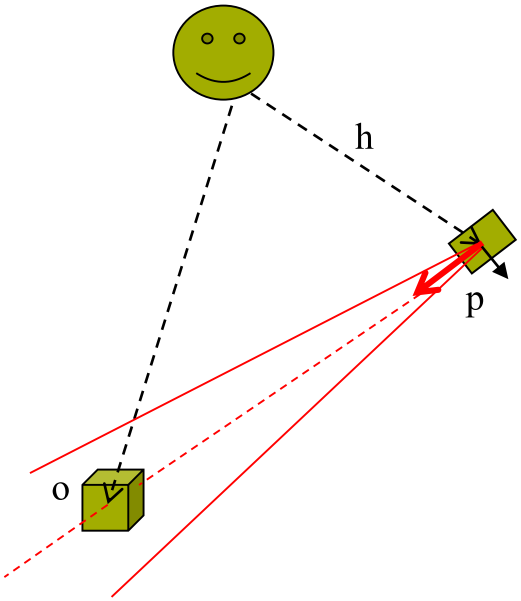


- Additional information:
  - Distance between hands = scale factor
  - Hand orientations: non-linear curve parameters
- Possible to disambiguate between several objects on ray

3.2.3 Flashlight and Aperture Techniques

Flashlight

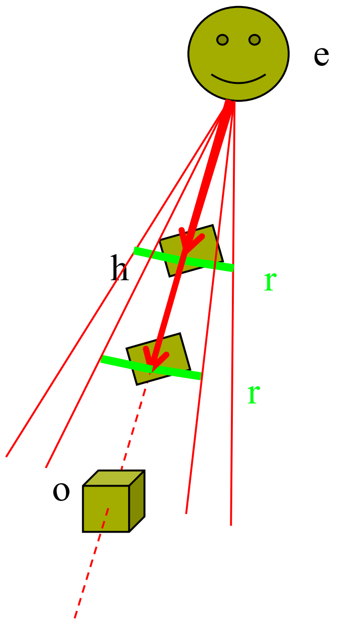
- „Soft“ selection technique
- Requires less precision of pointing
- Disambiguation between several objects inside the cone
  - Object closest to center line
  - Object closest to the device



3.2.3 Flashlight and Aperture Techniques

Aperture technique

- Interactive control of the opening angle of the cone
- Cone defined by
  - Apex position = eye position **e**
  - Cone orientation = hand-eye position **h-e**
  - Opening angle = acos (r / ||**h-e**||)
- Object position **o**(α) = **e** + α(**h** – **e**)



3.2.4 Image-Plane Techniques

- Select and manipulate 3D objects by touching and manipulating their 2D projections on a virtual plane located in front of the user
  - Sticky-finger (one finger or stylus)
  - Head-crusher (two fingers: data glove)

- Simulate direct touch
- Intuitive and easy to use for selection

3.2.5 Fishing-Reel Techniques

- Use additional input device to control the distance to virtual objects (length of virtual ray)
  - Select an object with ray casting
  - Reel it back and forth (via an additional input device)

- Separation of control between several devices
- Reduces user performance

Overview

3. Interaction Techniques for 3D Selection and Manipulation

3.1 Classifications of Selection and Manipulation Techniques

3.2 Interacting by Pointing

→ 3.3 Direct Manipulation: Virtual Hand Techniques

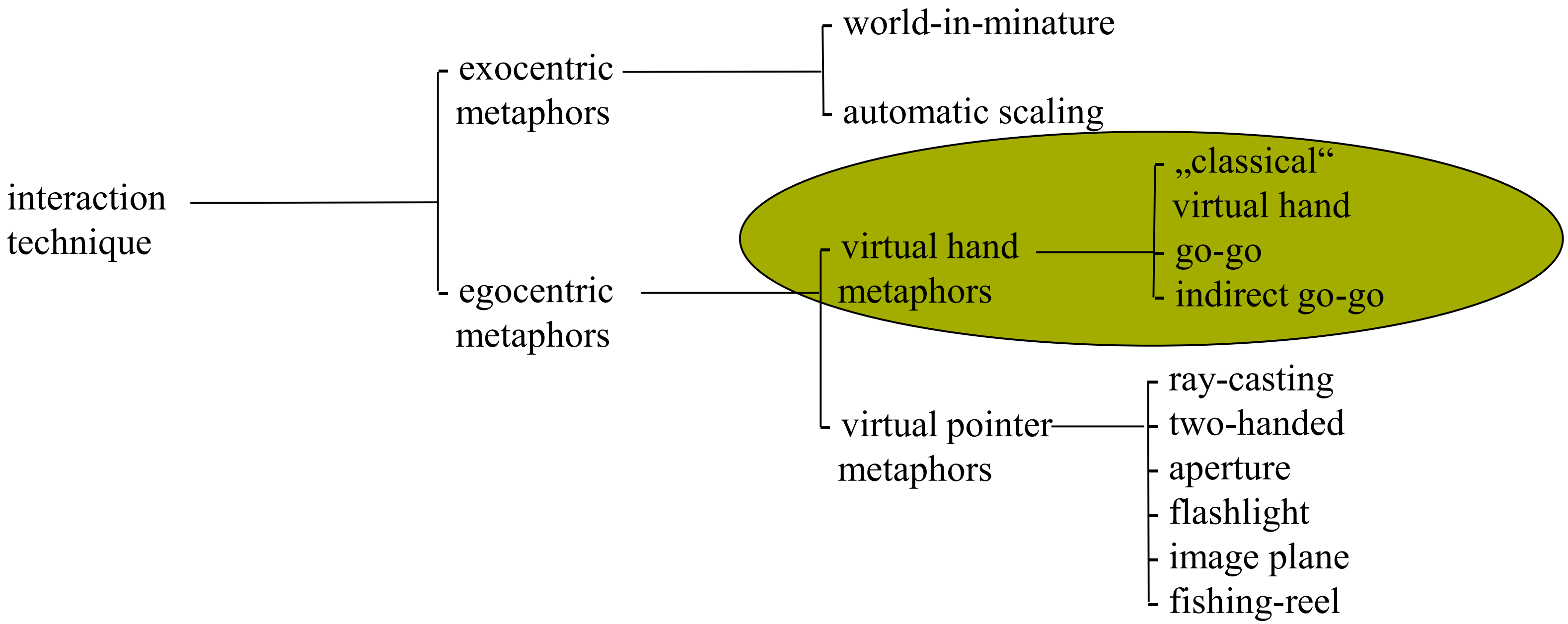
3.4 World-in-Miniature

3.5 Combining Techniques

3.6 Nonisomorphic 3D Rotation

3.7 Desktop 3D Manipulation

3.3 Virtual Hand Techniques (Isomorphic)



3.3 Virtual Hand Techniques (Isomorphic)

- Goal
  - Directly select and manipulate objects with hands
- Approaches
  - 3D cursor (e.g.: a hand icon) represents current position and orientation of user‘s hand in VE
  - Semitransparent volumetric cursors provide additional depth cue
  - Object selection =
    - Intersection of 3D cursor with virtual object
    - Triggering event (button, voice, hand gesture)
    - Object is then attached to virtual hand, can be manipulated
    - Object release via another triggering event
- Pro: Better **manipulation** performance than pointer-based techniques
    - Full 3D positioning
    - Full 3D rotations
- Con: Worse **selection** performance than pointer-based techniques
    - More physical hand movement
    - Limited reaching range

3.3 Virtual Hand Techniques

→ 3.3.1 Hand-based grasping

3.3.2 Finger-based grasping

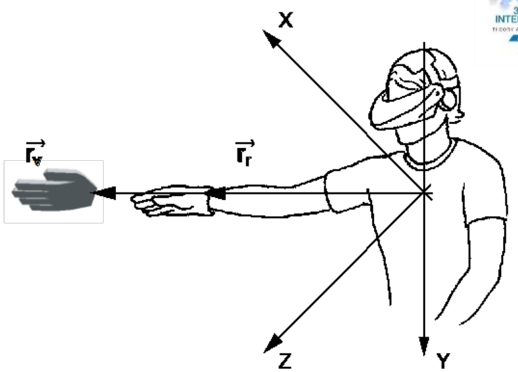
3.3.3 Enhancements for grasping metaphors

3.3.1 Hand-based Grasping

Simple virtual hand

- Direct mapping: user‘s hand motion (p_r,R_r) → virtual hand motion (p_v,R_v)
  $$p_v = \alpha p_r$$
  $$R_v = R_r$$
- *„Transfer functions“* (*„control-display gain functions“*)
- *Zero-order mappings*:
  displacement of input device = displacement of controlled element (linear mapping)
- *First-order mappings*:
  displacement of input device = change of velocity
- Pro: Intuitive due to directly simulated interaction with real objects
- Con: Only objects within the user‘s reach can be selected and manipulated

3.3.1 Hand-based Grasping

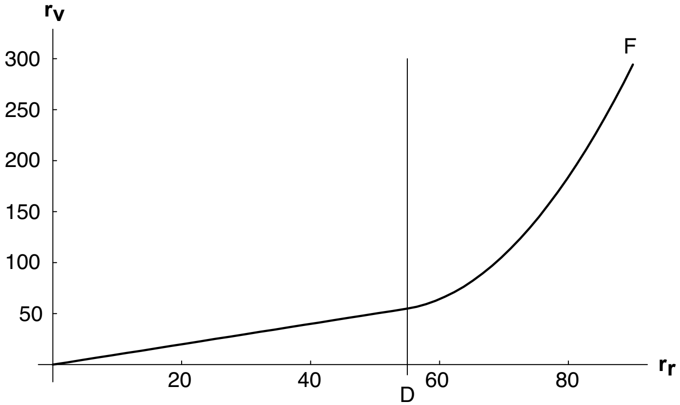


[Poupyrev et al. 96]

Go-go technique [Poupyrev et al. 1996]

- Interactively change the length of the virtual arm
- In user-centered egocentric coordinate system virtual distance r_v is non-linear function of real distance r_r

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



[Poupyrev et al. 96]

- Virtual hand shown at extended distance
- (For verification: small cube shown at measured distance)
- Direct, seamless 6-DOF object manipulation both at close range and at large distances
- Studies: users did not have difficulties understanding the technique

3.3 Virtual Hand Techniques

3.3.1 Hand-based grasping

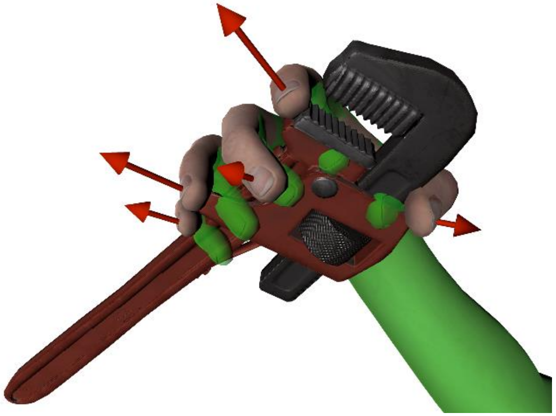
→ 3.3.2 Finger-based grasping

3.3.3 Enhancements for grasping metaphors

3.3.2 Finger-based Grasping

Different physical approaches to simulate the fingers and interactions

- Rigid-body fingers
  - Bend-sensing gloves
  - System of virtual torsional and linear spring-dampers
  - Dynamic influence on the mappings between the user‘s real hand („tracked hand“) and the virtual hand („spring hand“)
  - When the tracked hand collides with / penetrates the inner space of a virtual object, the spring dynamically prevents visual penetration
  - Produces forces and torques that enable direct interactions with the virtual object
  - Difficult to release an object due to clumsy spring-damping coefficients („sticky“)



[Borst and Indugula 05]

3.3.2 Finger-based Grasping

Different physical approaches to simulate the fingers and interactions

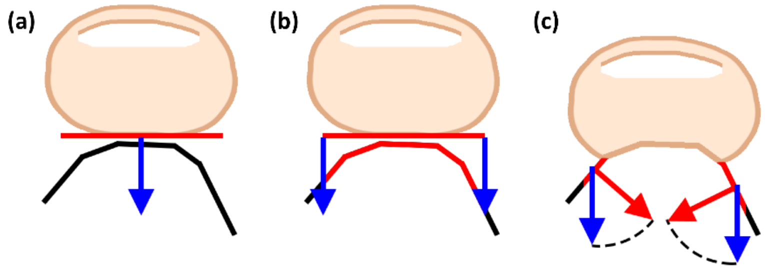
- Soft-body fingers
  - Deformable (soft-body) representations of
  - virtual fingers
  - Lattice shape-matching to dynamically adapt to the shapes of the grasped virtual objects (FastLSM algorithm)
  - Upon collision, virtual fingers deform slightly, resulting in a few points of collision
  - Upon penetration, deformation increases resulting in many points of collision

[Jacobs and Fröhlich 2011]

3.3.2 Finger-based Grasping

Different physical approaches to simulate the fingers and interactions

- God fingers
  - God object: Virtual point that adheres to rigid-body physics
  - Never penetrates virtual objects, but remains at their surfaces
  - Attach god objects to tracked fingers
  - Calculate direction of force upon penetration



[Talvas et al 13]

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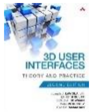


3.3.3 Enhancements for Grasping Metaphors

- 3D bubble cursor [Grossmann & Balakrishnan 2005]
  - Area cursor that dynamically changes its radius to always touch the closest object
- PRISM [Frees & Kessler 2007]
  - General enhancement for grasping metaphors, using scaled-down motion to the user‘s virtual hand: no motion, scaled motion, 1:1 motion, offset recovery
- Hook (for moving targets)
  - Make the user follow a target in an attempt to overtake it
  - Offer several targets, see which one the user chooses
- Intent-driven selection
  - Use the posture of the virtual fingers as an indication of the user‘s level of confidence in selecting an object.
  - Proximity sphere

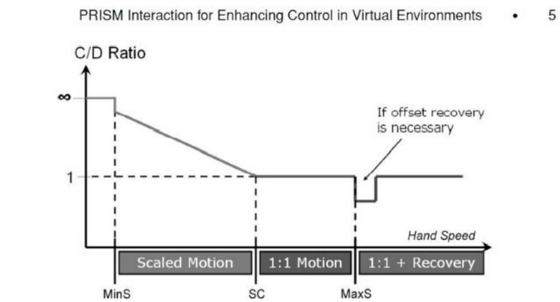
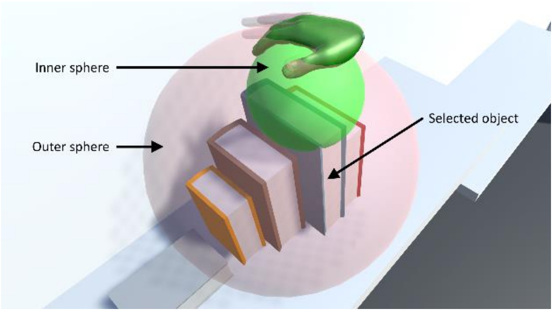


Fig. 1. Simplified interface diagram showing how PRISM uses Hand Speed to adjust CD.



[Periverzov and Ilies 15]

3. Interaction Techniques for 3D Selection and Manipulation

3.1 Classifications of Selection and Manipulation Techniques

3.2 Interacting by Pointing

3.3 Direct Manipulation: Virtual Hand Techniques

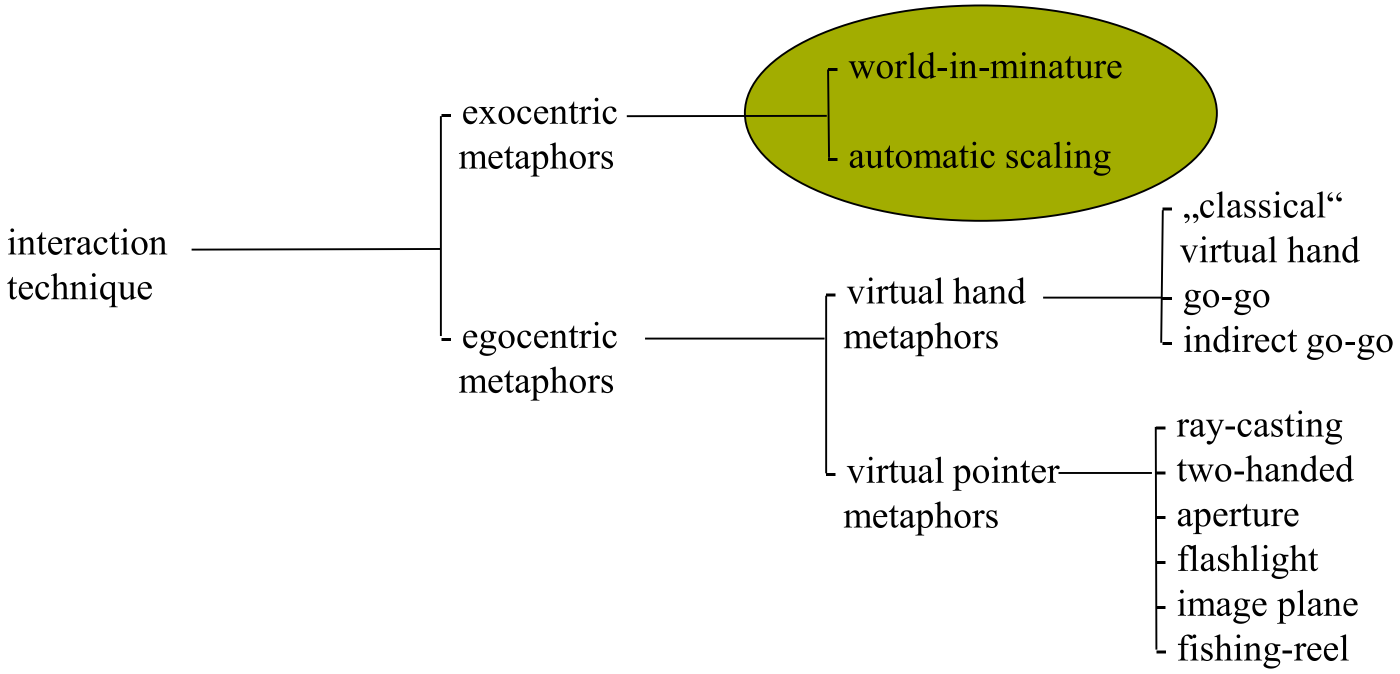
→ 3.4 World-in-Miniature

3.5 Combining Techniques

3.6 Nonisomorphic 3D Rotation

3.7 Desktop 3D Manipulation

3.4 World-in-Miniature (WIM)



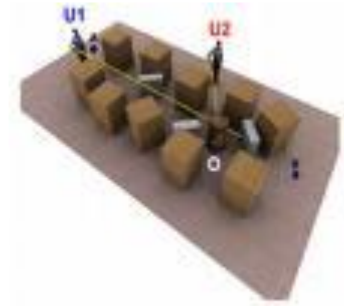
3.4 World-in-Miniature (WIM)

- Miniature (down-scaled) handheld model of the VE
- Seen from an exocentric (bird‘s eye) perspective

- Indirect manipulation of large-scale virtual objects by manipulating their down-scaled copies in WIM

- Pro
  - Easy object manipulation within and outside the user‘s reach
  - Combination of manipulation and navigation
- Con
  - Not easily scalable

- Well suited for augmented reality
- Generalization of overview maps in games



[Pinho et al 08] www.scielo.br

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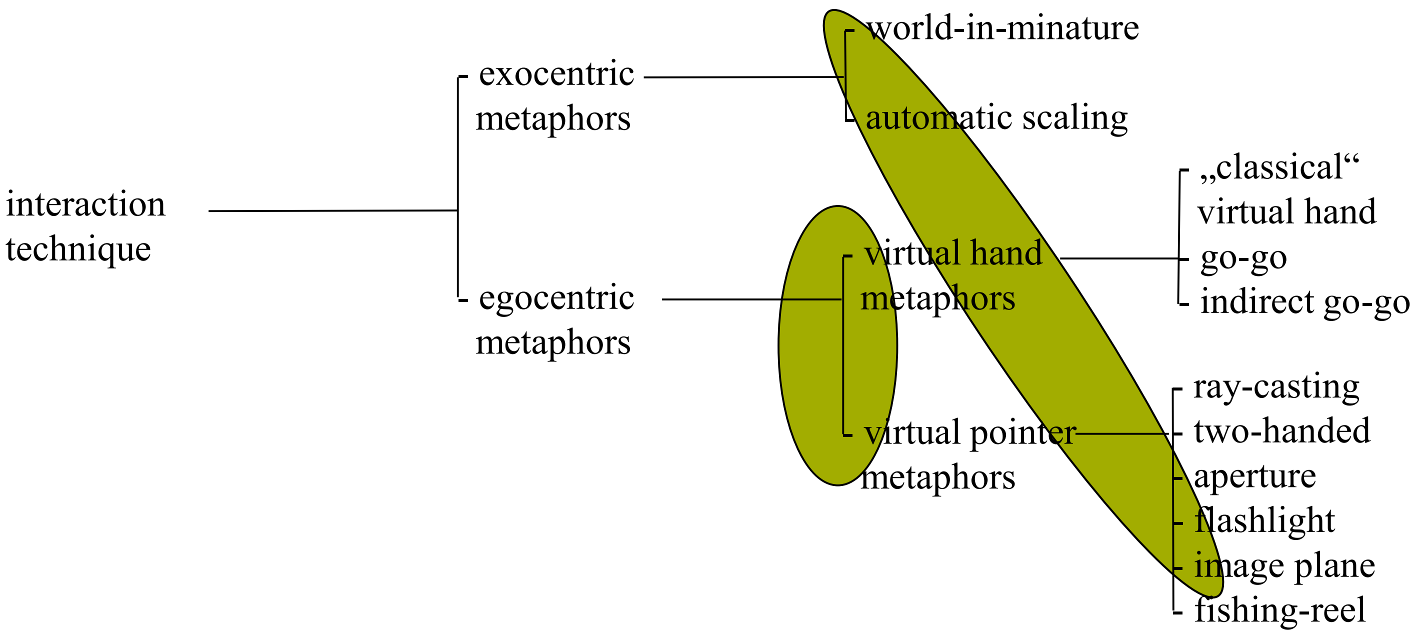


3.5 Combining Techniques

- Aggregation of techniques
  - Users have to select from a „bag of tricks“
- Integration of techniques
  - Interface switches transparently between interaction techniques depending on the *task context*
  - Task sequence
    - Selection
    - Manipulation

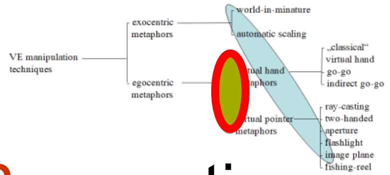
3.5 Combining Techniques

→ 3.5.1 HOMER

3.5.2 Scaled-world grab

3.5.3 Voodoo dolls

3.5.1 HOMER



Hand-centered Object Manipulation Extending Ray-casting

- Select an object (pointer-based ray-casting)
- Manipulate object with a virtual hand

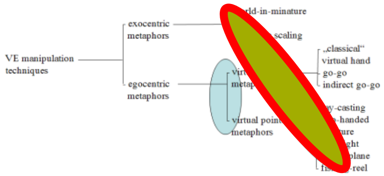
- Distance to virtual object at selection time determines scale factor α_h

$$r_v = \alpha_h \, r_r$$

$$\alpha_h = \frac{D_{virtual\ object}}{D_{real\ hand}}$$

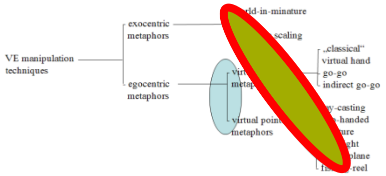
- Pro
  – Users can easily pull an object closer
- Con
  – It is difficult to push an object very much further away

3.5.2 Scaled-World Grab

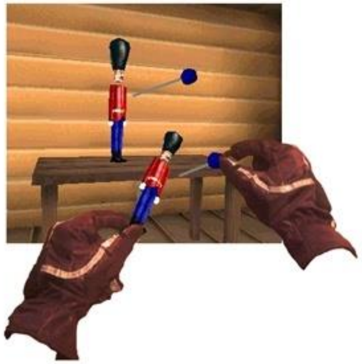


- Select an object (image-plane technique)
- Manipulate object
  - Down-scale entire VE around user‘s virtual viewpoint rather than scaling up user‘s hand motion
- Pro
  - Performs well for operations at a distance
- Con
  - May not be effective when user wants to „push away“ a close object

3.5.3 Voodoo Dolls



- Two-handed interaction
- Image-plane concept for selection (pinch gloves)
  Selected object → voodoo doll
- WIM-concept for manipulation
  Manipulate objects indirectly using temporary, miniature, handheld copies of objects („dolls“)
  - Doll in dominant hand: definition of position and orientation
  - Doll in non-dominant hand: stationary reference frame



[Pierce and Pausch 99]

3. Interaction Techniques for 3D Selection and Manipulation

3.1 Classifications of Selection and Manipulation Techniques

3.2 Interacting by Pointing

3.3 Direct Manipulation: Virtual Hand Techniques

3.4 World-in-Miniature

3.5 Combining Techniques

→ 3.6 Nonisomorphic 3D Rotation

3.7 Desktop 3D Manipulation

3.6 Nonisomorphic 3D Rotation

- Large ranges of virtual rotations controlled by small ranges of real rotations
  - Efficient use of limited rotational freedom in the real world (by scaling them down)
    - Suitable for users with disabilities
    - Minimizes need for *clutching*
  - Useful for highly accurate control of minimal rotations (by scaling them up)
    - Useful in tele-operation applications (robotic surgery)

3. Interaction Techniques for 3D Manipulation

3.1 Classifications of Selection and Manipulation Techniques
3.2 Interacting by Pointing
3.3 Direct Manipulation: Virtual Hand Techniques
3.4 World-in-Miniature
3.5 Combining Techniques
3.6 Nonisomorphic 3D Rotation
→ 3.7 Desktop 3D Manipulation

3.7 Desktop 3D Manipulation

- 6 DOF interaction devices are very expensive
- Many applications have to use cheap devices: WIMP-based tools
- Problems:
  - Mouse has only 2 DOF
- Solution:
  - Separation of DOFs
  - User switches between controlling different subsets of DOFs (potentially using both mouse buttons and arrow keys on keyboard)

3.7 Desktop 3D Manipulation

→ 3.7.1 2D interface controls
3.7.2 Surface metaphors
3.7.3 Indirect metaphors
3.7.4 3D widgets and handles
3.7.5 Virtual sphere
3.7.6 ARCBALL technique

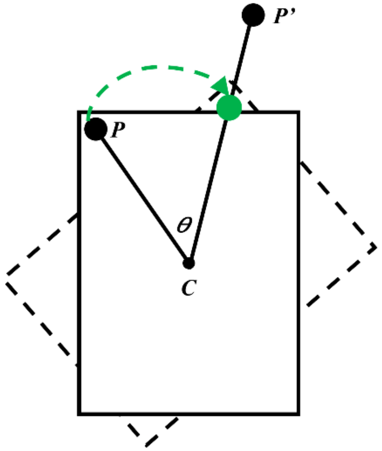
3.7.1 2D Interaction Controls

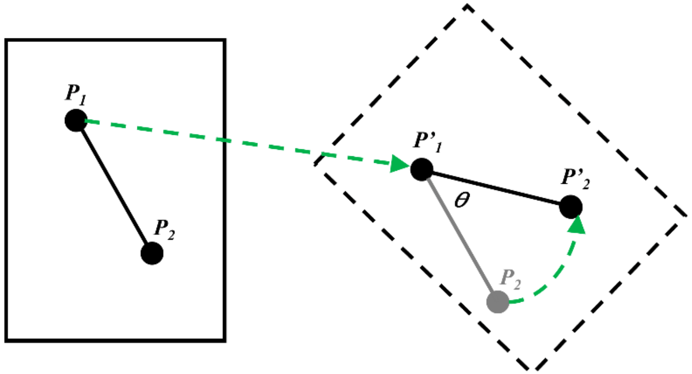
- Keyboard input:
  directly type in values for position and orientation
  - Precise definition of object pose
  - But: usually easier for users to specify object poses iteratively
- Separation of DOFs:
  - Use several, joint orthographic views of a scene
  - 2 DOFs per view, linked cursors
  - Alternative to direct mouse control: a separate slider for every dimension

3.7.2 Surface Metaphors

Surface-based 2D Interaction Techniques

- Direct touch (tablets, smartphones, surfaces)
  - Dragging: 1 finger → $P(x,y)$
  - Rotating: 2 fingers → $P_1(x,y)$, $P_2(\theta)$ around P_1
  - Rescaling (pinching) → scale ~ P_2-P_1

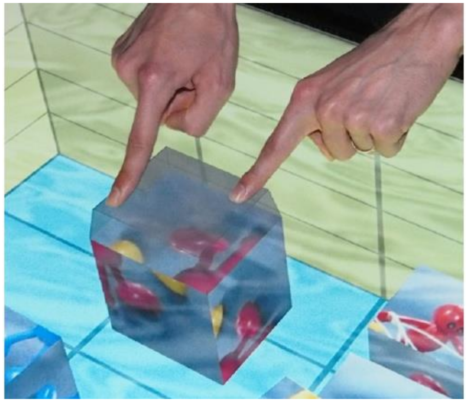


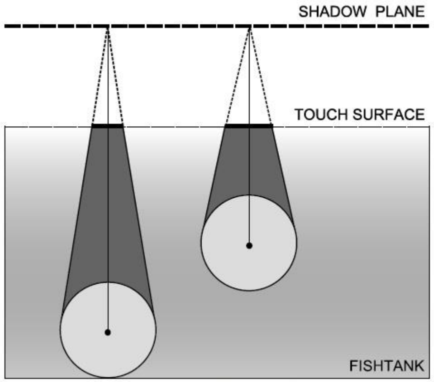


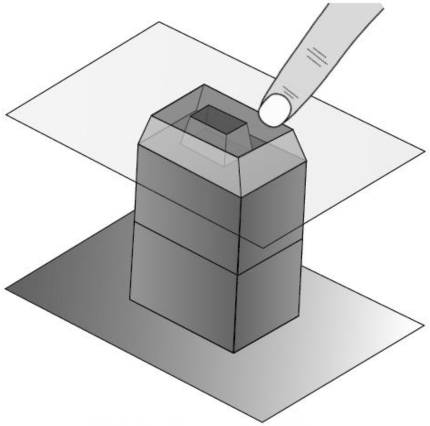
3.7.2 Surface Metaphors

Surface-based 3D Interaction Techniques

- Stereo displays
- Control depth relative to the surface
  - Pinching
    - Changing 2D scale
    - Changing 3D depth
  - Void shadows
    Deal with stacked (occluded) objects by presenting virtual shadows





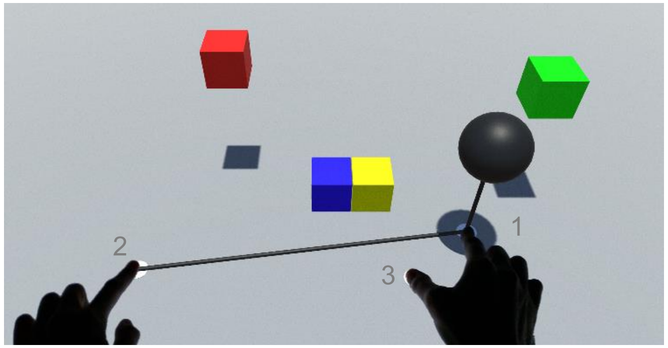


[Giesler et al 2014]

3.7.2 Surface Metaphors

Surface-based 3D Interaction Techniques

- Stereo displays
- Control depth relative to the surface
  - Balloon selection
    - Finger 1: anchor point P_1 = pos(x,y)
    - Finger 2: height $z = \left\|\overline{\overline{P_1 P_2}}\right\|$
      orientation of $\overline{\overline{P_1 P_2}}$
    - Finger 3: balloon size $s = \left\|\overline{\overline{P_1 P_3}}\right\|$
  - Significantly faster than keyboard-based 3 DOF positioning
  - Significantly lower error rate than simple virtual hand

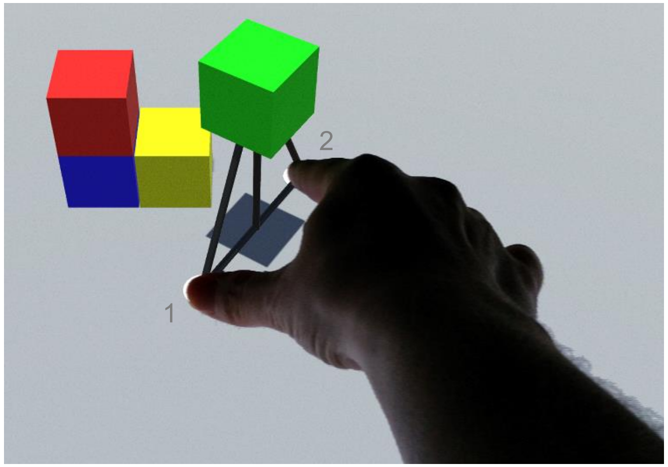


[Benko and Feiner 2007, image by McMahon]

3.7.2 Surface Metaphors

Surface-based 3D Interaction Techniques

- Stereo displays
- Control depth relative to the surface
  - Triangle cursor
    - Finger 1: P_1, Finger 2: P_2
    - anchor point = midpoint (P_1,P_2)
    - Height $z = \left\|\overline{P_1 P_2}\right\|$ (dist = 0 → z = 0)
    - Rotation = orientation of $\overline{P_1 P_2}$
  - Faster completion times than balloon selection
  - Fewer positional errors
  - Fewer orientational errors



[Strothoff et al 2011
image by McMahon]

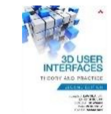
3.7.3 Indirect Metaphors

Manipulate virtual objects without directly interacting with them.

Benefits for

- Handling remote objects
- Avoiding occlusion
- Constraining manipulation by reducing DOFs

→ Indirect control-space
separate control from display



3.7.3 Indirect Metaphors

Indirect control-space

- Separate control from display
- Users can interact in a physical space distinct from the apparent location of the virtual environment (“unclutched”)

3.7.3 Indirect Metaphors

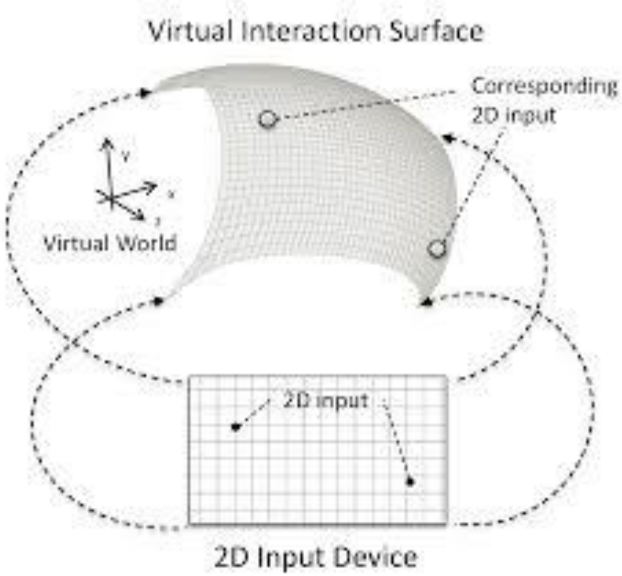
Indirect control-space

- Indirect touch
  - Use a multi-touch surface separate from the primary display
    - Select virtual object:
      - Finger 1: touch the multi-touch display to move a 3D cursor on the primary display
      - Finger 2: confirm selection of object under the cursor
    - Manipulate virtual object:
      - Conventional surface-based interaction

3.7.3 Indirect Metaphors

Indirect control-space

- Virtual interaction surface
  indirect touch for non-planar surfaces within the virtual environment
  - Mapping: 2D interaction (surface)
    → 3D interpretation (world)
    (aka texture mapping)

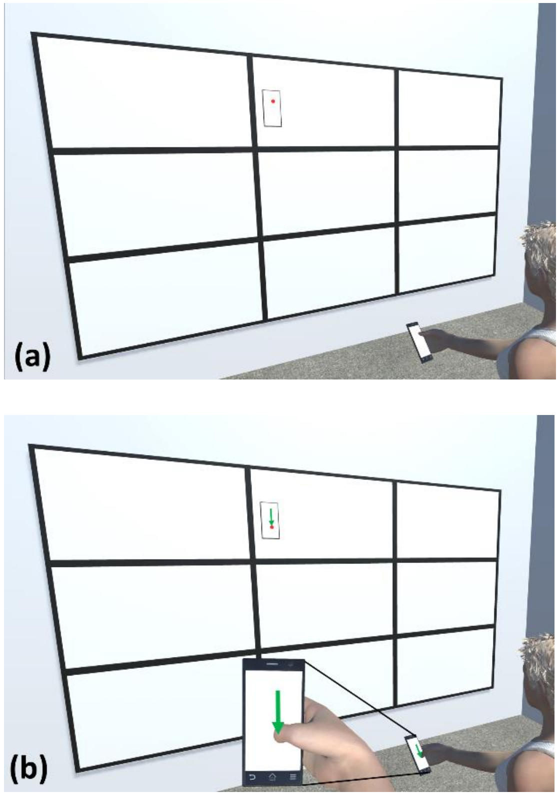


[Ohnishi et al 2012]

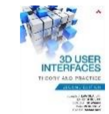
3.7.3 Indirect Metaphors

Indirect control-space

- Levels-of-precision cursor
  - Do not use a **fixed** multi-touch display; rather: use a **mobile** smartphone
  - Thus 3D interaction (motion) + 2D interaction (touch)
  - Staggered approach:
    - 3D motion for coarse selection
    - 2D touch-based motion for fine tuning



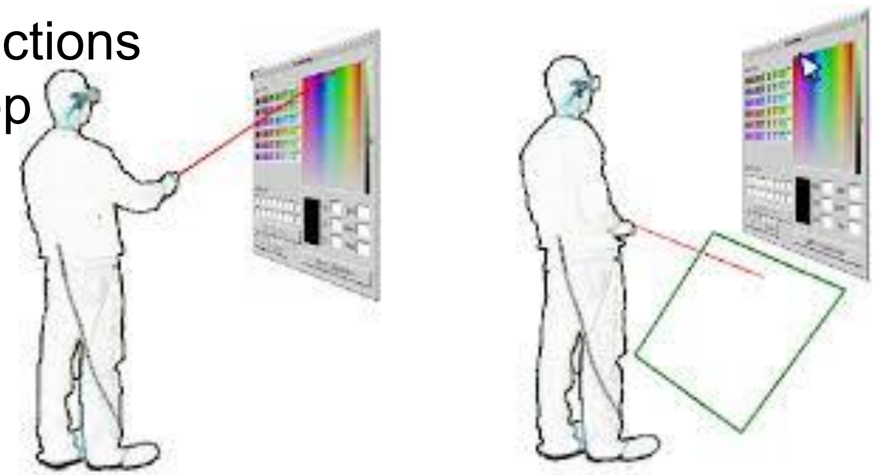
[Debarba 2012]



3.7.3 Indirect Metaphors

Indirect control-space

- Virtual pad
  - Interaction 2D adapted menus
  - Without a secondary multi-touch surface (use a nearby "virtual pad" instead)
    - User can customize interactions independently of 3D UI app



[Andujar and Argulaguet 2007]

3.7.4 3D Widgets and Handles

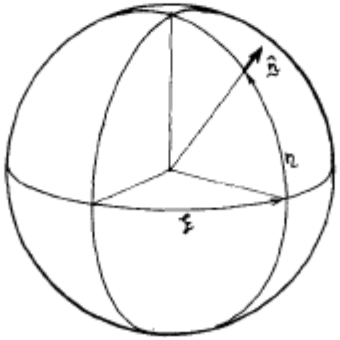
- Put controls directly into the 3D scene with the objects to be manipulated
- When an object is selected, a number of graphical manipulation widgets become visible
- Each widget is responsible for a small subset of DOFs

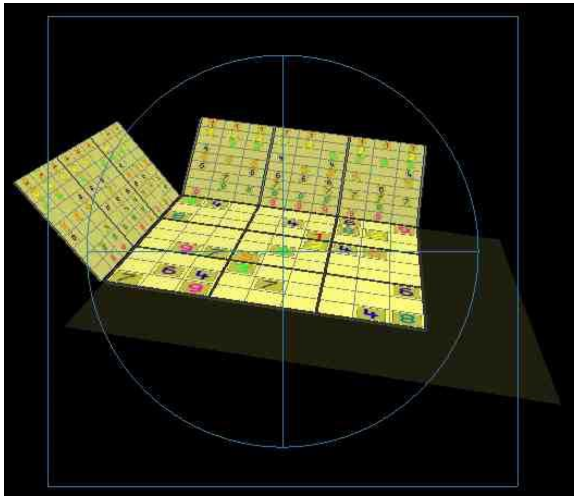
Widgets = visual manipulation constraints

- Pro
  - Easy and seamless transition between different manipulation sequences
- Con
  - Visual clutter

3.7.5 Virtual Sphere

- Several similarly integrated methods of using 2-DOF mouse movement
  - Virtual sphere
  - Rolling ball
  - Virtual trackball





- General approach
  - Enclose all rotations in a unit sphere, positioned around object center
  - Object rotations = rotations of unit sphere (grab it with your interaction devices at surface point P; pull P to a new location P´).
- Steps
  - Determine axis of rotation (perpendicular to mouse motion)
  - Calculate angle of rotation

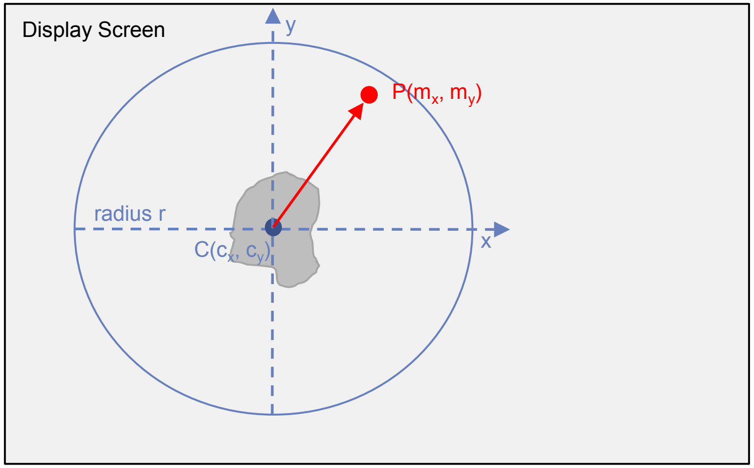
3.7.5 Virtual Sphere

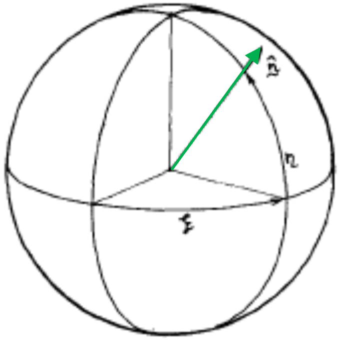
Gaussian Sphere surrounding an object

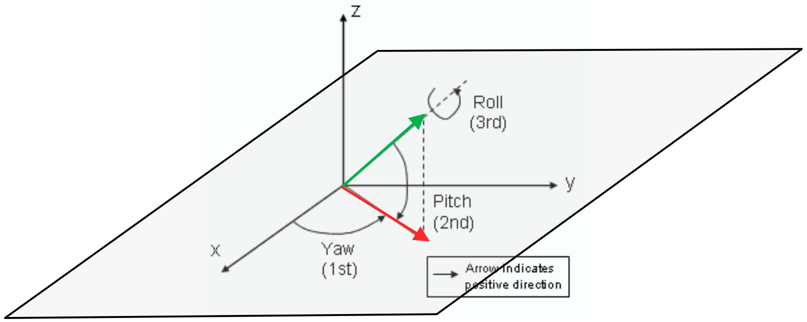
- centered at position $C(c_x,c_y)$
- with radius r
- mouse position $P(m_x,m_y)$

Interpret vector $C(c_x,c_y)P(m_x,m_y)$

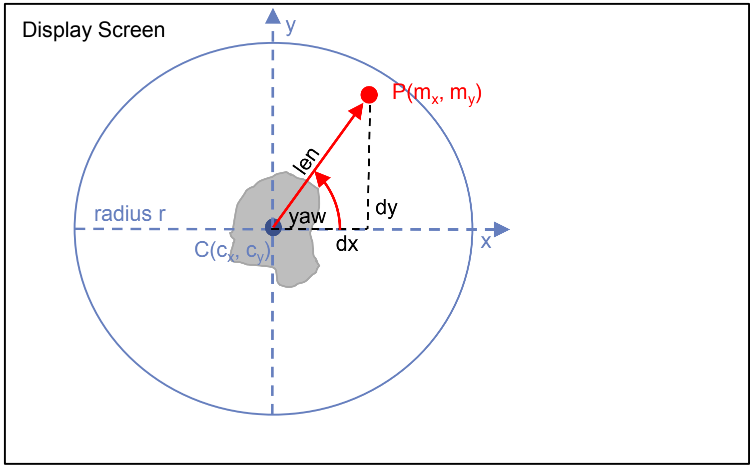
as a 3D vector „sticking out of the screen“







3.7.5 Virtual Sphere



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Interpret vector $C(c_x,c_y)P(m_x,m_y)$
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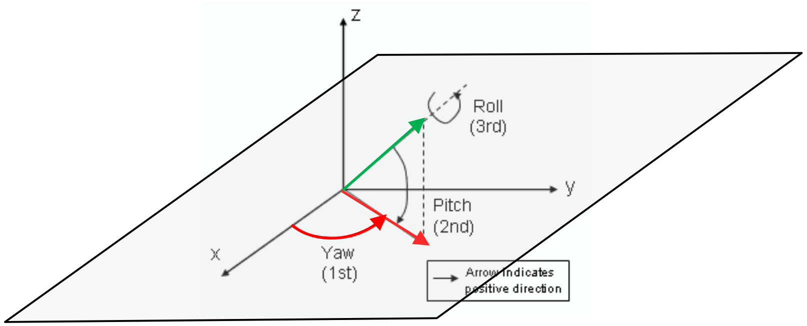
$$yaw = \tan^{-1}(dy/dx)$$



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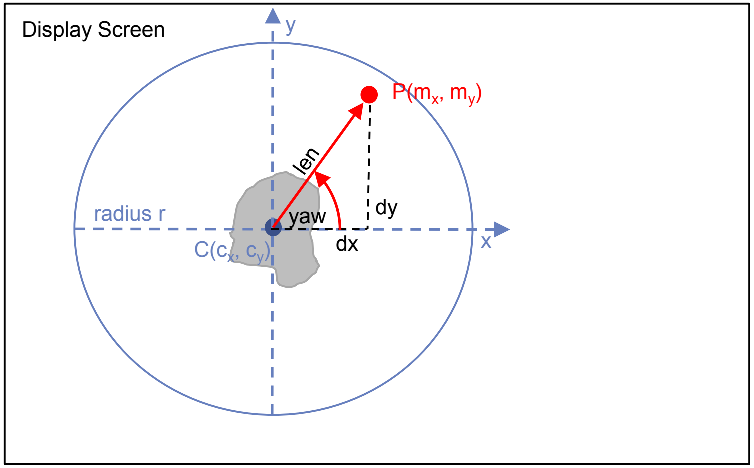
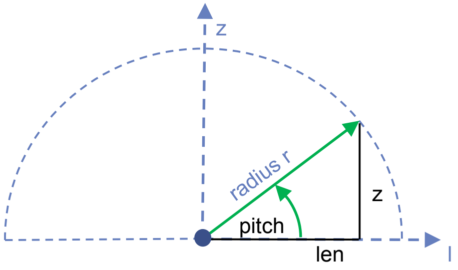
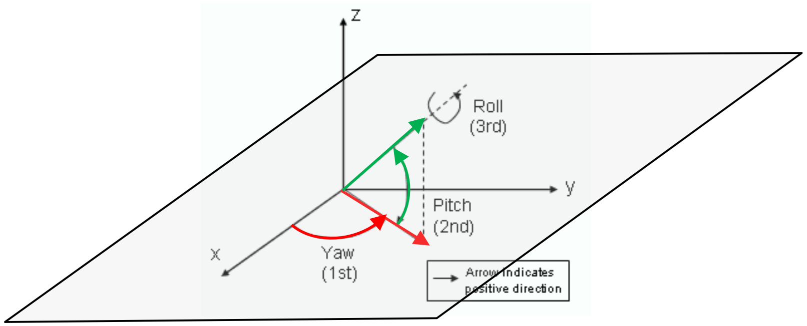


$$yaw = \tan^{-1}(dy/dx)$$
$$pitch = \cos^{-1}(len/r) \quad (in\ unit\ sphere)$$

$$z = \sin pitch$$
$$x = \cos yaw$$
$$y = \sin yaw$$





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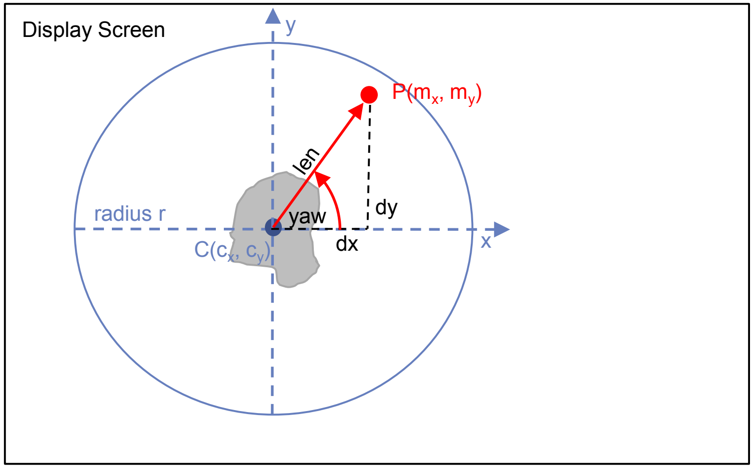
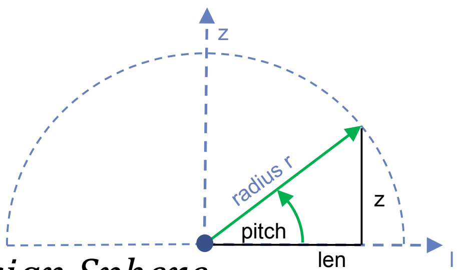


$$yaw = \tan^{-1}(dy/dx)$$
$$pitch = \cos^{-1}(len/r) \quad (in\ unit\ sphere)$$

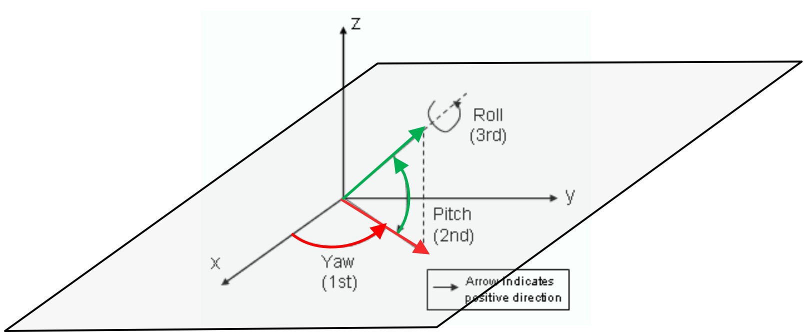
Rescale

$$z = \sin pitch \quad * r$$
$$x = \cos yaw \quad * r$$
$$y = \sin yaw \quad * r$$



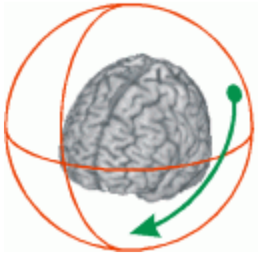
$len\ restricted\ to\ Gaussian\ Sphere$

$len \leq r$!!!



3.7.6 ARCBALL Technique

- Use spherical geometry to interpret 2D mouse movements as 3D rotations



http://www.sph.sc.edu/comd/rorden/3d.html

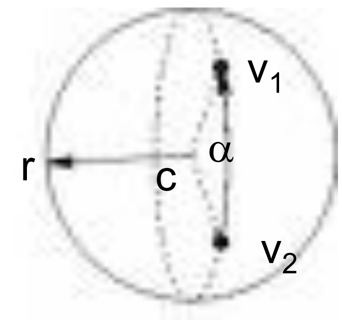
- Great circle (arc) on the sphere = rotation around the axis perpendicular to the circle
- Point on sphere = family of rotations (all great circles intersecting at this point)
- Rotation = 4D unit quaternion

http://rainwarrior.thenoos.net/dragon/arcball.html

3.7.6 ARCBALL Technique

ARCBALL technique

- 2 Vectors: v_1, v_2
- Rotation on a great circle
  (circle going through the sphere center c)

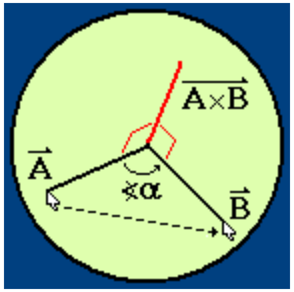


- Rotation axis: cross product

$$\text{rotation } axis\ r = v_1 \times v_2$$

- Rotation angle: scalar product

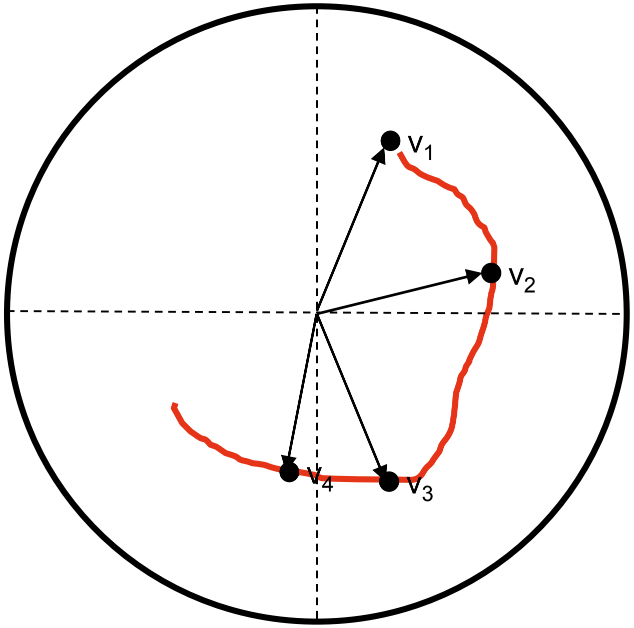
$$\text{rotation } angle\ \alpha = v_1 \cdot v_2$$



3.7.6 ARCBALL Technique

Interpretation of consecutive vector positions

- n Vectors: $v_1, v_2, v_3, \ldots v_n$



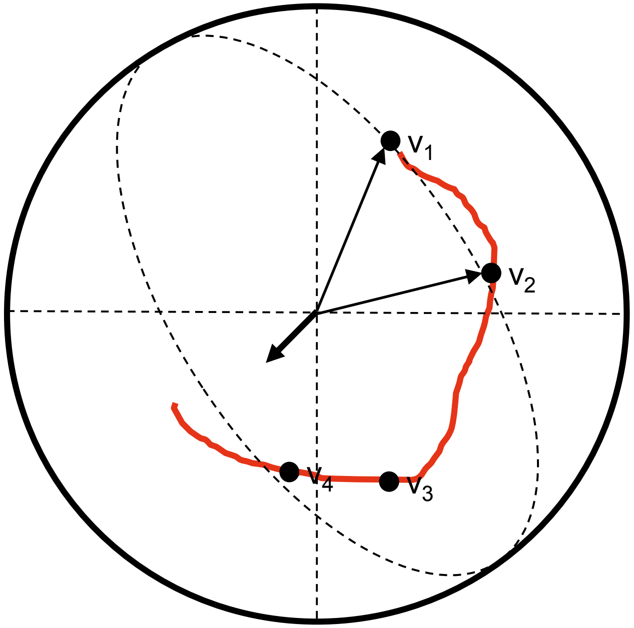
3.7.6 ARCBALL Technique

Interpretation of consecutive vector positions

- n Vectors: $v_1, v_2, v_3, \ldots v_n$

- Rotate v_i
  - With respect to v_1
    - Global (absolute)

$$r = v_i \times v_1$$
$$\alpha = v_i \cdot v_1$$



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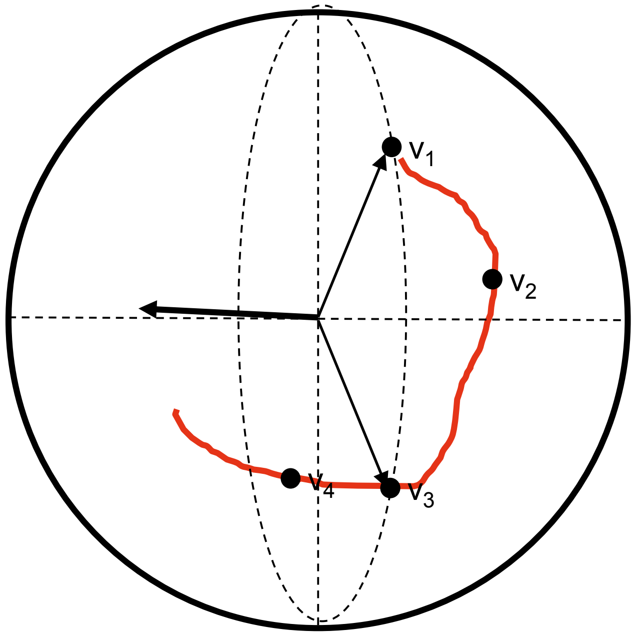

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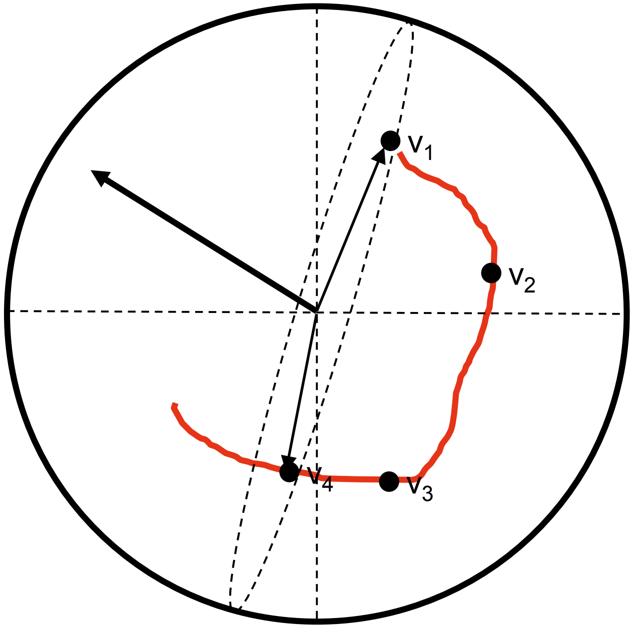

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  - With respect to v_{i-1}
    - Local (incrementally)

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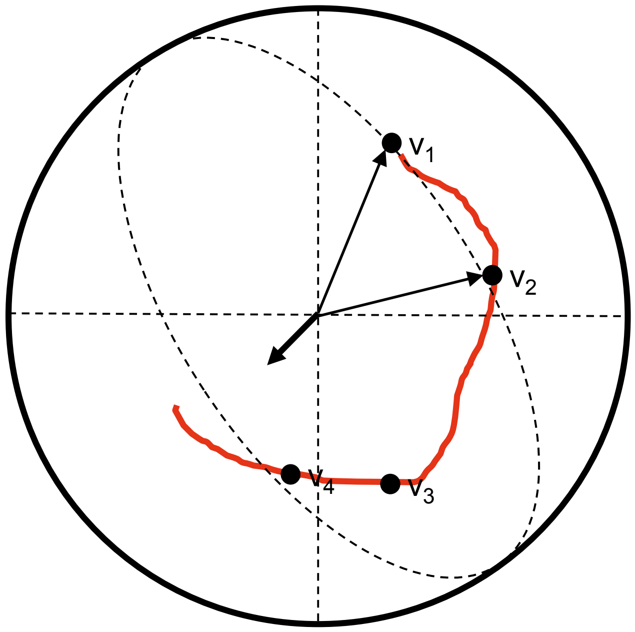

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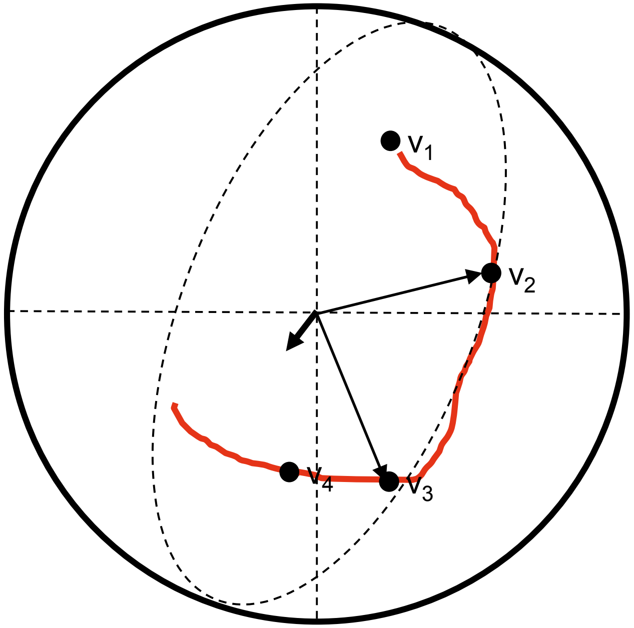

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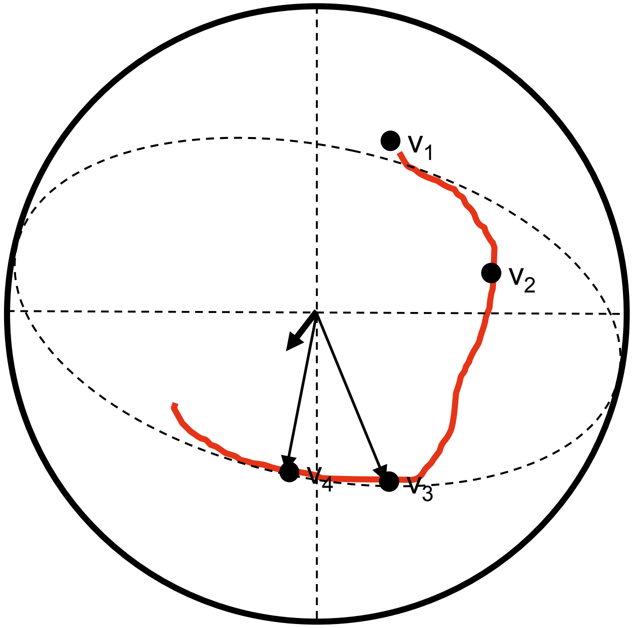
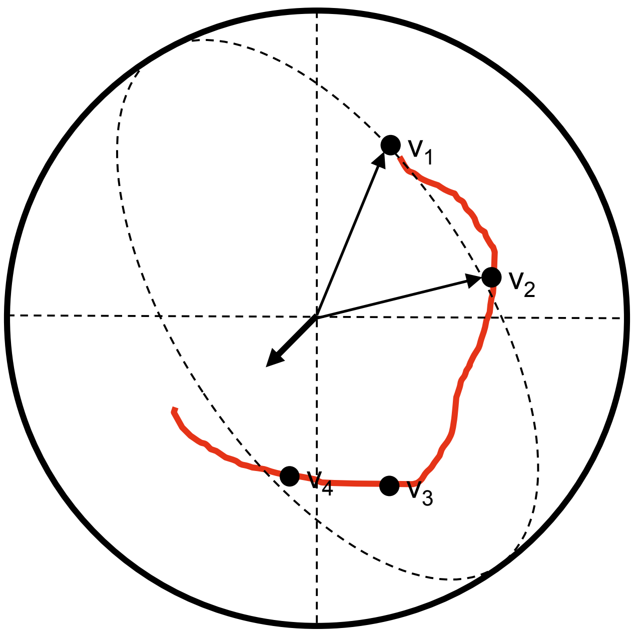
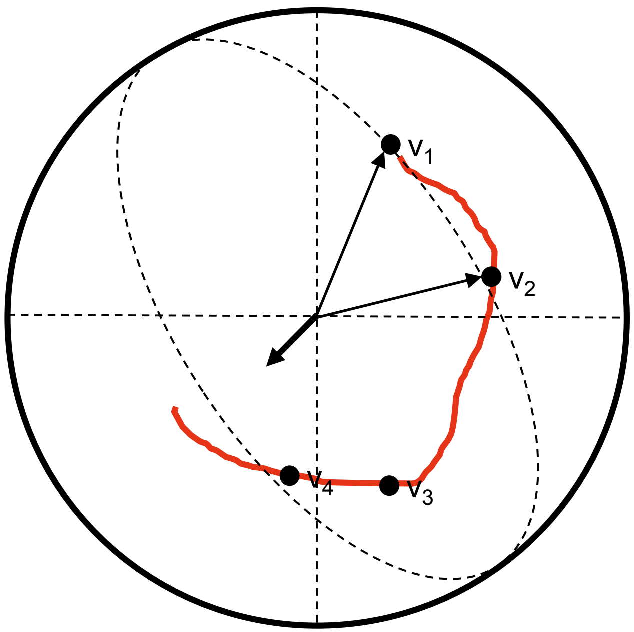


3.7.6 ARCBALL Technique

- Rotate v_i
  - with respect to v_1



- Rotate v_i
  - With respect to v_{i-1}



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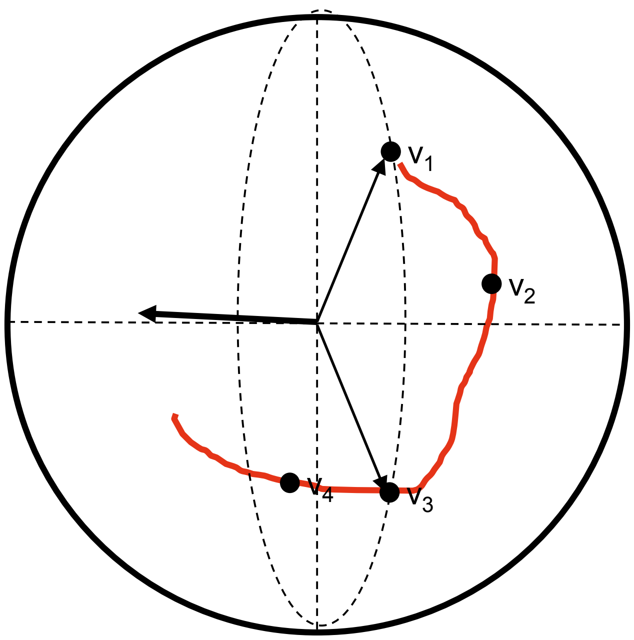
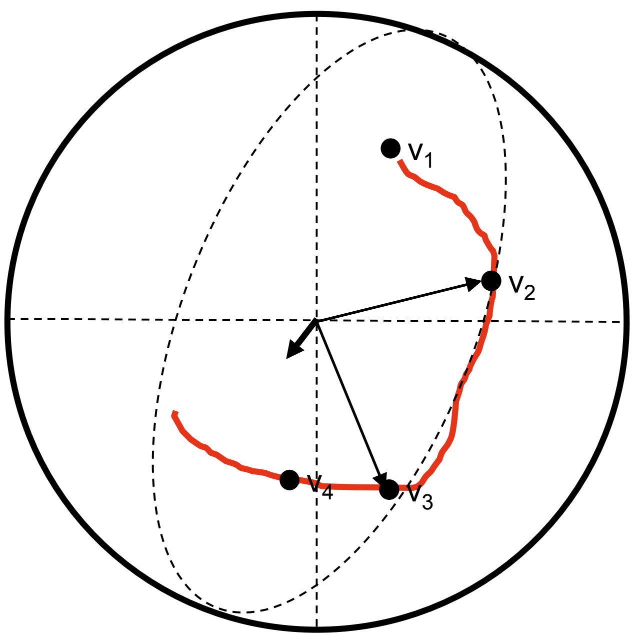


- Rotate v_i
  - With respect to v_{i-1}



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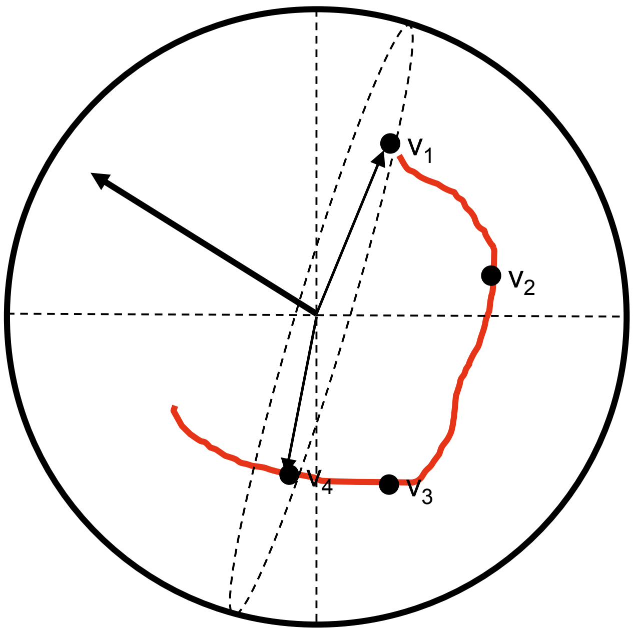
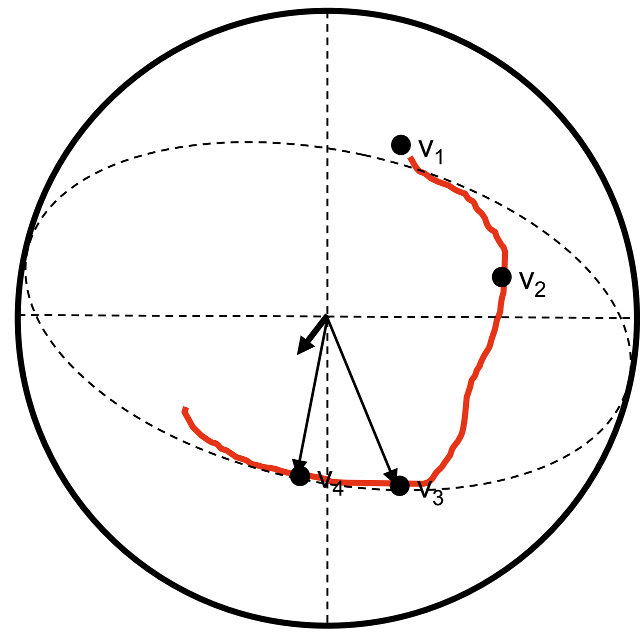


- Rotate v_i
  - With respect to v_{i-1}



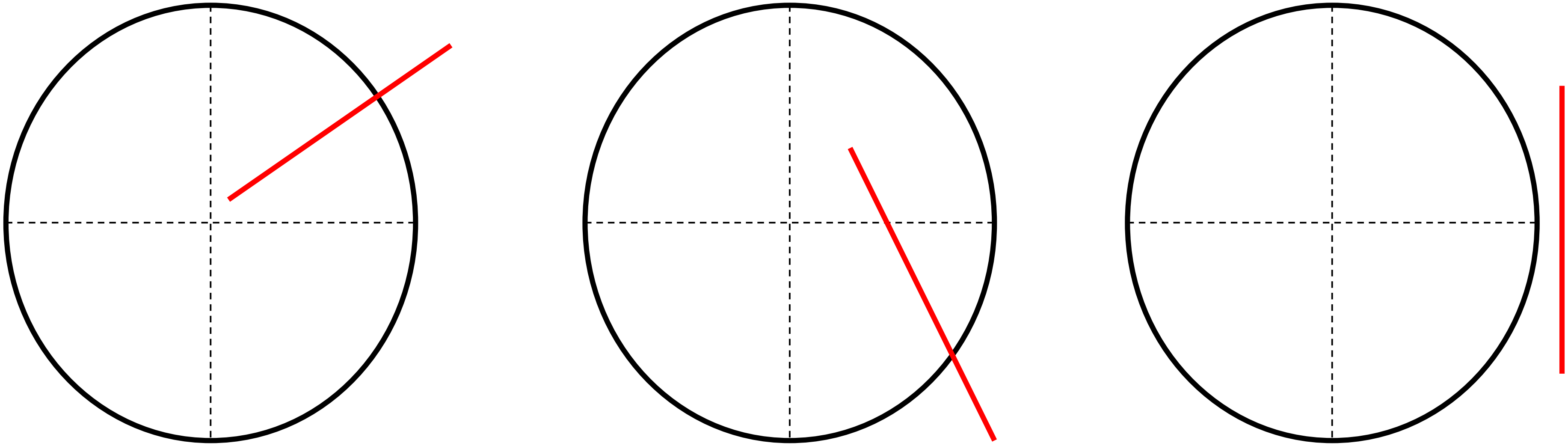
3.7.6 ARCBALL Technique

Interpretation of consecutive vector positions

- n Vectors: $v_1, v_2, v_3, \ldots v_n$

Further parameter choices:

- Fixed motion $r = v_1 \times v_2, \quad \alpha = \cdot\, v_1 v_2$
- Position (x,y), size of Gaussian Sphere r



Agenda

1. 3D Selection and Manipulation Tasks
2. Interaction Techniques and Input Devices
3. Interaction Techniques for 3D Manipulation
4. Design Guidelines

4. 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
- Non-isomorphic techniques are useful and intuitive
- Use pointing techniques for selection and virtual hand techniques for manipulation

4. Design Guidelines

- Use grasp-sensitive object selection
- Reduce degrees of freedom where possible
- Consider the tradeoff between technique design and environment design
- There is no single best manipulation technique

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Thank you!