Virtual Reality and Multi-Sensory Interaction

Master Research in Computer Science (SIF)

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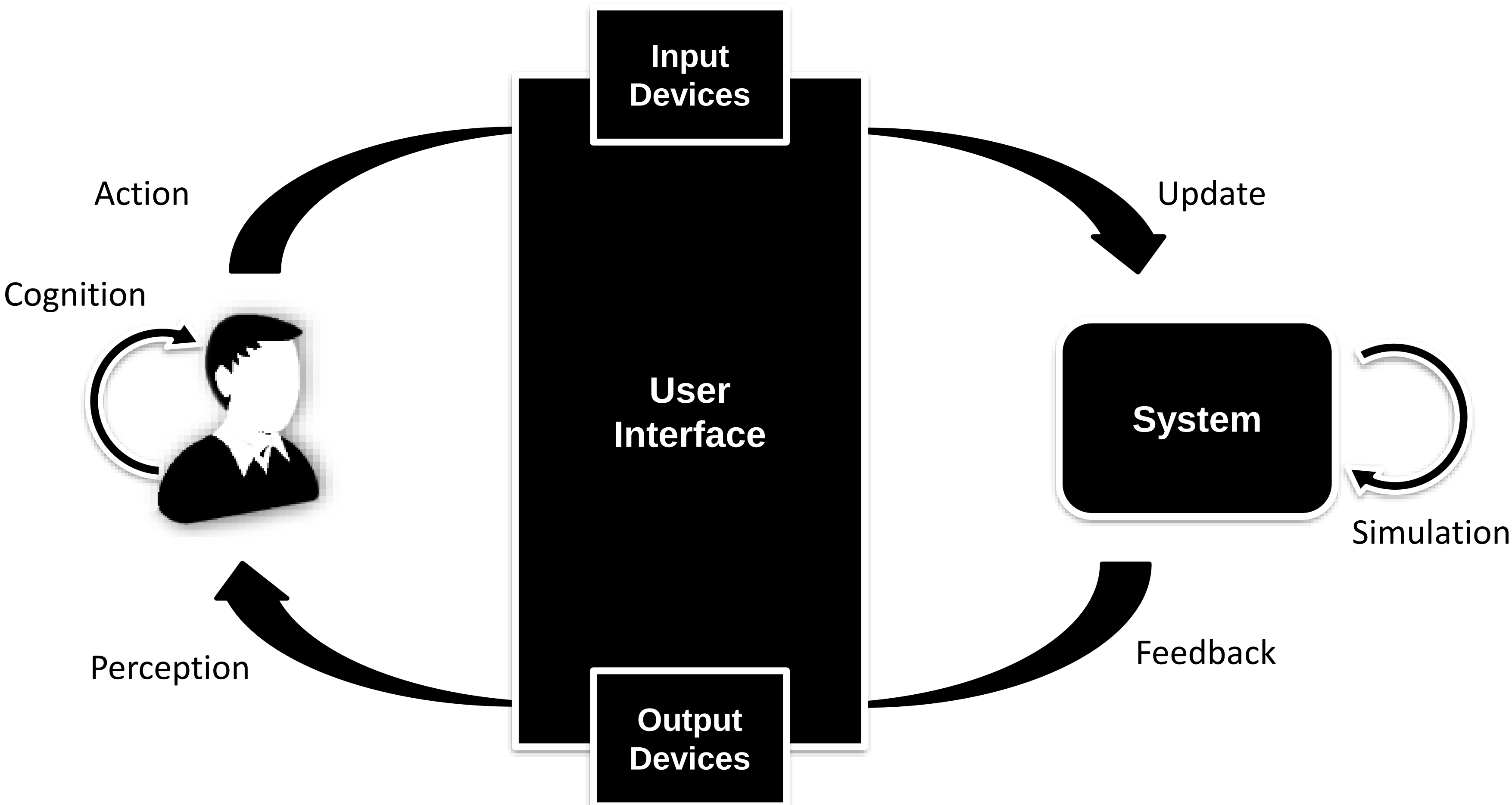
Contents

The Interaction Loop



3D User Interfaces

3D User Interfaces

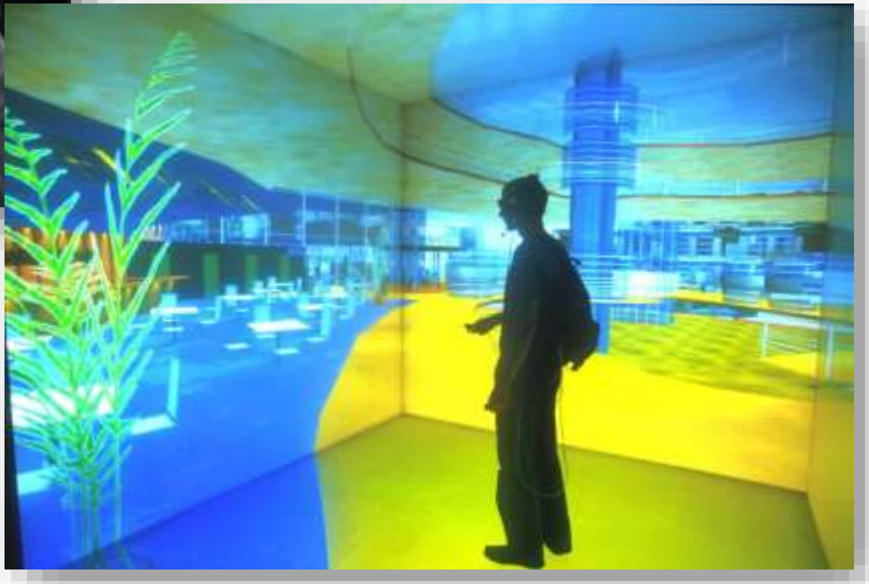
- User interfaces that involves **3D interaction**
  - Interaction is carried out in a 3D spatial context (e.g. Virtual Environment)

Virtual Pointing

Virtual Grasping

Why 3D User Interfaces?

- Traditional user interfaces are inappropriate



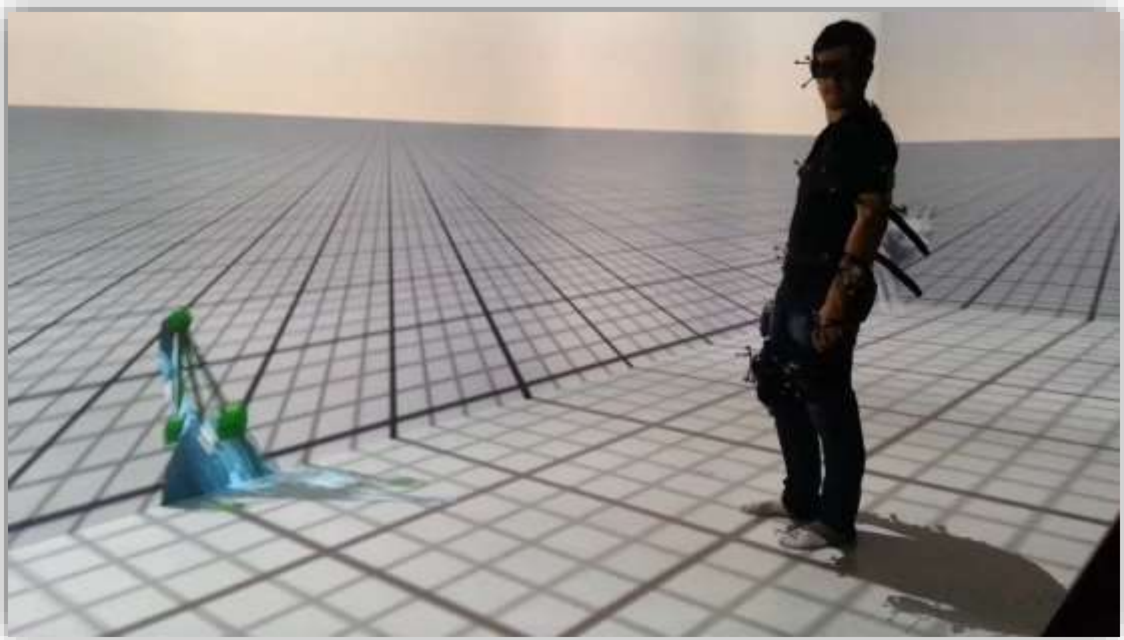
Why 3D User Interfaces?

- Relevant for real-world tasks
  - Increased interaction space
  - More natural interaction (e.g. gestures)
  - Increased richness and expressiveness
  - Simultaneous control of additional degrees of freedom

- Application areas
  - Design and prototyping
  - Scientific visualization
  - Psychiatric treatment
  - Training and collaborative work
  - Cultural heritage and tourism

Challenges of 3DUI

- Interacting in free opens a new world of possibilities for exploiting the richness and expressiveness of user interaction
  - Control simultaneously more DoFs
  - Exploiting well-known real world actions
- 3D interaction is more physically-demanding (increased dextrerity)



Challenges of 3DUI (cont..)

- Which action for which task?
  - Mouse movement involves small and fast muscles.
  - Grasping involving larger and slow muscles.

- Overcoming perceptual limitations in VR technology
  - Fail to provide the same level of cues for understanding the environment.
  - Unable to reproduce faithfully the physical constraints of the real world.

- S. K. Card, J. D. Mackinlay, and G. G. Robertson. A Morphological Analysis of the Design Space of Input Devices. ACM Transactions on Information Systems, 9(2):99–122, 1991.
- S. Zhai, P. Milgram, and W. Buxton. The Influence of Muscle Groups on Performance of Multiple Degree-of-Freedom Input. ACM SIGCHI conference on Human factors in computing systems: common ground, CHI ’96, pages 308–315. 1996.
- A. Kulik. Building on Realism and Magic for Designing 3D Interaction Techniques. IEEE Computer Graphics and Appl., 29(6):22–33, 2009.
- Bruder, G., Argelaguet Sanz, F., Olivier, A.-H., Lécuyer, A. Distance estimation in large immersive projection setups, revisited. IEEE Virtual Reality (VR) (pp. 27–32). 2015.

and …

- Required development skills
  - Computer graphics
  - Computational Geometry
  - 3D modeling and authoring
- There is no standard hardware platform
  - Wide range of input devices
  - Heterogeneous output devices
  - Robustness issues
  - Quality vs Performance (€)
- Iterative design and evaluation
  - Non-automatable
  - Requires the final setup
  - Ergonomics

Input Devices

Towards the Holodeck

Input Devices

- Enable the user to efficiently perform interaction tasks
- "2D" Tasks
  - **Selection**: The user makes a selection from a set of alternatives
  - **Position**: The user indicates a position on the interactive display.
  - **Quantify**: The user specifies a value to quantify a measure.
  - **Text**: The user inputs a text string.

Input Devices

- Enable the user to efficiently perform interaction tasks
- "3D" Tasks
  - **Selection**: The user makes a selection from a set of alternatives
  - **Navigation**: The user changes the viewpoint
  - **Manipulation**: The user applies a rigid transformation
  - **Application Control**: The user issues a command

⇩

The need to control additional DoF

3D Input Devices

Full-body tracking

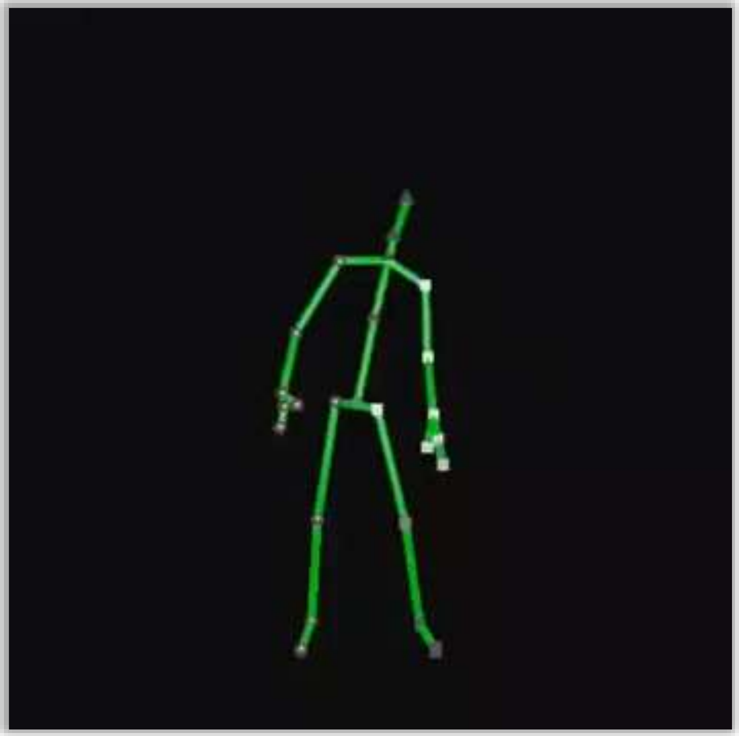
Hand-held Devices

Globes

3D Mouse

Spatial Input Devices (SID)

- Capture the user's movements
  - Position (3DoFs) and orientation (3DoFs)
- Requirements for most 3DUI applications
  - Head tracking
  - Hand tracking
- Provide new means of interaction
  - Increased number of DoFs
  - Multiple interaction points
  - Larger interaction space

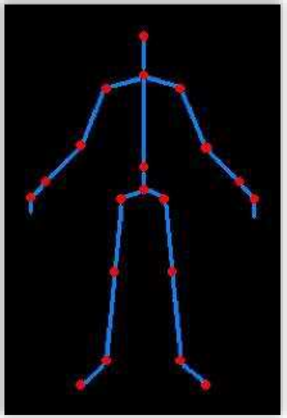


Existing SID Technologies

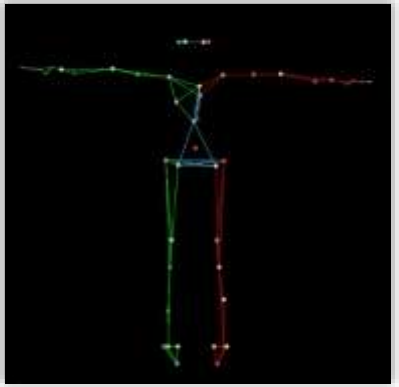
- Absolute tracking
  - Camera (Markers/Structured Light)
  - Magnetic
  - Acoustic (position only)
  - Mechanical (robotic arms/wires)
- Relative tracking
  - Accelerometers (position)
  - Gyroscopes (orientation)

SIDs - Camera-based

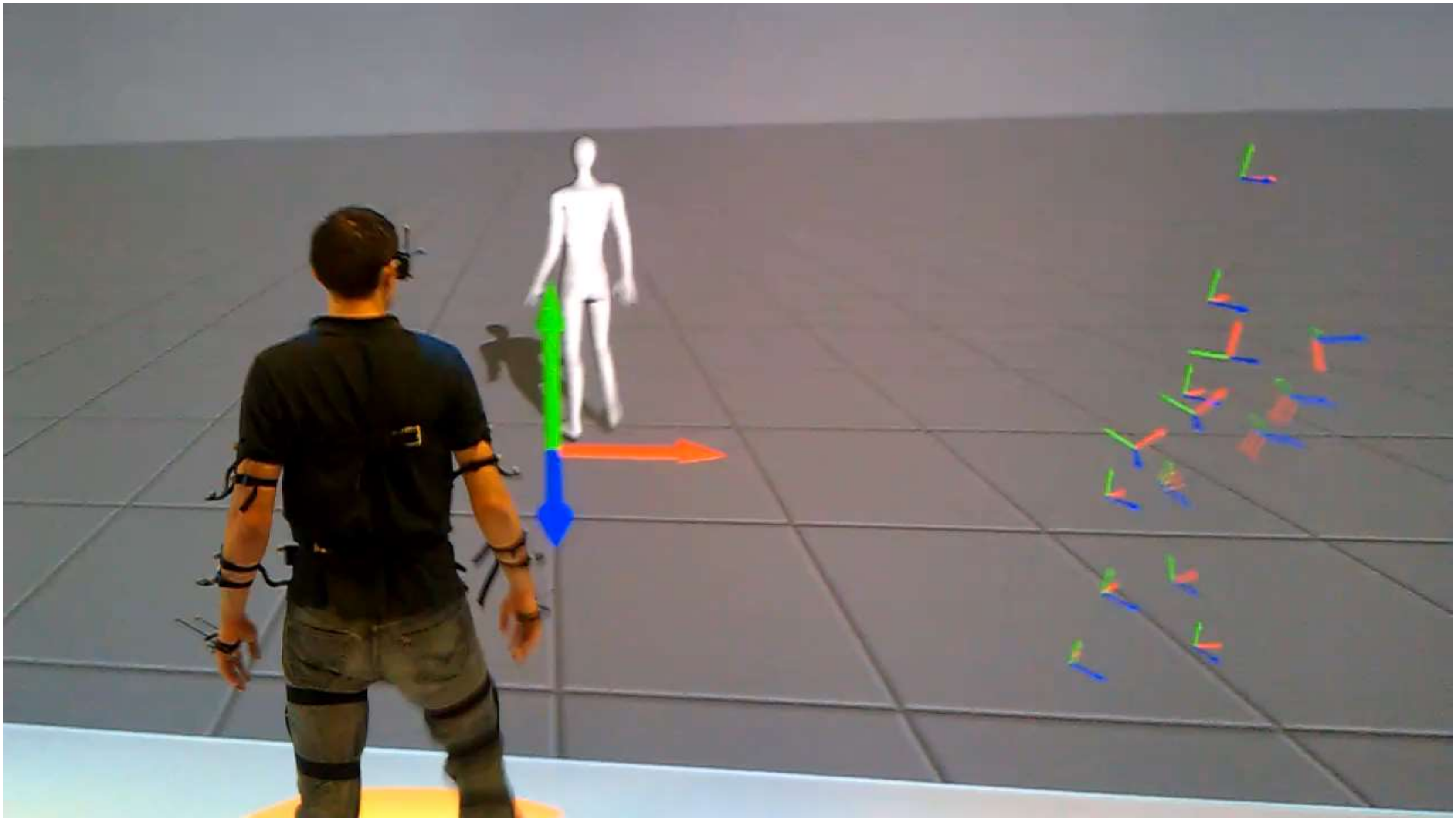
- Depth Cameras



- Marker-based



SIDs - Camera-based



SIDs - Camera-based (II)

- Fiducial Markers

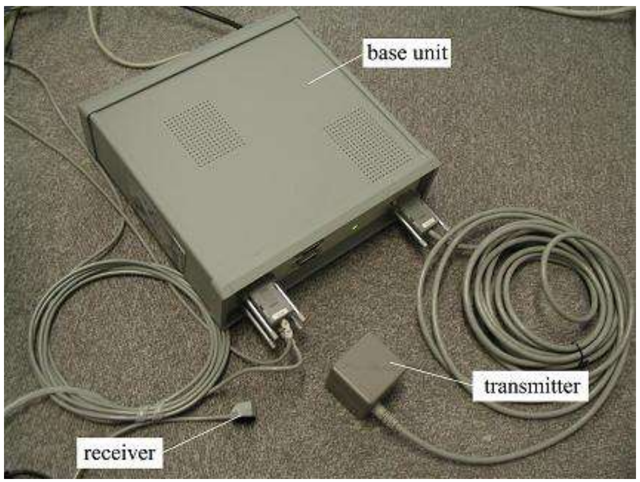


- Natural Feature Tracking



SIDs - Magnetic Tracking

- Polhemus
  - Fasttrak, InsideTrak, LongRanger

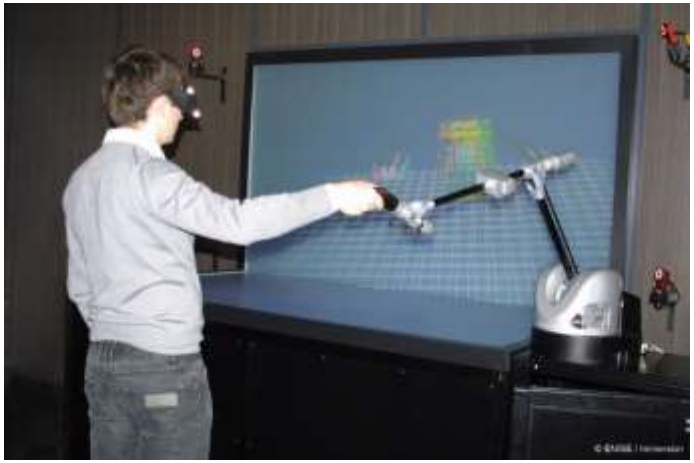


SIDs - Accelerometers and Gyroscopes

- Measure accelerations (position and rotation)

SIDs - Others

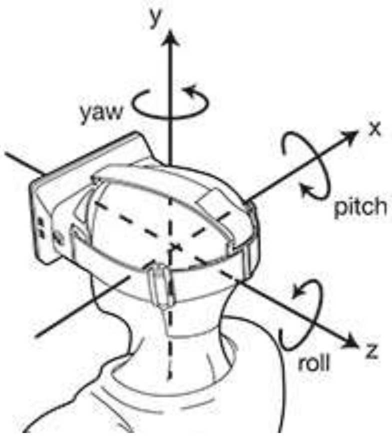
- Acoustic tracking
  - E.g InterSense



- Mechanical tracking
  - E.g. Haption

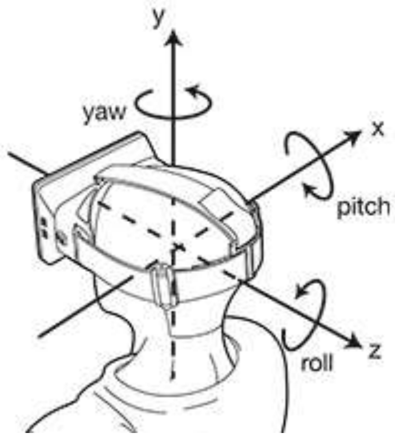
Characteristics of Input Devices

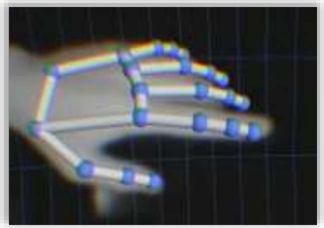
- Degrees of freedom & DoF composition
  - Number of DoFs – Integral / Separable
- Reported values
  - Digital / Analog – Direct / Rate Control
- User action required
  - Active / Passive

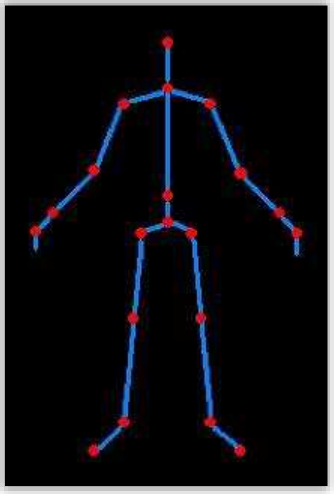


Characteristics of Input Devices

- Latency and jitter (and refresh rate)
  - ms / s – (30 Hz / 200Hz)
  - Detrimental on interaction performance
- Precision and noise
  - mm / cm

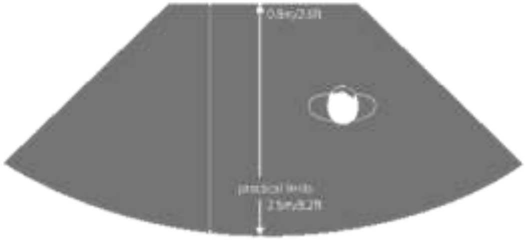


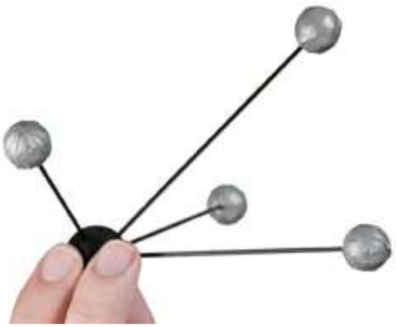




Characteristics of Input Devices

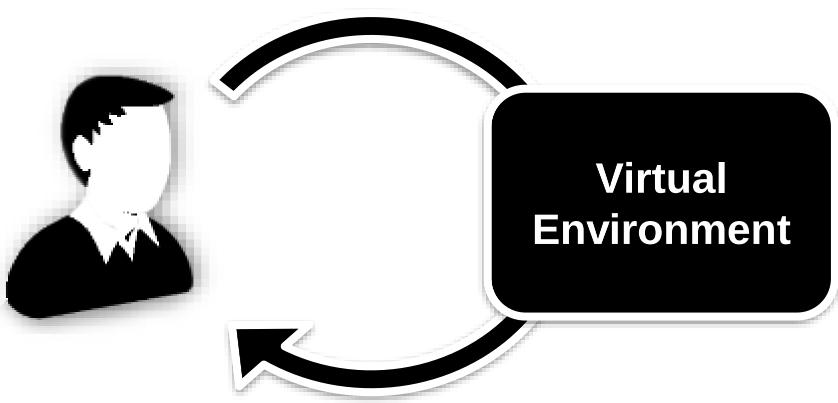
- Reference frame
  - Absolute vs Relative
- Workspace size
  - 30cm / 20m
- Potential limitations
  - Sensible to occlusions
  - Wires





Characteristics of Input Devices

- End-to-end latency
  - Software and hardware components introduce latency
  - Humans have a small tolerance to latency
  - … and ever smaller to jitter



3D Input Devices

Full-body tracking

Hand-held Devices

Globes

3D Mouse

Task Decomposition

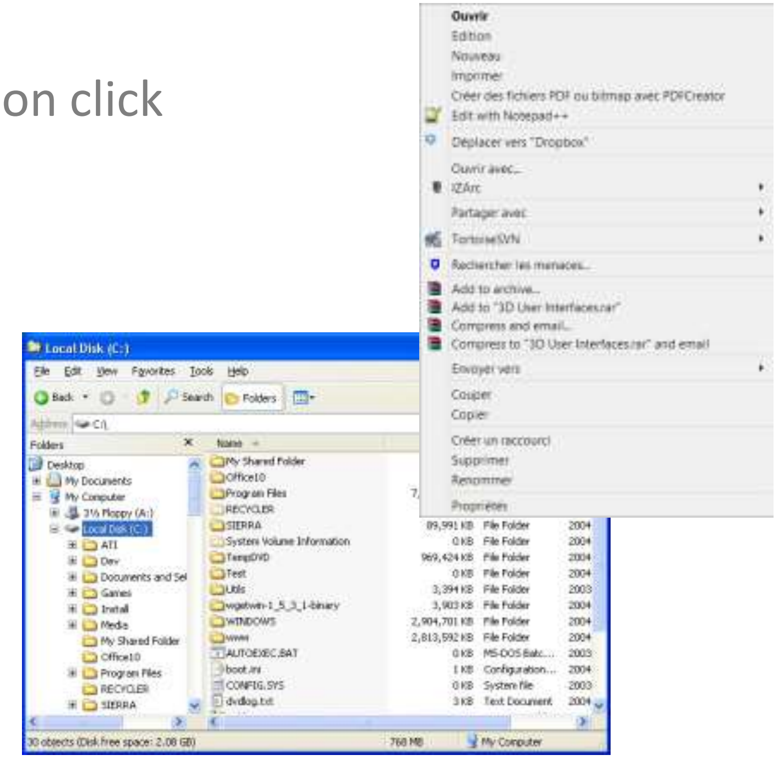
Why task decomposition?

- Improve and evaluate each task independently

Siggraph 2017 – Unity VR Editor
https://www.youtube.com/watch?v=DkMfBIn81Xk

Task Decomposition

- In order to better understand human interaction, complex interaction tasks are decomposed in basic interaction tasks.
- Example : Rename a file
  - Find the file we want to rename
  - Select the file and press the right button click
  - Select rename in the context menu
  - Type the new name and press return

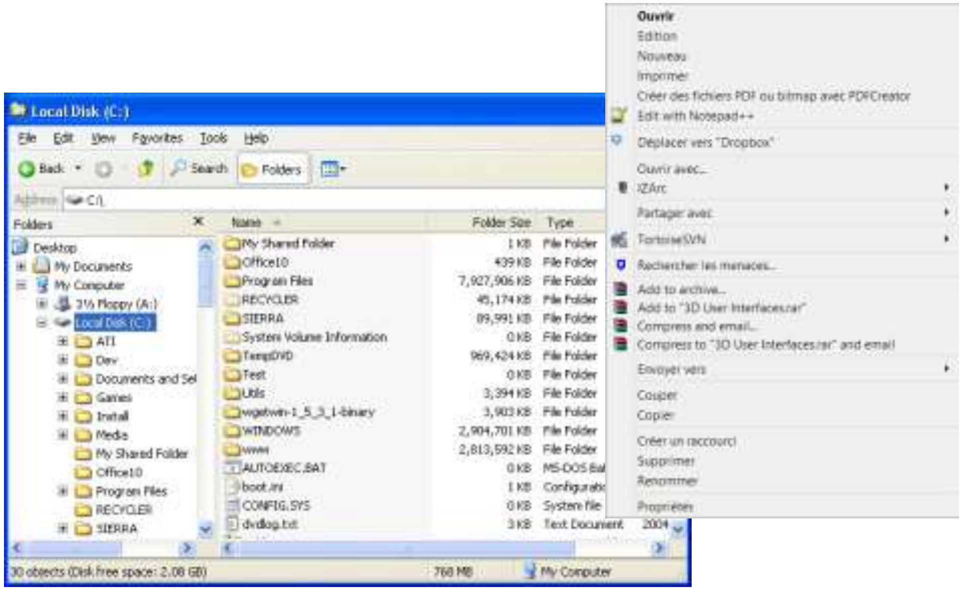


2D Basic interaction Tasks

- Tasks decomposition proposed by James D. Foley (1980)
  - **Selection**: The user makes a selection from a set of alternatives
  - **Position**: The user indicates a position on the interactive display.
  - **Orient**: The user orients an entity in 2D or 3D.
  - **Path**: The user generates a path, which is a series of positions and orientations over time.
  - **Quantify**: The user specifies a value (i.e. number) to quantify a measure.
  - **Text**: The user inputs a text string.

2D Basic interaction Tasks

- Back to the example : Rename a file
  - Find the file we want to rename (Position + Selection)*
  - Select the file and press the right button click (Selection)
  - Select rename in the context menu (Selection)
  - Type the new name and press return (Text)

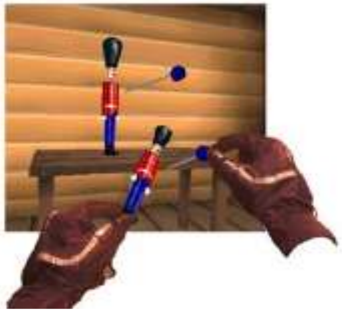


3D Interaction Tasks

➢ **Basic** 3D Interaction Tasks

- **Selection**: The user choses a 3D object from a set of objects
- **Manipulation**: The user applies spatial rigid transformations
- **Navigation**: The user modifies its virtual position in the environment
- **Application Control**: The user issues commands to the application
  - **Quantify**: The user specifies a value (i.e. number) to quantify a measure.
  - **Text**: The user inputs a text string.

Selection



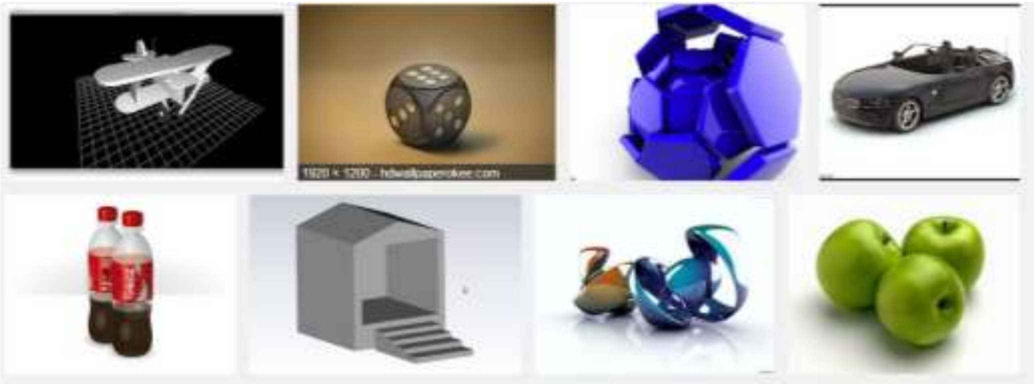
Manipulation

Navigation

3D Object Selection

3D Object Selection

- Identify a particular object from a set
  - Fundamental tasks in any 3D user interface
  - Initial task for most common user interactions in a VE



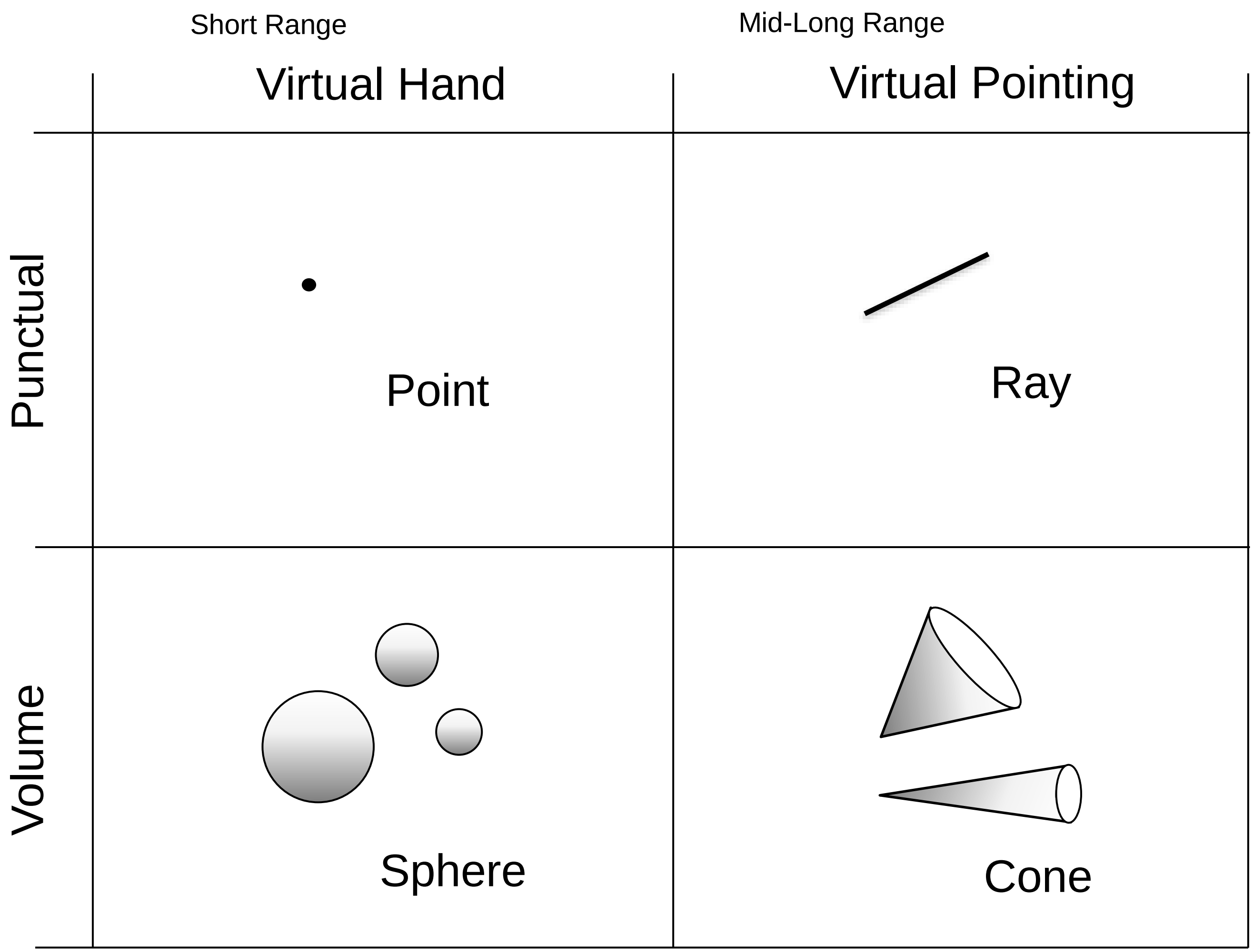
A lot of options for selecting just an object!

Technique	Selection Tool	Selection Control DoFs			Disambiguation Mechanism	CD Ratio	Motor and Visual Space Relationship
		Origin	Orientation	Dominant			
Virtual-hand [64]	Hand Avatar	(x, y, z)	None	(x, y, z)	N/A	Isomorphic	Offset / Clutching
Go-go [75]	Hand Avatar	(x, y, z)	None	(x, y, z)	N/A	Anisomorphic	Offset / Clutching CD Ratio
Bubble-Cursor [93]	Adjustable sphere	(x, y, z)	None	(x, y, z)	Heuristic	Isomorphic	Offset / Clutching
Silk Cursor [107]	Axis aligned box	(x, y, z)	None	(x, y, z)	N/A	Isomorphic	Offset / Clutching
RayCasting [63]	Ray	(x, y, z)	(θ, φ)	(θ, φ)	N/A	Isomorphic	Coupled
Virtual Pads [2]	Ray	(x, y, z)	(θ, φ)	(θ, φ)	N/A	Anisomorphic	Coupled
Direct Image plane [53]	Ray	(x, y, z)	None $^{(1)}$	(x, y)	N/A	Isomorphic	Offset / Clutching
RayCasting from the Eye [8]	Ray	(x_e, y_e, z_e)	(θ, φ)	(θ, φ)	N/A	Isomorphic	Coupled
View Finder [7]	Ray	(x_e, y_e, z_e)	(θ, φ)	(θ, φ)	N/A	Isomorphic	Coupled
Eye-gazed selection [87, 27]	Ray	(x_e, y_e, z_e)	(θ_e, φ_e)	(θ_e, φ_e)	N/A	Isomorphic	Coupled
Occlusion Selection [73]	Ray	(x_e, y_e, z_e)	(x, y, z)	(x, y)	N/A	Isomorphic	Offset
One-Eyed Cursor [98]	Ray	(x_e, y_e, z_e)	(x, y, z)	(x, y)	N/A	Isomorphic	Offset / Clutching
Two-handed Pointing [64]	Ray	(x, y, z)	(x_n, y_n, z_n)	(x, y, z, x_n, y_n, z_n)	N/A	Isomorphic	Coupled
IntenSelect [30]	Ray	(x, y, z)	(θ, φ)	(θ, φ)	Behavioral	Isomorphic	Coupled
Smart Ray [41]	Ray	(x, y, z)	(θ, φ)	(θ, φ)	Manual	Isomorphic	Coupled
Sticky Ray [85]	Cone	(x, y, z)	(θ, φ)	(θ, φ)	Heuristic	Isomorphic	Coupled
Flashlight [54]	Cone	(x, y, z)	(θ, φ)	(θ, φ)	Heuristic	Isomorphic	Coupled
Sense Shapes [68]	Cone	(x, y, z)	(θ, φ)	(θ, φ)	Behavioral	Isomorphic	Coupled
Shadow Cone Selection [84]	Cone	(x, y, z)	(θ, φ)	(θ, φ)	Manual	Isomorphic	Coupled
Probabilistic Pointing [80]	Cone	(x, y, z)	(θ, φ)	(θ, φ)	Heuristic	Isomorphic	Coupled
Enhanced Cone Selection [83]	Cone	(x, y, z)	(θ, φ)	(θ, φ)	Behavioral	Isomorphic	Coupled
Aperture [36]	Adjustable cone	(x_e, y_e, z_e)	(x, y, z)	$(x, y, z)^{(2)}$	Heuristic	Isomorphic	Offset
iSith [71]	Two rays	(x, y, z) (x_n, y_n, z_n)	(θ, φ) (θ_n, φ_n)	$(x, y, z, \theta, \varphi)$ $(x_n, y_n, z_n, \theta_n, \varphi_n)$	Manual	Isomorphic	Coupled
Flexible Pointing [69]	Curved ray	(x, y, z)	(θ, φ) $(x_n, y_n, z_n, \theta_n, \varphi_n)$	$(x, y, z, \theta, \varphi)$ $(x_n, y_n, z_n, \theta_n, \varphi_n)$	N/A	Isomorphic	Coupled
Depth Ray [41, 93]	Ray & 3D cursor	(x, y, z)	(θ, φ)	(z, θ, φ)	Manual	Isomorphic	Coupled
Lock Ray [41]	Ray & 3D cursor	(x, y, z)	(θ, φ)	(z, θ, φ)	Manual	Isomorphic	Coupled
Flow Ray [41]	Ray	(x, y, z)	(θ, φ)	(θ, φ)	Manual	Isomorphic	Coupled
Friction Surfaces [1]	Ray	(x, y, z)	(θ, φ)	(θ, φ)	N/A	Anisomorphic	CD Ratio
PRISM [38]	Ray	(x, y, z)	(θ, φ)	(θ, φ)	N/A	Anisomorphic	CD Ratio
Adaptative pointing [48]	Ray	(x, y, z)	(θ, φ)	(θ, φ)	N/A	Anisomorphic	CD Ratio
SQUAD [49]	Ray & Adjustable sphere	(x, y, z)	(θ, φ)	(θ, φ)	Manual	Isomorphic	Coupled

Table 1: Summary of the classification of selection techniques. $(x, y, z, \theta, \varphi)$ refers to the dominant hand position, and yaw and pitch angles. $(x_n, y_n, z_n, \theta_n, \varphi_n)$ refers to the user's non-dominant hand and $(x_e, y_e, z_e, \theta_e, \varphi_e)$ to the user's eye. We assume a user-centered coordinate system. $^{(1)}$ The orientation of the selection ray is determined by a vector orthogonal to the screen plane. $^{(2)}$ The third DoF is used to adjust the apex angle of the selection cone.

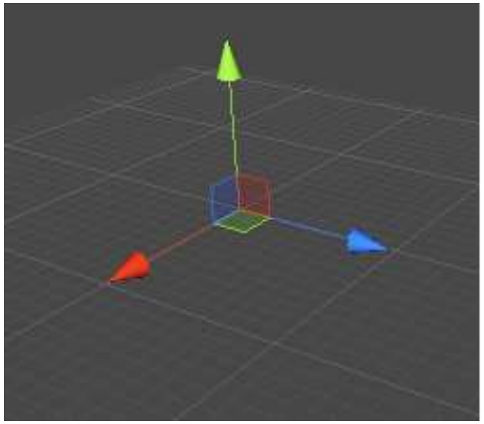
Argelaguet, F., & Andujar, C. (2013). A survey of 3D object selection techniques for virtual environments. Computers & Graphics. https://doi.org/10.1016/j.cag.2012.12.003

How to determine a 3D position in Space?

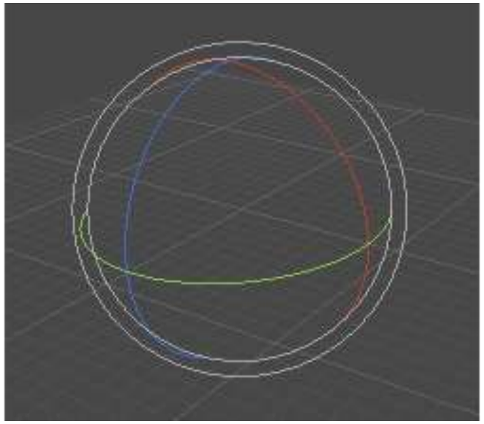


Degrees of Freedom

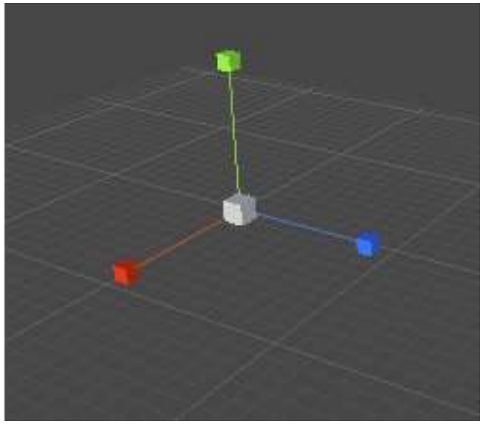
- The number of independent **dimensions** of the motion of a body.



Position



Orientation

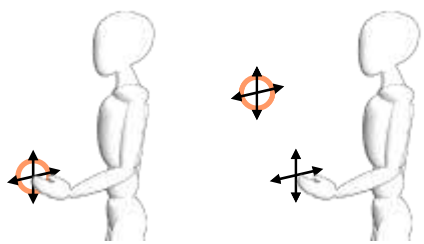


Scale

- DoFs can describe
  - The movements of input devices (e.g. mouse)
  - The motion of a complex articulated object (e.g. arm)
  - The possible movements of a virtual object

How to control the selection tool?

Short Range	Mid-Long Range
Virtual Hand	Virtual Pointing



Collocated

Non-collocated

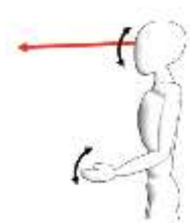
3DoFs

Raycasting

2+3DoFs

Image Plane

3DoFs

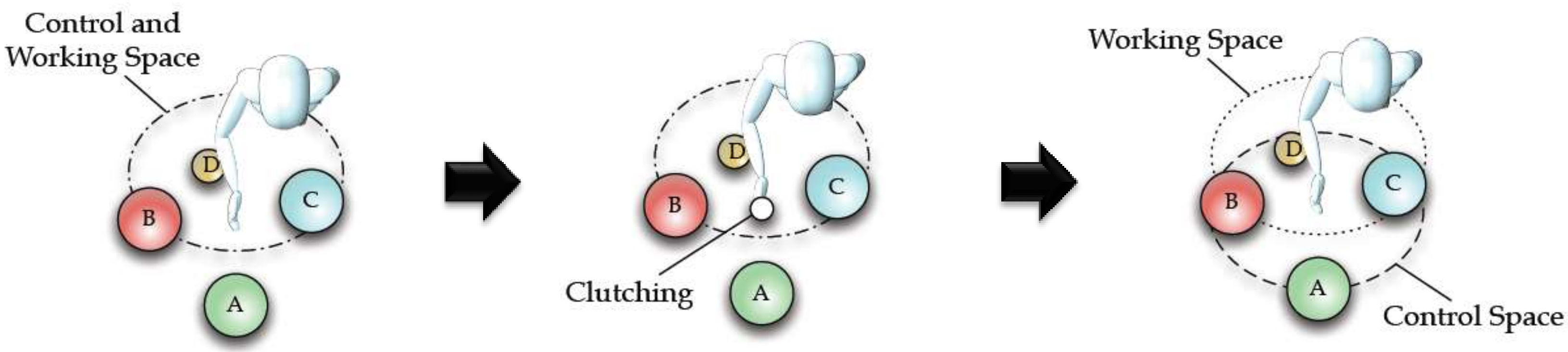


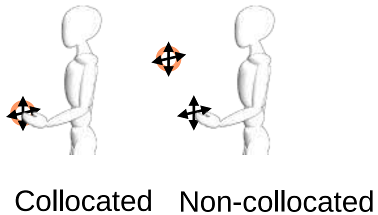
Raycasting from the eye

2DoFs

Motor, Control and Visual Spaces

- Clutching mechanisms
  - Common technique for haptic-based interactions were the working space is limited.



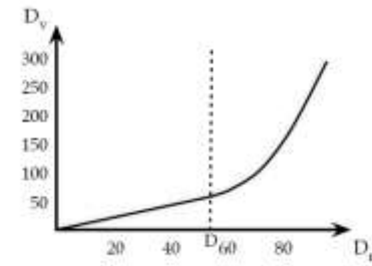


Anisomorphic Control Mappings

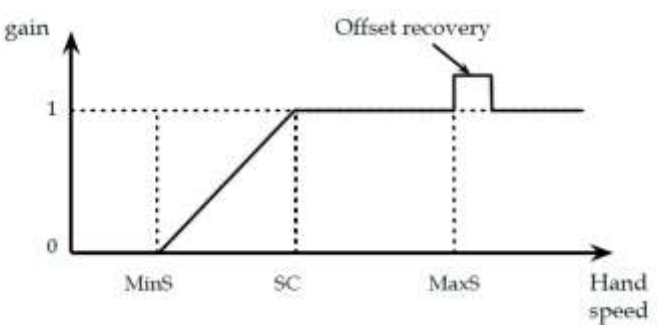
- Go-Go selection
  - Enable the selection of further away objects for virtual hand metaphors.
  - Decreased precision for the selection of further away objects.

- Friction surfaces
  - Fixed control gain to increase precision to achieve precise selections

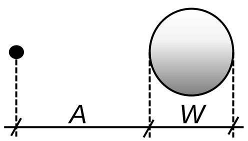
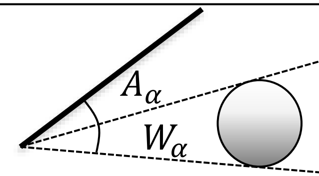
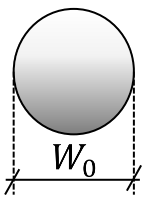
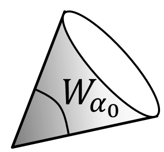
- PRISM selection
  - Adaptive CD ratio control based on the angular/tangential velocity.
  - Filter noise and increase precision for slow motions.



Go-Go
CD-Ratio

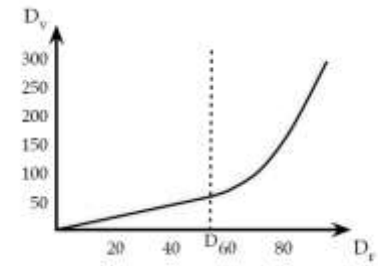


Fitts' law and 3D object selection

	Virtual Hand	Virtual Pointing
Punctual	 $MT = a + b\log_2\left(\frac{A+W}{W}\right)$	 $MT = a + b\log_2\left(\frac{A_\alpha+W_\alpha}{W_\alpha}\right)$
Volume	 $MT = a + b\log_2\left(\frac{A+(W+W_0)}{(W+W_0)}\right)$	 $MT = a + b\log_2\left(\frac{A+(W_\alpha+W_{\alpha_0})}{(W_\alpha+W_{\alpha_0})}\right)$

Quiz: Implications w.r.t. Fitts' Law?

- Go-Go selection
  - Enable the selection of further away objects for virtual hand metaphors.
  - Decreased precision for the selection of further away objects.



Go-Go
CD-Ratio

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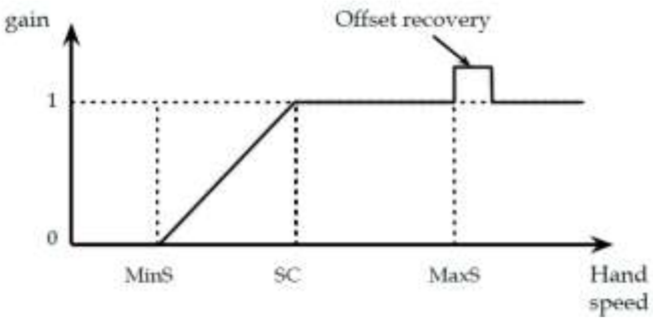
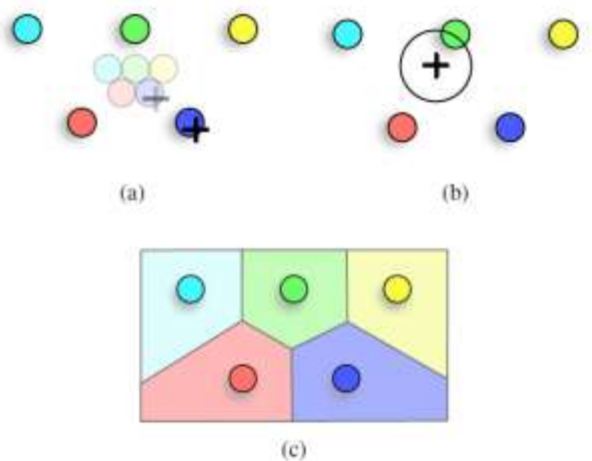


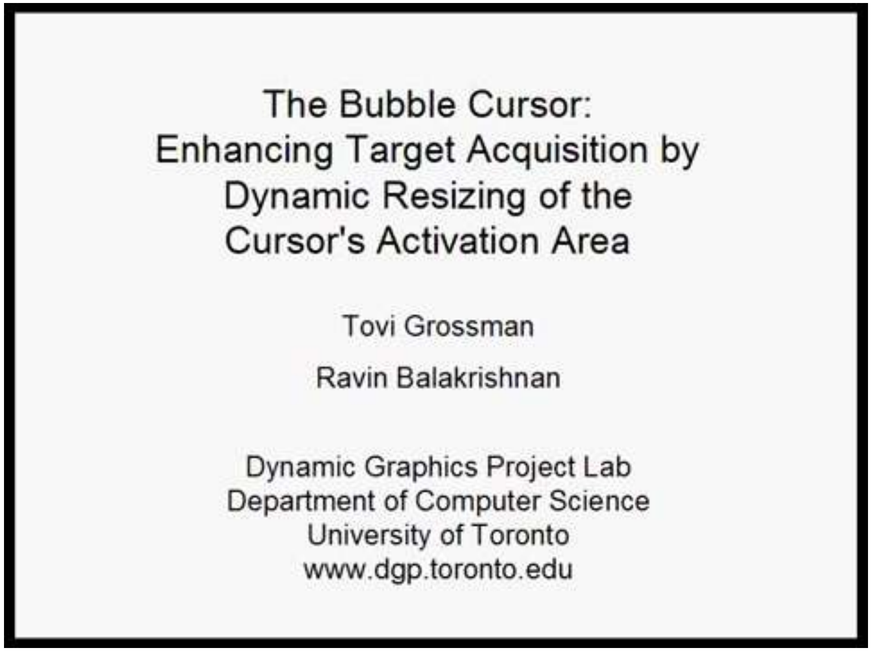
Improving Acquisition of Small Targets

- Cursor manipulation



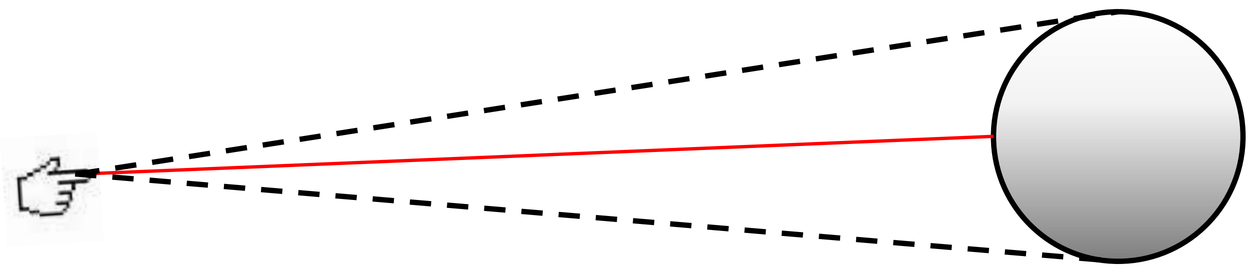
- VE manipulation

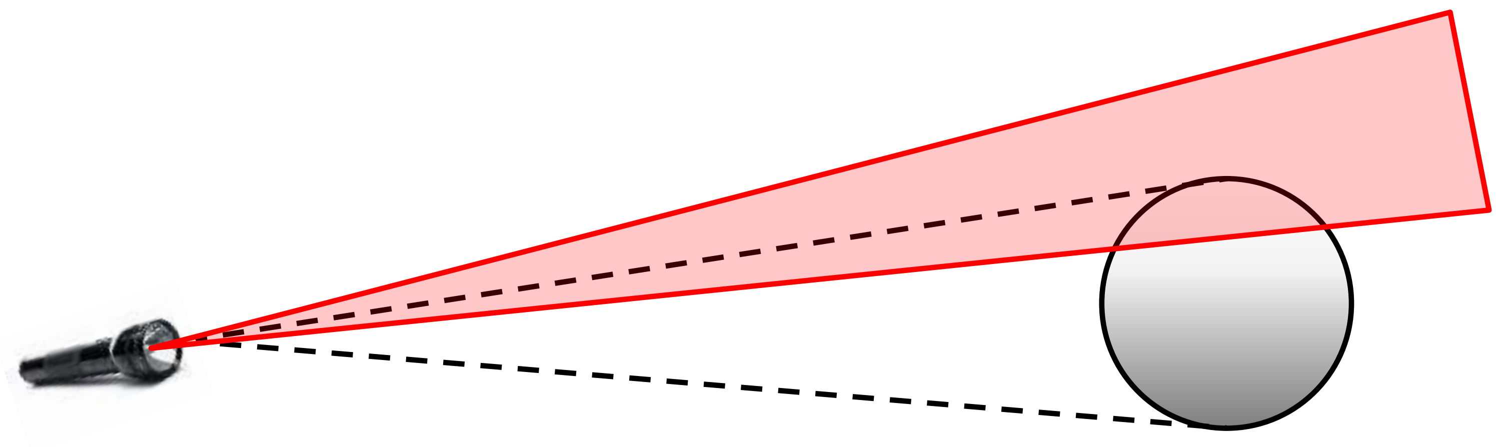
- The Bubble cursor



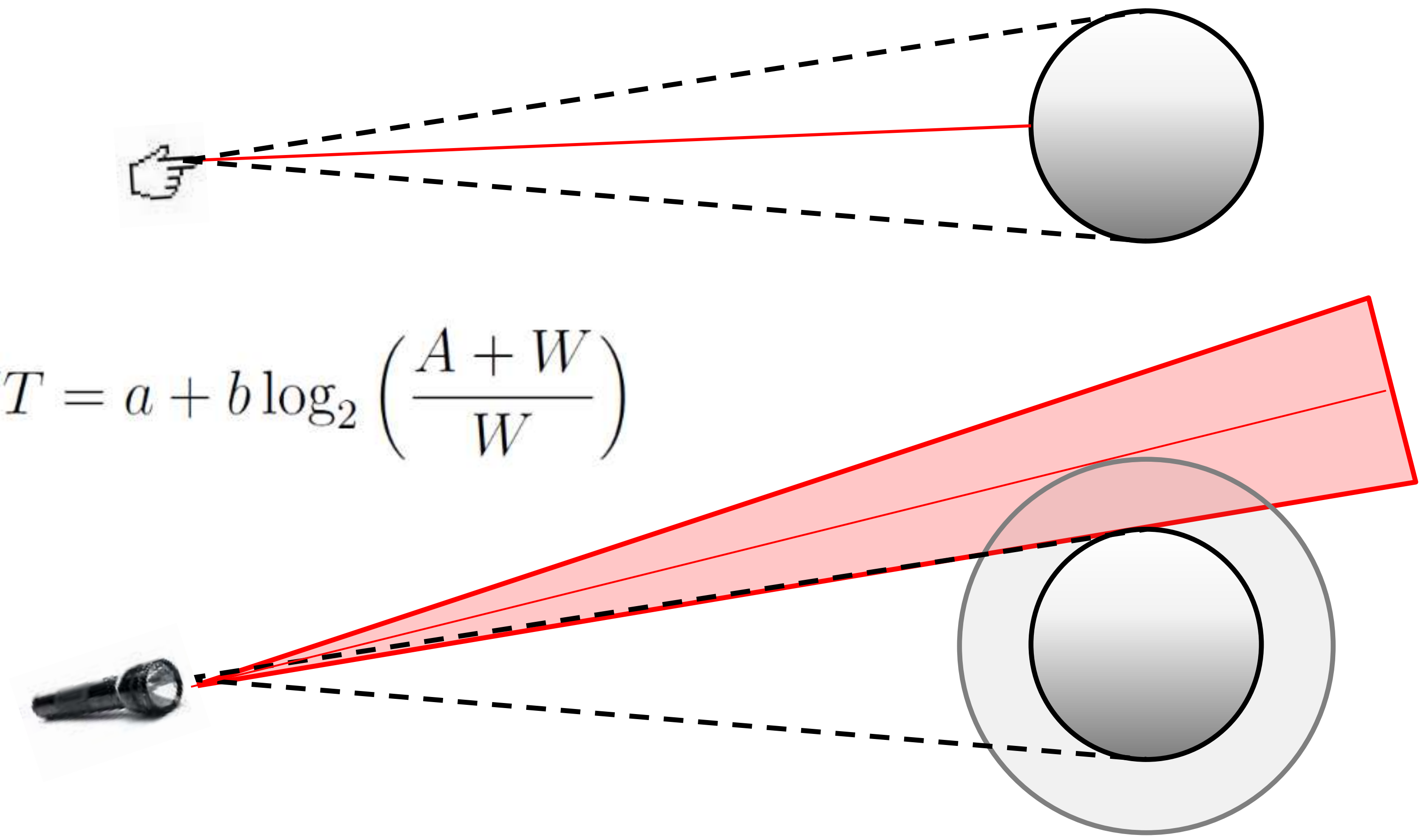
https://www.youtube.com/watch?v=JUBXkD_8ZeQ

Raycasting vs FlashLight



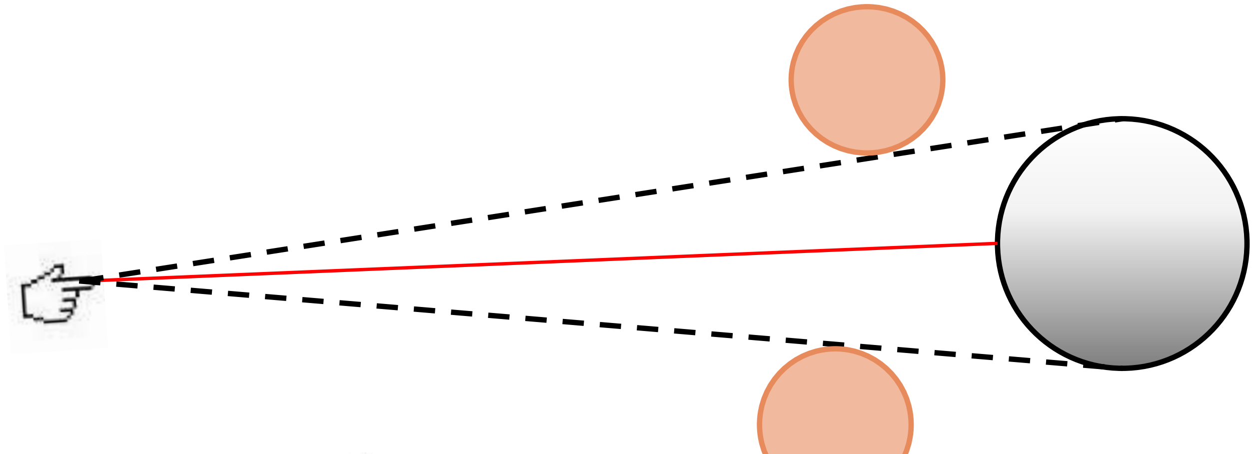


Raycasting vs FlashLight

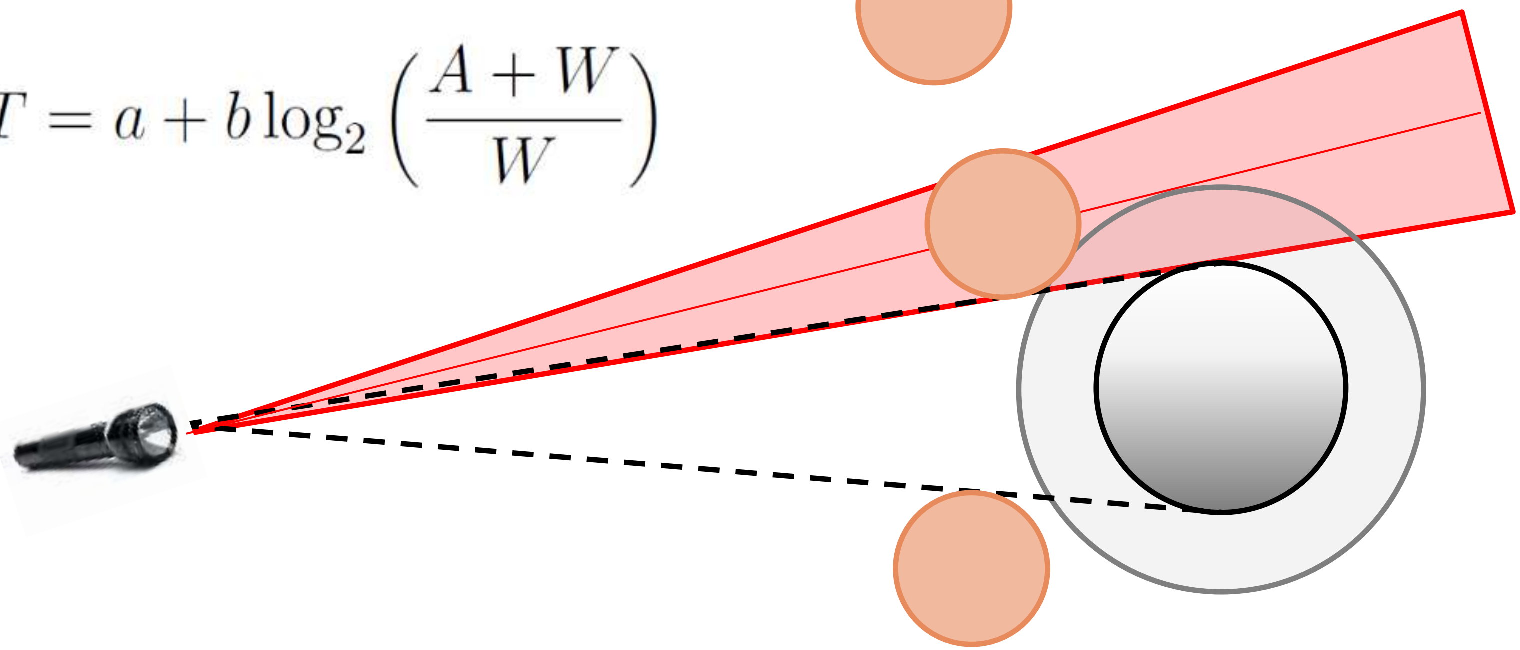


$$MT = a + b\log_2\left(\frac{A+W}{W}\right)$$

Raycasting vs FlashLight



$$MT = a + b\log_2\left(\frac{A+W}{W}\right)$$



Dissambiguation Mechanisms

- Manual approaches
  - The user has to decide, among the indicated targets, which target is the desired one.
- Heuristic approaches
  - Objects are ranked according to a heuristic and the higher ranked object is selected.
- Behavioral approaches
  - Continuously rank objects during the selection process, gathering statistical information.

A lot of options for selecting just an object!

Technique	Selection Tool	Selection Control DoFs			Disambiguation Mechanism	CD Ratio	Motor and Visual Space Relationship
		Origin	Orientation	Dominant			
Virtual-hand [64]	Hand Avatar	(x,y,z)	None	(x,y,z)	N/A	Isomorphic	Offset / Clutching
Go-go [75]	Hand Avatar	(x,y,z)	None	(x,y,z)	N/A	Anisomorphic	Offset / Clutching CD Ratio
Bubble-Cursor [93]	Adjustable sphere	(x,y,z)	None	(x,y,z)	Heuristic	Isomorphic	Offset / Clutching
Silk Cursor [107]	Axis aligned box	(x,y,z)	None	(x,y,z)	N/A	Isomorphic	Offset / Clutching
RayCasting [63]	Ray	(x,y,z)	(θ,φ)	(θ,φ)	N/A	Isomorphic	Coupled
Virtual Pads [2]	Ray	(x,y,z)	(θ,φ)	(θ,φ)	N/A	Anisomorphic	Coupled
Direct Image plane [53]	Ray	(x,y,z)	None [(1)]	(x,y)	N/A	Isomorphic	Offset / Clutching
RayCasting from the Eye [8]	Ray	(x_e,y_e,z_e)	(θ,φ)	(θ,φ)	N/A	Isomorphic	Coupled
View Finder [7]	Ray	(x_e,y_e,z_e)	(θ,φ)	(θ,φ)	N/A	Isomorphic	Coupled
Eye-gazed selection [87, 27]	Ray	(x_e,y_e,z_e)	(θ_e,φ_e)	(θ_e,φ_e)	N/A	Isomorphic	Coupled
Occlusion Selection [73]	Ray	(x_e,y_e,z_e)	(x,y,z)	(x,y)	N/A	Isomorphic	Offset
One-Eyed Cursor [98]	Ray	(x_e,y_e,z_e)	(x,y,z)	(x,y)	N/A	Isomorphic	Offset / Clutching
Two-handed Pointing [64]	Ray	(x,y,z)	(x_n,y_n,z_n)	(x,y,z,x_n,y_n,z_n)	N/A	Isomorphic	Coupled
IntenSelect [30]	Ray	(x,y,z)	(θ,φ)	(θ,φ)	Behavioral	Isomorphic	Coupled
Smart Ray [41]	Ray	(x,y,z)	(θ,φ)	(θ,φ)	Manual	Isomorphic	Coupled
Sticky Ray [85]	Cone	(x,y,z)	(θ,φ)	(θ,φ)	Heuristic	Isomorphic	Coupled
Flashlight [54]	Cone	(x,y,z)	(θ,φ)	(θ,φ)	Heuristic	Isomorphic	Coupled
Sense Shapes [68]	Cone	(x,y,z)	(θ,φ)	(θ,φ)	Behavioral	Isomorphic	Coupled
Shadow Cone Selection [84]	Cone	(x,y,z)	(θ,φ)	(θ,φ)	Manual	Isomorphic	Coupled
Probabilistic Pointing [80]	Cone	(x,y,z)	(θ,φ)	(θ,φ)	Heuristic	Isomorphic	Coupled
Enhanced Cone Selection [83]	Cone	(x,y,z)	(θ,φ)	(θ,φ)	Behavioral	Isomorphic	Coupled
Aperture [36]	Adjustable cone	(x_e,y_e,z_e)	(x,y,z)	$(x,y,z)^{(2)}$	Heuristic	Isomorphic	Offset
iSith [71]	Two rays	(x,y,z) (x_n,y_n,z_n)	(θ,φ) (θ_n,φ_n)	(x,y,z,θ,φ) $(x_n,y_n,z_n,\theta_n,\varphi_n)$	Manual	Isomorphic	Coupled
Flexible Pointing [69]	Curved ray	(x,y,z)	(θ,φ) $(x_n,y_n,z_n,\theta_n,\varphi_n)$	(x,y,z,θ,φ) $(x_n,y_n,z_n,\theta_n,\varphi_n)$	N/A	Isomorphic	Coupled
Depth Ray [41, 93]	Ray & 3D cursor	(x,y,z)	(θ,φ)	(z,θ,φ)	Manual	Isomorphic	Coupled
Lock Ray [41]	Ray & 3D cursor	(x,y,z)	(θ,φ)	(z,θ,φ)	Manual	Isomorphic	Coupled
Flow Ray [41]	Ray	(x,y,z)	(θ,φ)	(θ,φ)	Manual	Isomorphic	Coupled
Friction Surfaces [1]	Ray	(x,y,z)	(θ,φ)	(θ,φ)	N/A	Anisomorphic	CD Ratio
PRISM [38]	Ray	(x,y,z)	(θ,φ)	(θ,φ)	N/A	Anisomorphic	CD Ratio
Adaptative pointing [48]	Ray	(x,y,z)	(θ,φ)	(θ,φ)	N/A	Anisomorphic	CD Ratio
SQUAD [49]	Ray & Adjustable sphere	(x,y,z)	(θ,φ)	(θ,φ)	Manual	Isomorphic	Coupled

Table 1: Summary of the classification of selection techniques. (x,y,z,θ,φ) refers to the dominant hand position, and yaw and pitch angles. $(x_n,y_n,z_n,\theta_n,\varphi_n)$ refers to the user's non-dominant hand and $(x_e,y_e,z_e,\theta_e,\varphi_e)$ to the user's eye. We assume a user-centered coordinate system. [(1)] The orientation of the selection ray is determined by a vector orthogonal to the screen plane. [(2)] The third DoF is used to adjust the apex angle of the selection cone.

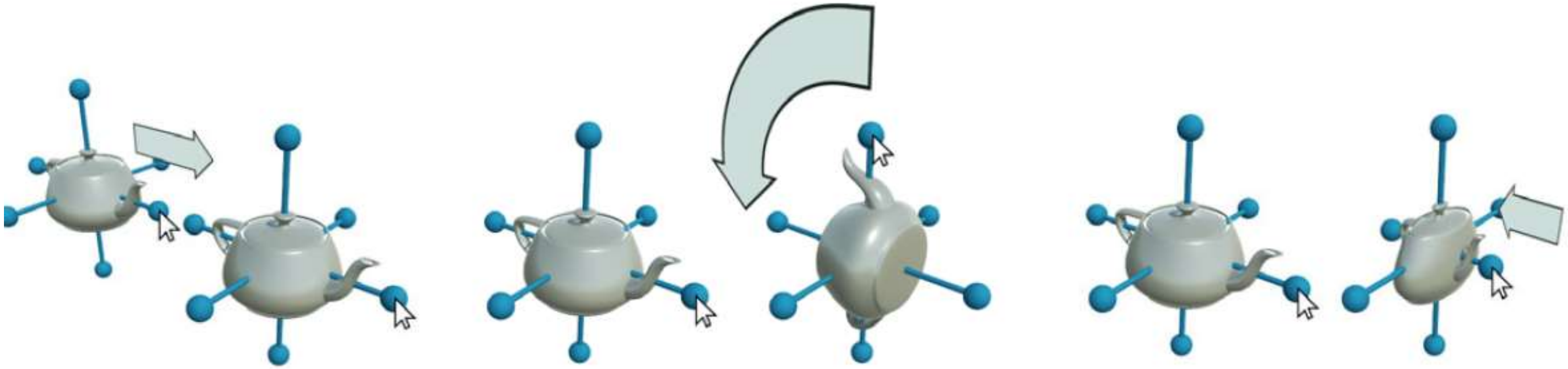
Argelaguet, F., & Andujar, C. (2013). A survey of 3D object selection techniques for virtual environments. Computers & Graphics. https://doi.org/10.1016/j.cag.2012.12.003

Manipulation

3D Manipulation Techniques

- Manipulation tasks range from applying **rigid transformations** to 3D objects (translations and rotations), to modifying their **physical properties** or their shapes.

- Most 3D interaction techniques for object manipulation focus only on **spatial** rigid transformations.



Manipulation Techniques Classification

Technique	Hands/DOF Tracked	Separation	Transformations											
			Translation				Rotation				Scaling			
			Mapping	CP	TD	MD	Mapping	CP	TD	MD	Mapping	CP	TD	MD
Simple Virtual Hand [BKLJP04]	1/6	None: {T,R}	Exact	1	3	3	Exact	1	3	3	No control			
In the Air[HIW*09]	1/4	None: {T,R}	Exact	1	3	3	Exact	1	1	1	No control			
Air-TRS[ACJH13]	2/3	Partial: {T},{T,R,S}	Exact	1-2	3	3	Exact	2	3	3	Distance	2	1	1
VHGM[KP14]	1/6	None: {T,R}	Exact	1	3	3	Exact	1	3	3	No control			
Handle Bar[SGH*12]	2/3	Partial: {T,Ryz},{Rx}	Exact	2	3	3	Hybrid	2	3	1	Distance	2	1	1
Spindle+Wheel[CW15]	2/6	None: {T,R}	Exact	2	3	3	Hybrid	2	3	3	Distance	2	1	1
Crank Handle[BMA*14]	1/3	Total: {T},{R}	Exact	1	3	3	Remapped	1	3	1	No control			
Grasping Object[BMA*14]	1/3	Partial: {T},{T,R}	Exact	1	3	3	Remapped	1	3	3	No control			
3-DOF Hand[MFA*14]	2/6	Partial: {T},{T,R,S}	Exact	1	3	3	Exact	1	3	3	Distance	2	1	1
6-DOF Hand[MFA*14]	2/6	None: {T,R},{T,R,S}	Exact	1	3	3	Exact	1	3	3	Distance	2	1	1
PRISM[FKK07]	1/6	None: {T,R}	Scaled N:1	1	3	3	Scaled N:1	1	3	3	No control			
Viewpoint Adjustment[Osa08]	2/6	None: {T,R}	Exact	1	3	3	No control				No control			
7 Handle[NDP14]	2/3	None: {T,R}	Remapped	1-2	3	3	Remapped	1-2	3	1	No control			
Widgets[MRFJ16]	1/3	Total: {T},{R}	Remapped	1	3	1	Remapped	1	3	1	No control			
Go-Go[PBWI96]	1/6	None: {T,R}	Scaled 1:N	1	3	3	Exact	1	3	3	No control			
HOMER[BH97, WB08]	1/6	None: {T,R}	Scaled 1:N	1	3	3	Exact	1	3	3	No control			
Worlds in Miniature[SCP95]	2/6	None: {T,R}	Remapped	1	3	3	Remapped	1	3	3	No control			
Voodoo Dolls[PSP99]	2/6	None: {T,R}	Remapped	1	3	3	Remapped	1	3	3	No control			

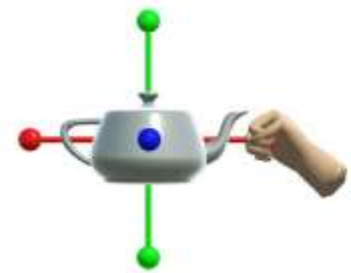
CP: number of contact points required, TD: Total transformation DoFs, MD: mínimum explicitly simultaneously controlled DoFs.

Mendes, D., Caputo, F. M., Giachetti, A., Ferreira, A., & Jorge, J. (2019, February). A survey on 3D virtual object manipulation: From the desktop to immersive virtual environments. In *Computer Graphics Forum* (Vol. 38, No. 1, pp. 21-45).

One-hand Manipulation Techniques

- Most straightforward techniques
- Only requires to track one hand

Virtual Hand

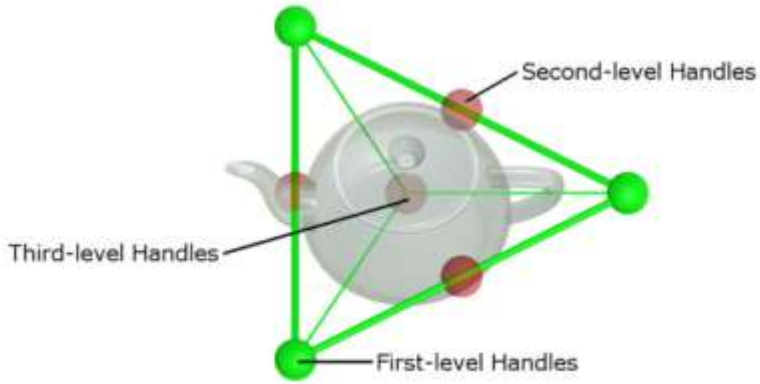


3D Widgets

Kim T., Park J.: 3D object manipulation using virtual handles with a grabbing metaphor. IEEE Computer Graphics and Applications, 3 (2014), 30–38.
Mendex D., Relvas F., Ferreira A., Jorge J.: The benefits of DOF separation in mid-air 3D object manipulation. ACM Conference on Virtual Reality Software and Technology (2016), pp. 261–268.

One-hand Manipulation Techniques

- Most "straightforward" techniques
- Only requires to track one hand

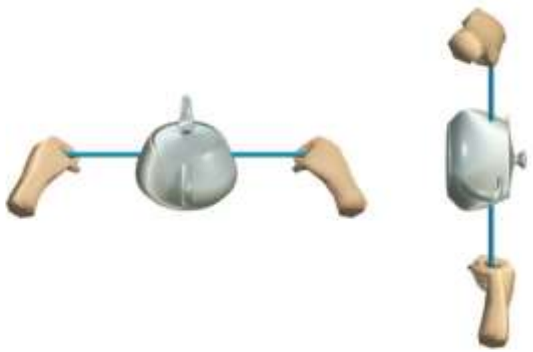


7-Handle Technique

Nguyen, T. T. H., Duval, T., & Pontonnier, C.. A new direct manipulation technique for immersive 3d virtual environments. In ICAT-EGVE 2014 (p. 8).

Bimanual Manipulation Techniques

- Requires to track two hands.
- They can result less intuitive (e.g. center of rotation).
- Allow a positional mapping to perform rotations.

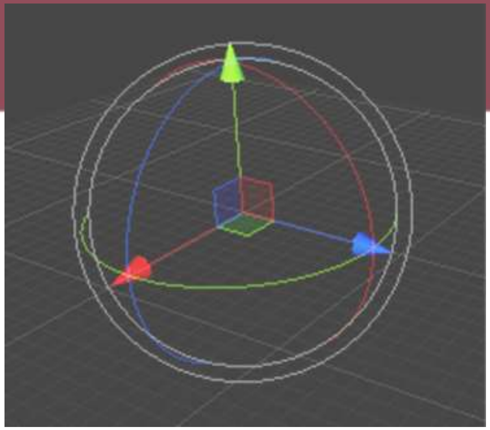


The Handlebar Metaphor

Air-TRS

Song P., Goh W. B., Hutama W., Fu C.-W., Liu X.: A handle bar metaphor for virtual object manipulation with mid-air interaction. ACM Conference *on Human Factors in Computing Systems*, pp. 1297–1306.
Araujo B. R. D., Casiez G., Jorge J. A., Hachet M.: Mockup builder: 3D modeling on and above the surface. Computers & Graphics 37, 3 (2013), 165–178.
Cho I.,Wartell Z.: Evaluation of a bimanual simultaneous 7DOF interaction technique in virtual environments. In IEEE Symposium on 3D User Interfaces, 2015, pp. 133–136.

DoF Separation



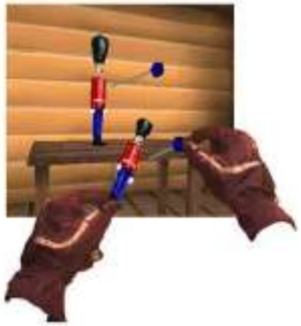
- Best number of DoF to control at a time?
  - Simplicity vs Flexibility
- Additional DoFs increases user's workload
- DoF separation can reduce errors at the cost of increased time for complex tasks.
- Use task analysis
  - Reduce the degrees of freedom when possible

Indirect 3D Manipulation Techniques

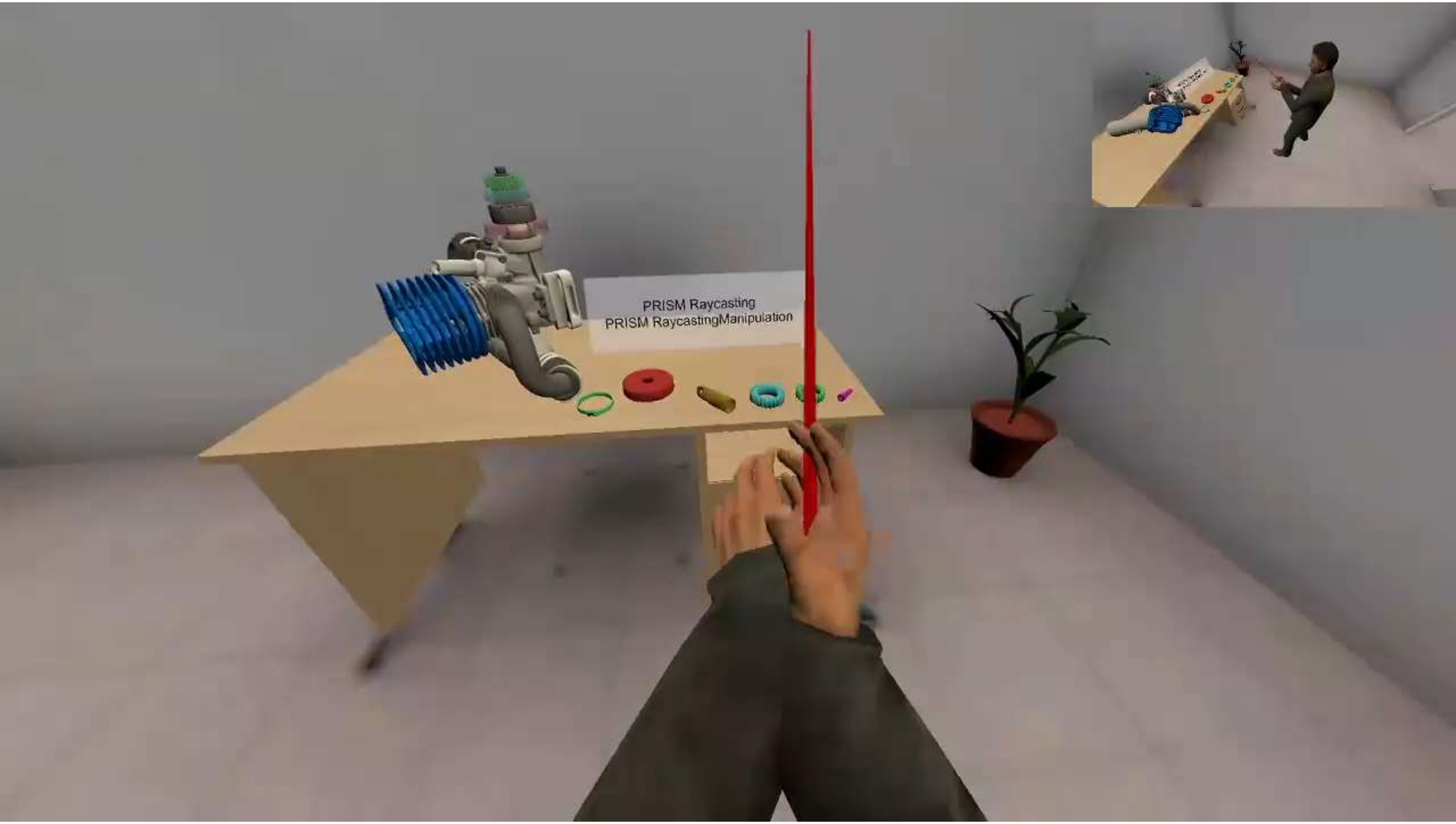
- HOMER
  - Hand-Centred Object Manipulation Extending Ray-casting

- World-in-miniature
  - Enables the manipulation of all objects
  - Precision issues for large environments

- Voodoo Dolls
  - Create a copy of the object to manipulate
  - “At a distance” manipulation



Bowman D. A., Hodges L. F.: An evaluation of techniques for grabbing and manipulating remote objects in immersive VEs . Symposium on Interactive 3D Graphics (1997), ACM, pp. 35–ff.
Pierce J. S., Stearns B. C., Pausch R.: Voodoo dolls: Seamless interaction at multiple scales in virtual environments. Symposium on Interactive 3D Graphics (1999), ACM, pp. 141–145.
Stoakley R., Conway M. J., Pausch R.: Virtual reality on a WIM: Interactive worlds in miniature. SIGCHI Conference on Human Factors in Computing Systems (1995), ACM, pp. 265–272.


PRISM Raycasting
PRISM RaycastingManipulation

Solving Precision Issues

- Adding constraints
  - Use discrete placement constraints (snapping)
  - Collision avoidance mechanisms

- Scaling down motions
  - Increase precision (Control display ratio greater than 1)
  - PRISM - Precise and Rapid Interaction through Scaled Manipulation) Best for translations, less performant for rotations
  - Scaled HOMER - Velocity-based scaling to allow more precise manipulation at both near and far distances

Kiyokaya K., Takemura H., Yokoya N.: Manipulation aid for two-handed 3-D designing within a shared virtual environment. *Human–Computer Interaction 2* (1997), 937–940.
Frees S., Kessler G. D.: Precise and rapid interaction through scaled manipulation in immersive virtual environments. In IEEE Virtual Reality, 2005. pp. 99–106.
Wilkes C., Bowman D. A.: Advantages of velocity-based scaling for distant 3D manipulation. ACM Symposium on Virtual Reality Software and Technology (2008), pp. 23–29.
Auteri C., Guerra M., Frees S.: Increasing precision for extended reach 3D manipulation. The International Journal of Virtual Reality 12, 1 (2013), 66–73.

Design Guidelines

- Naturalism not always desirable
  - Techniques that move away from direct manipulations can avoid unwanted side effects of replicating the physical world exactly
- Match the interaction technique with the device
  - Exact mapping between tracked hand/device and virtual object has often been followed in mid-air interactions
- Non-isomorphic techniques are useful and intuitive
  - Yet, it is only appealing for translations.
- Accuracy in mid-air manipulation is still a relevant issue.
- DOF separation using widgets shows benefits in specific conditions.

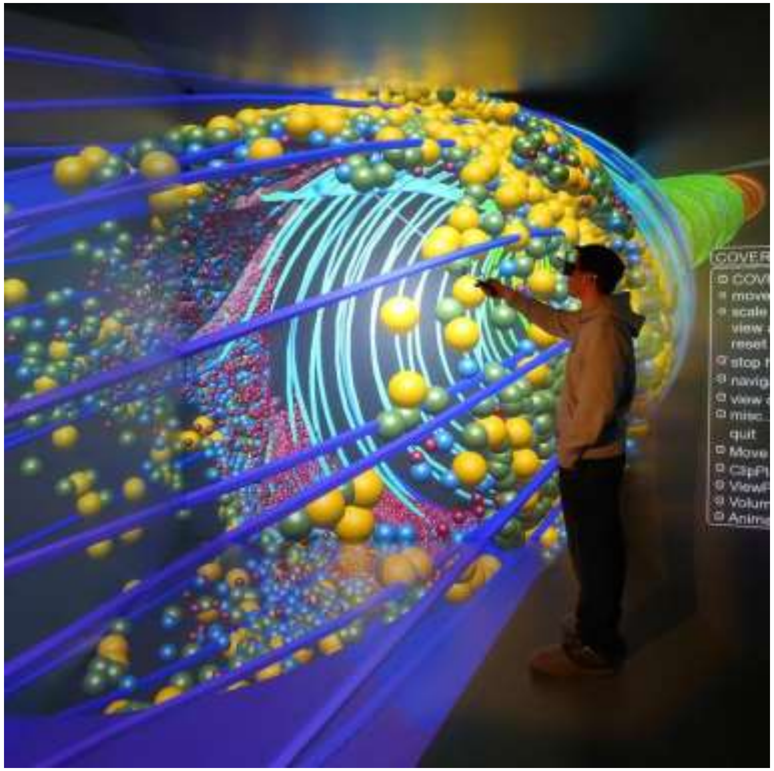
3D Manipulation and Haptics

3D Manipulation and Haptics

Application Control

Application Control

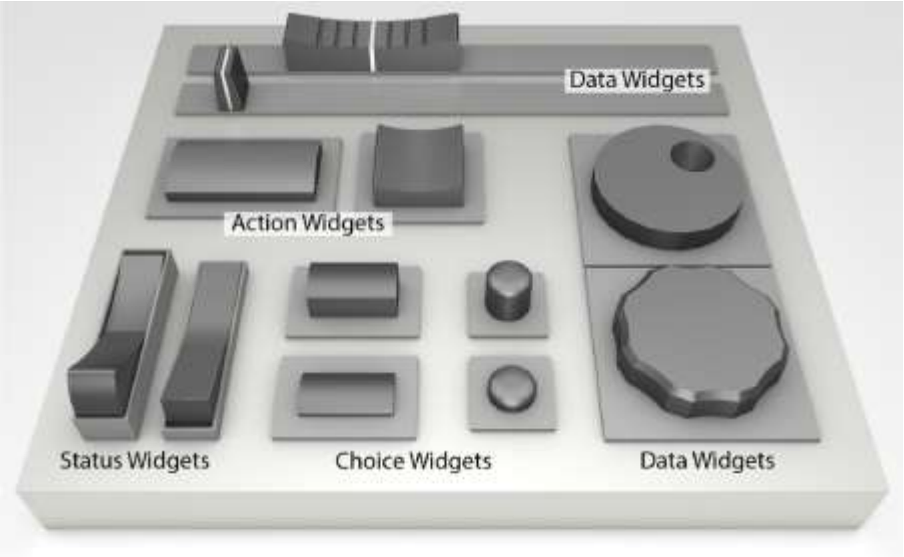
- **Commands** are issued to request a function
  - Change interaction **mode** (e.g. brush tool → eraser tool)
  - Change system **state** (e.g. change a simulation parameter)



Application Control

- Allows the user to control the **interaction flow**
  - Selection, Manipulation and Navigation tasks have to be combined with many application control tasks

- Classification
  - Graphical menus
  - Dedicated Tools
  - Gestural commands
  - Voice commands



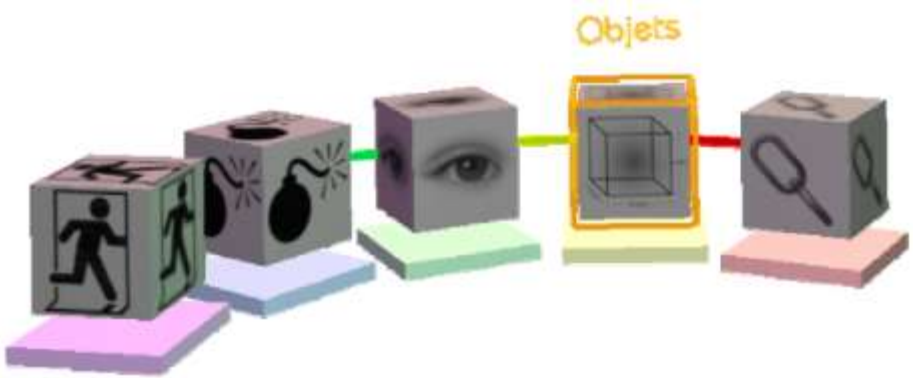
Graphical Menus : 1 DoF Menus

- Menus using only 1-DoF

- Example : Ring menus
  - Items arranged in a circle around the hand
  - Hand rotations causes all the items to rotate
  - The selected item is the one with a selection basket

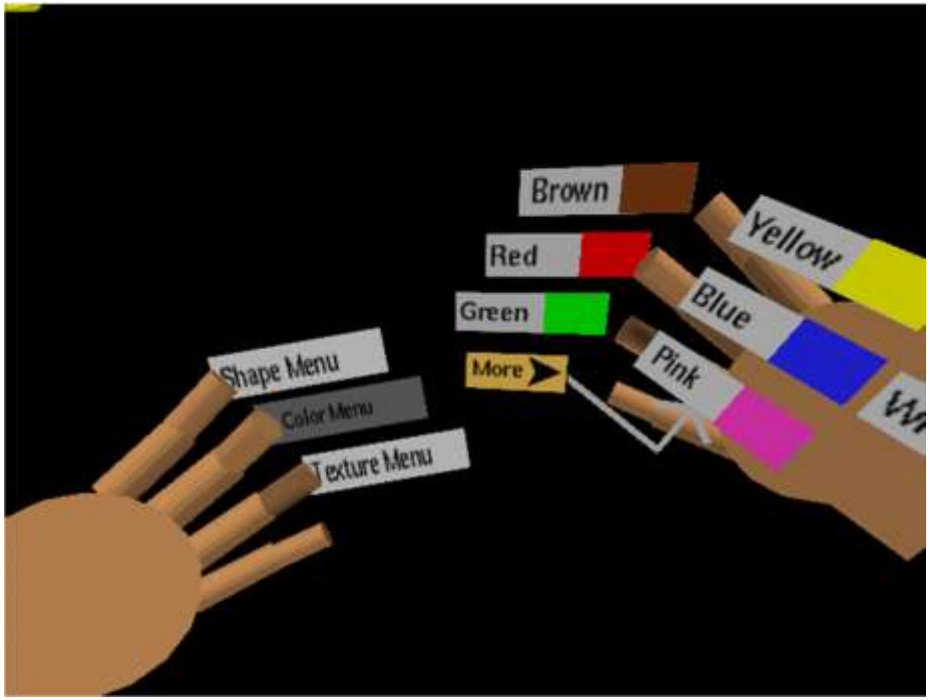
- Benefits:
  - Simple to use

- Drawbacks:
  - Effective for few items



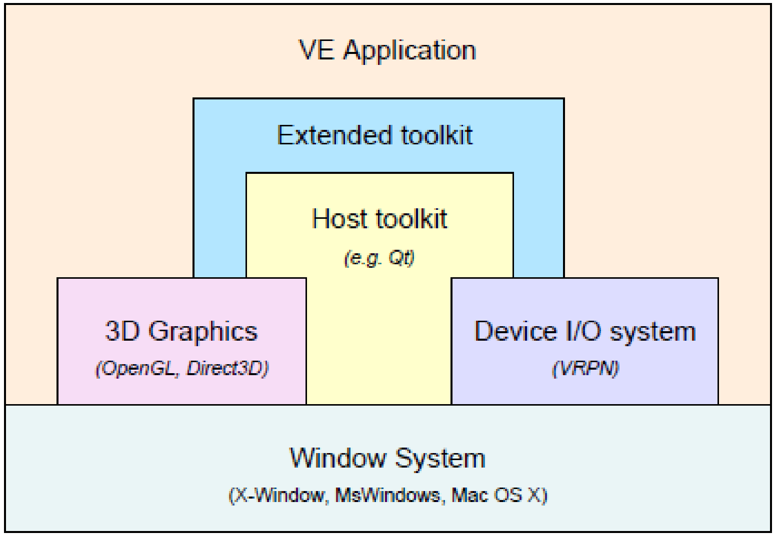
Graphical Menus : TULIP Menu

- A menu item is assigned to each finger
  - A pinch gesture selects the desired item
  - Limited number of items



Graphical Menus : Adapted 2D Menus

- Classic 2D menus displayed on a 3D world
  - Same functionality than **desktop** menus
  - Menus can be held by the non-dominant hand
  - Often they are semitransparent to reduce occlusion



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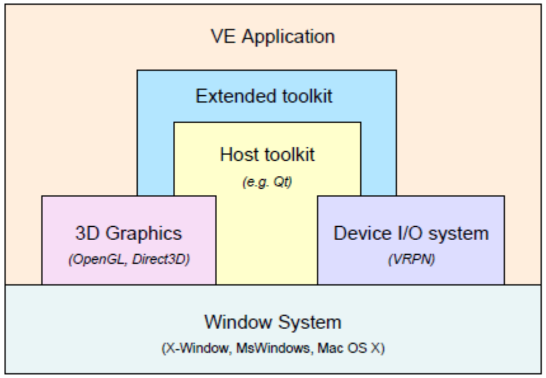
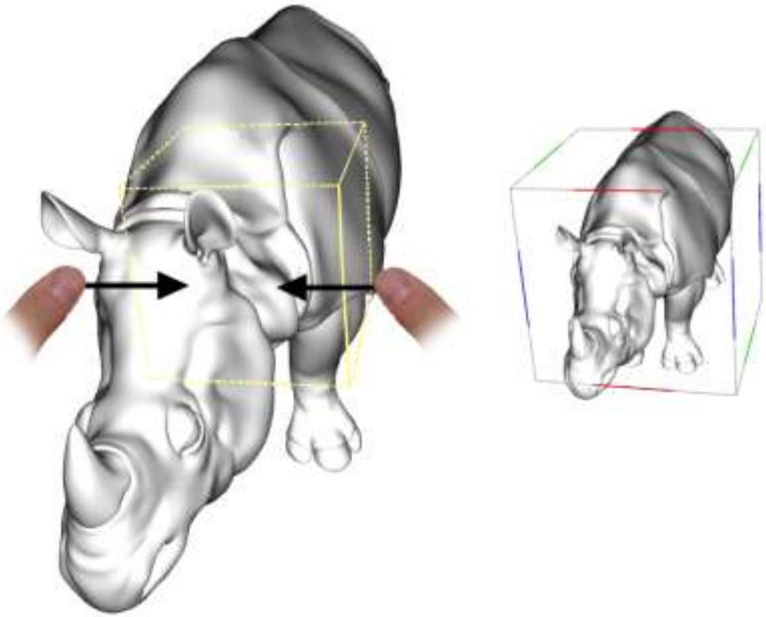


- Benefits
  - Users are familiar with these menus
- Drawbacks
  - Can occlude the environment
  - Users might have trouble to find the menu
  - The selection and manipulation of widgets can be difficult

Graphical Menus : 3D Widgets

- **Collocated** 3D Widgets:
  - Appear close to the selected object
  - Provides contextual information
  - Typically used for changing geometric parameters
    - Combine selection and manipulation in a single step

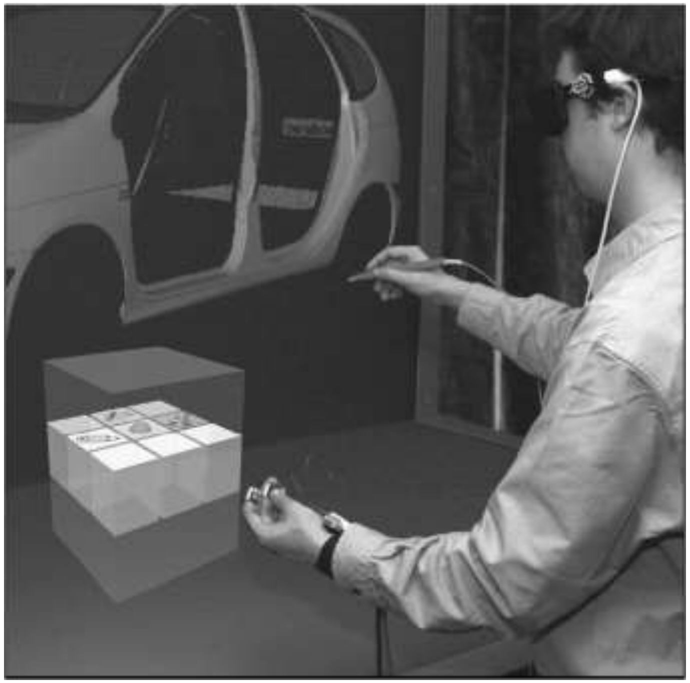


Cohé, Aurélie, Fabrice Dècle, and Martin Hachet. "tBox: a 3d transformation widget designed for touch-screens." *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 2011.

Graphical Menus : 3D Widgets

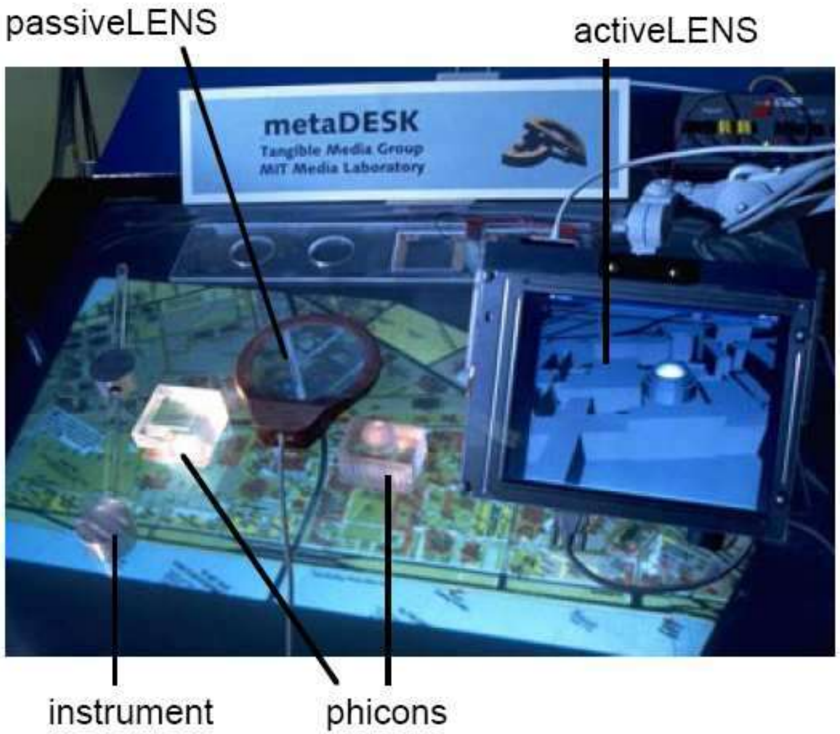
➢ **Non-collocated** 3D Widgets

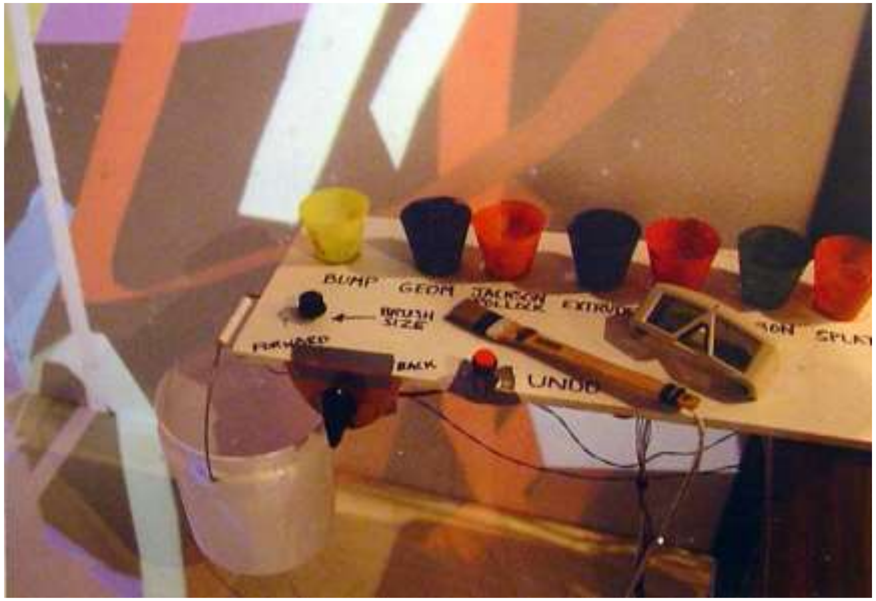
- Not associated with a particular object
- Example: Command and Control Cube



Tangible Interfaces

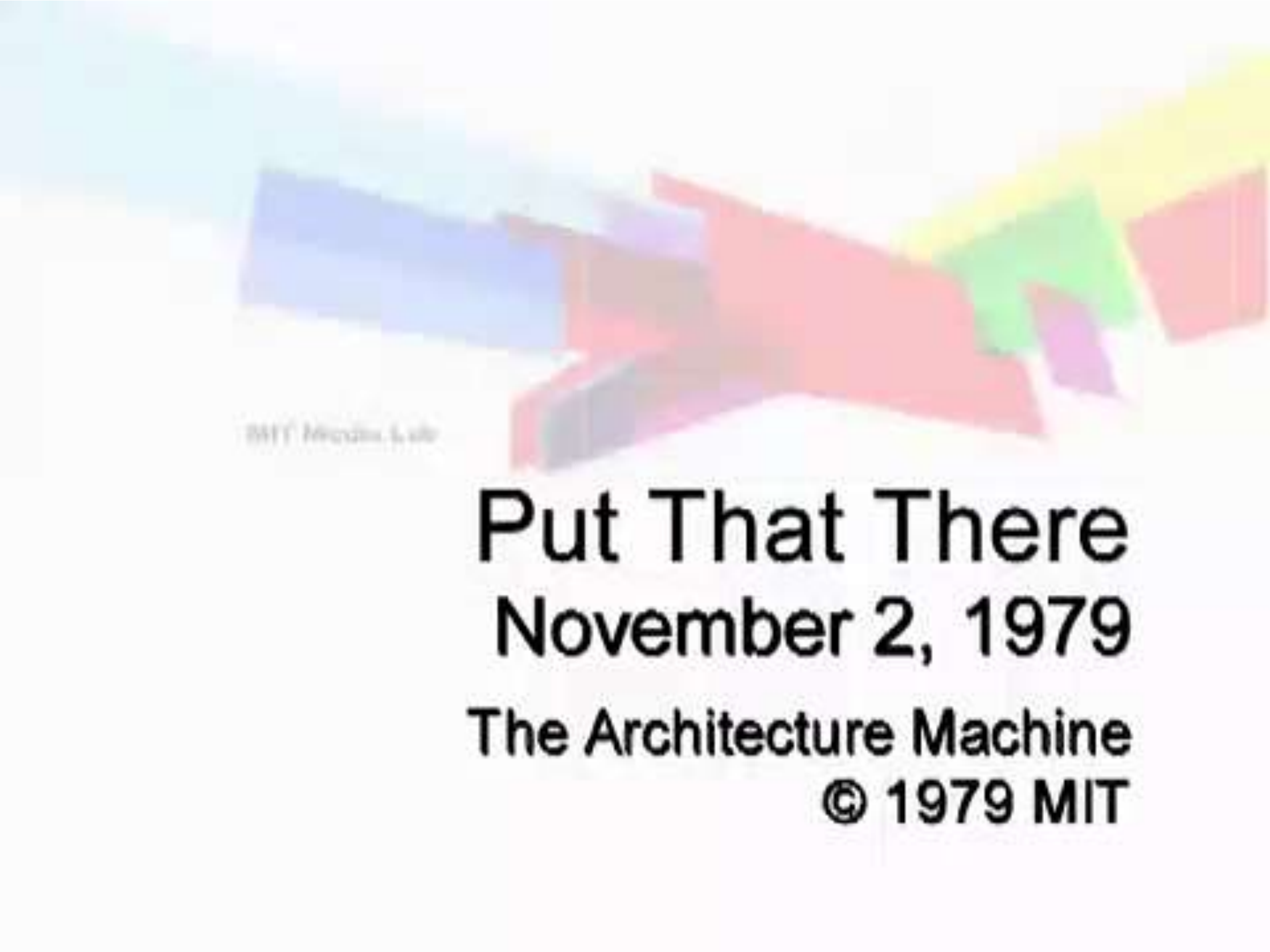
- Use of familiar device for 3D interaction
  - Exploiting the real-world correspondence (Affordances)





Gesture Interaction

- One of the first techniques in VR



Gesture Interaction

- Gesture interaction exploits the **affordances** and **experience** of users
  - User's knowledge of the real world

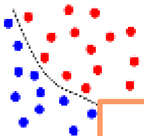
Tilt Brush

- A **gesture** can be considered as a meaningful and intentional movement
  - Encoded information based on the spatial, pathic, symbolic and affective characteristics [Mitra et al. 2007]

Gesture-Based Systems

Pattern Analysis

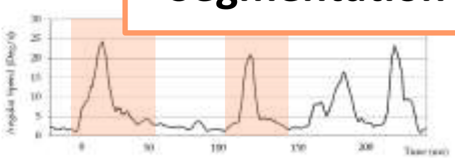
User Interface



Classification

Recognition

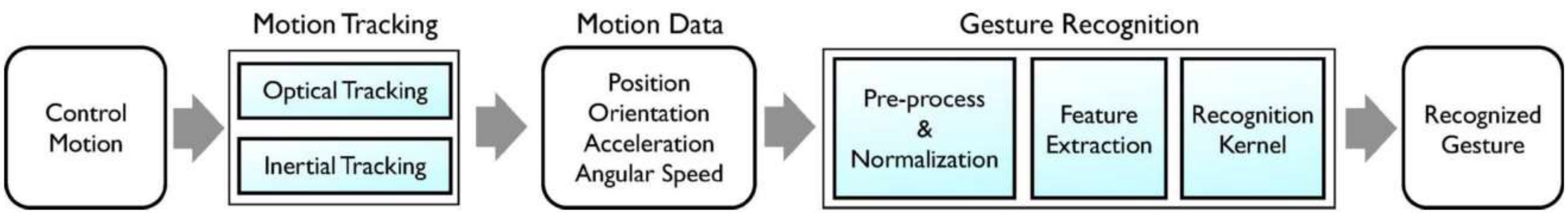
Segmentation



System Training

Usage

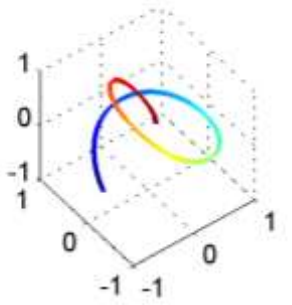
User Experience



M. Chen, G. AlRegib, and B.-H. Juang. Feature Processing and Modeling for 6D Motion Gesture Recognition. IEEE Transactions on Multimedia, 15(3):561–571, 2013.

Gesture Classification

- Gesture characterization through a set of distinctive features
  - Mean speed, curvature... [Chen et al. 2013]



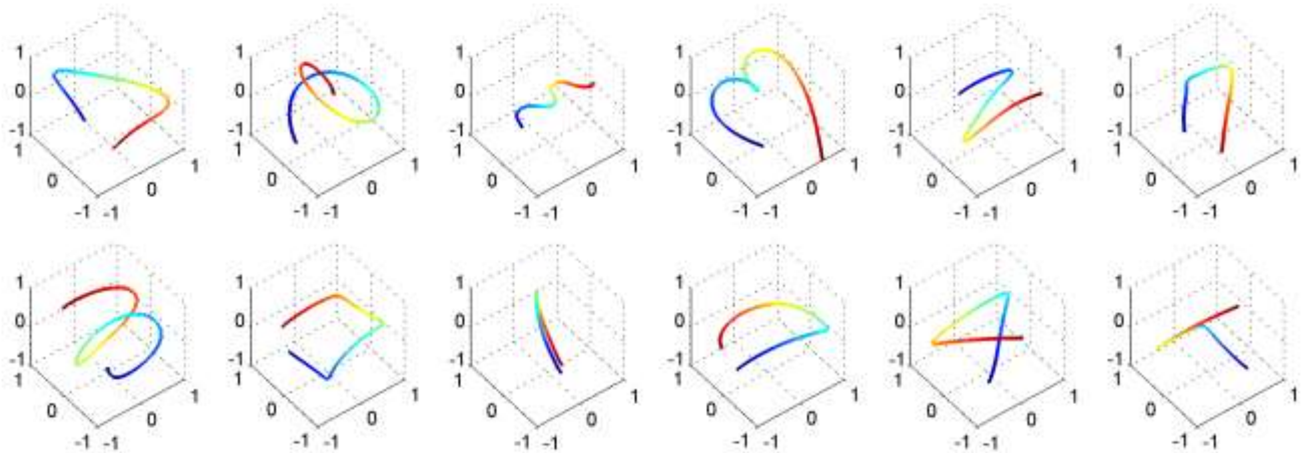
$$[f_1, f_2, f_3, \dots f_n]$$

- A broad range of alternatives
  - Hidden Markov Models [Chen et al. 2013]
  - Nearest Neighbors [Lai et al. 2012]
  - Support Vector Machines [Kela et al. 2006]

M. Chen, G. AlRegib, and B.-H. Juang. Feature Processing and Modeling for 6D Motion Gesture Recognition. IEEE Transactions on Multimedia, 15(3):561–571, 2013.
K. Lai, J. Konrad, and P. Ishwar. A Gesture-Driven Computer Interface Using Kinect. In IEEE Southwest Symposium on Image Analysis and Interpretation, pages 185–188, 2012.
J. Kela, P. Korpip¨a¨a, J. M¨antyj¨arvi, S. Kallio, G. Savino, L. Jozzo, and S. D. Marca. Accelerometer-Based Gesture Control for a Design Environment. Personal and Ubiquitous Comp., 10(5):285–299, 2006.

Template-based Classifiers

- Gesture characterization through a set of representative gestures



Sample Patterns

- Error minimization based on a distance function
    - Mean Square Error [Woobroock et al. 2007]
    - Angular Inverse Cosinus [Li 2010]
    - Dynamic Time Warping [Liu et al. 2009]

Design Guidelines

- Avoid disturbing the **interaction flow** of actions
- Prevent unnecessary **focus** of attention changes
- Avoid mode errors through unambiguous **feedback**
- Use appropriate spatial **reference** frame
- Consider using **multimodal** input

Virtual Reality and Multi-Sensory Interaction

Master Research in Computer Science (SIF)

Ferran Argelaguet

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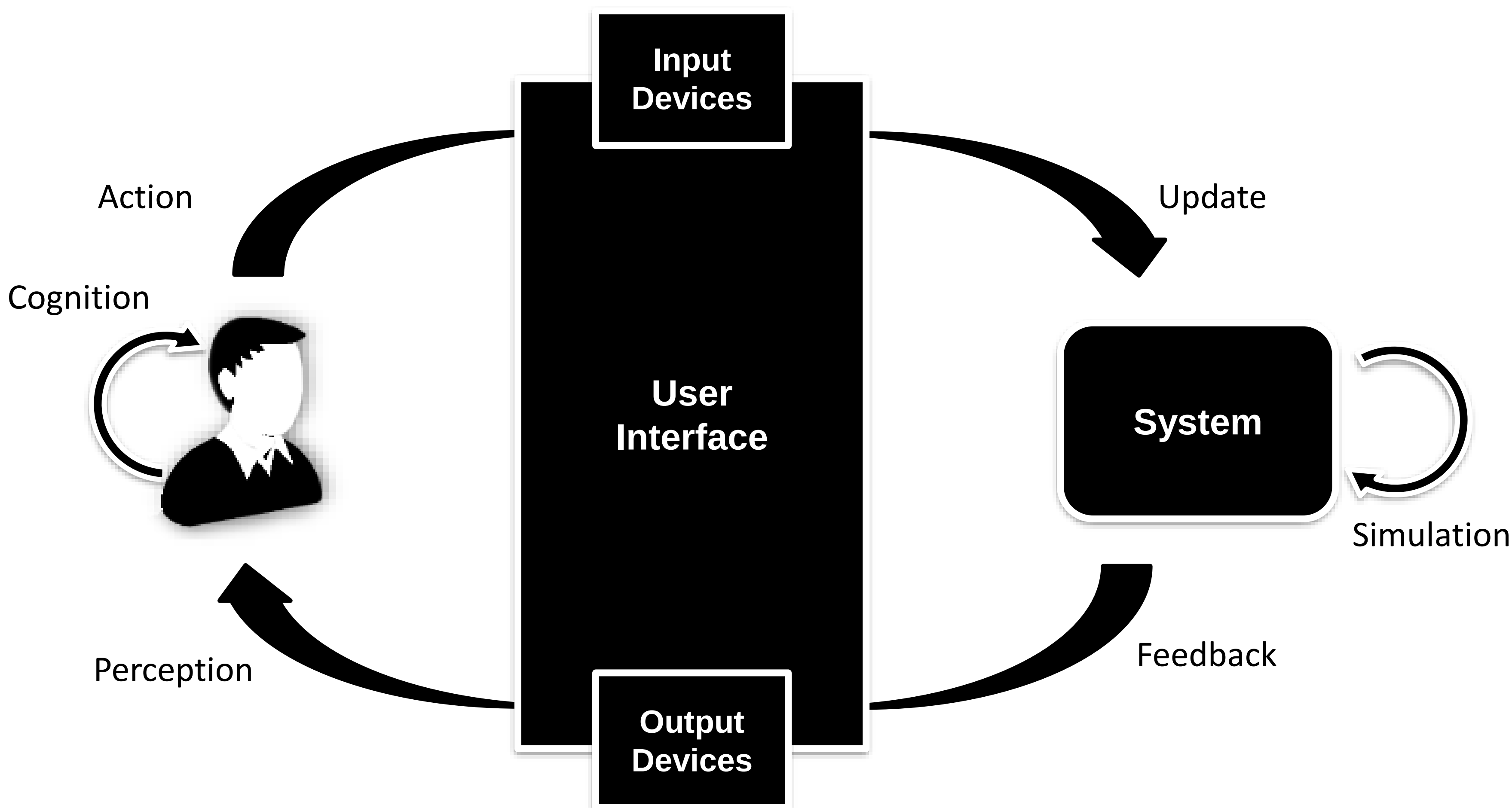
Contents

The Interaction Loop

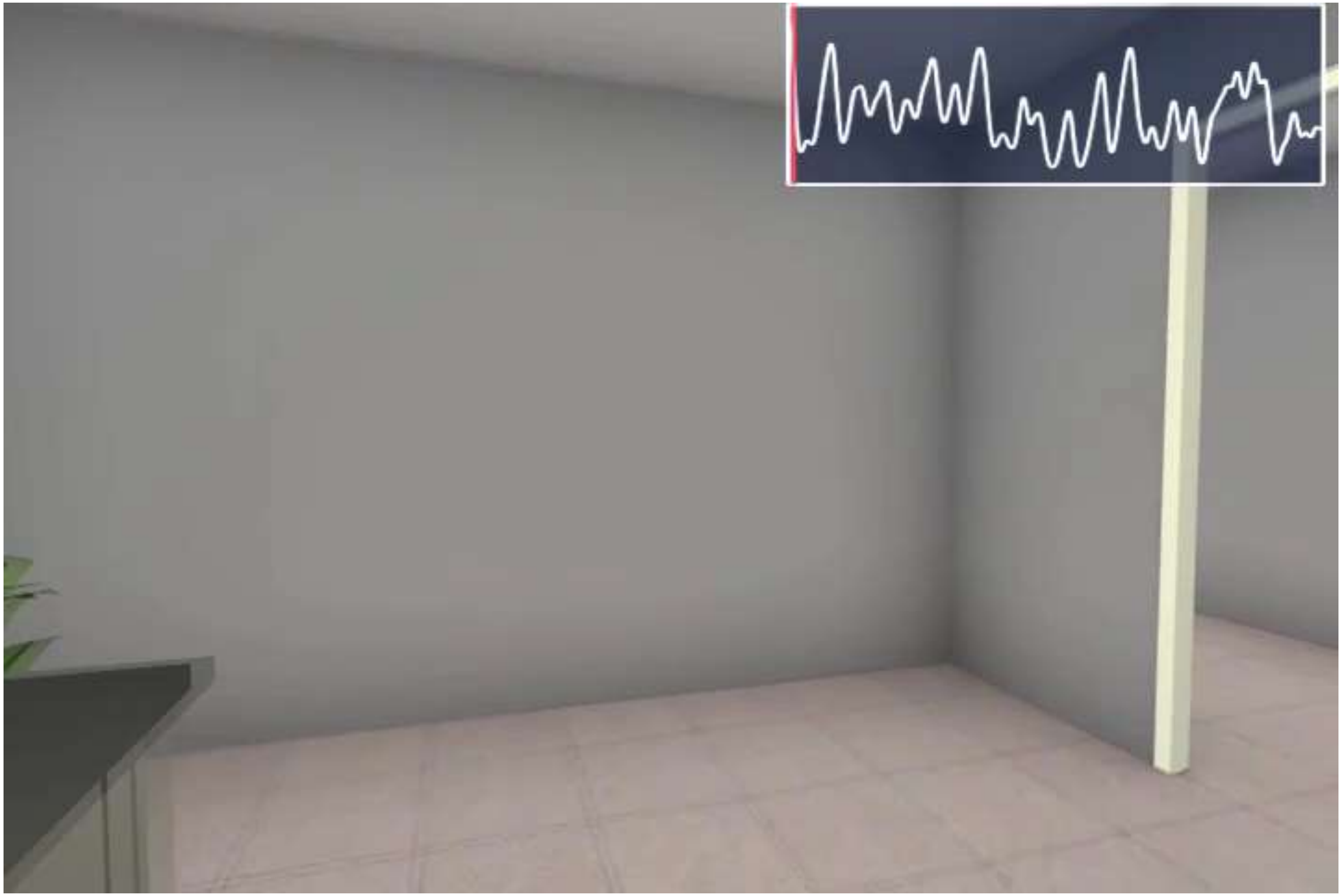


Navigation

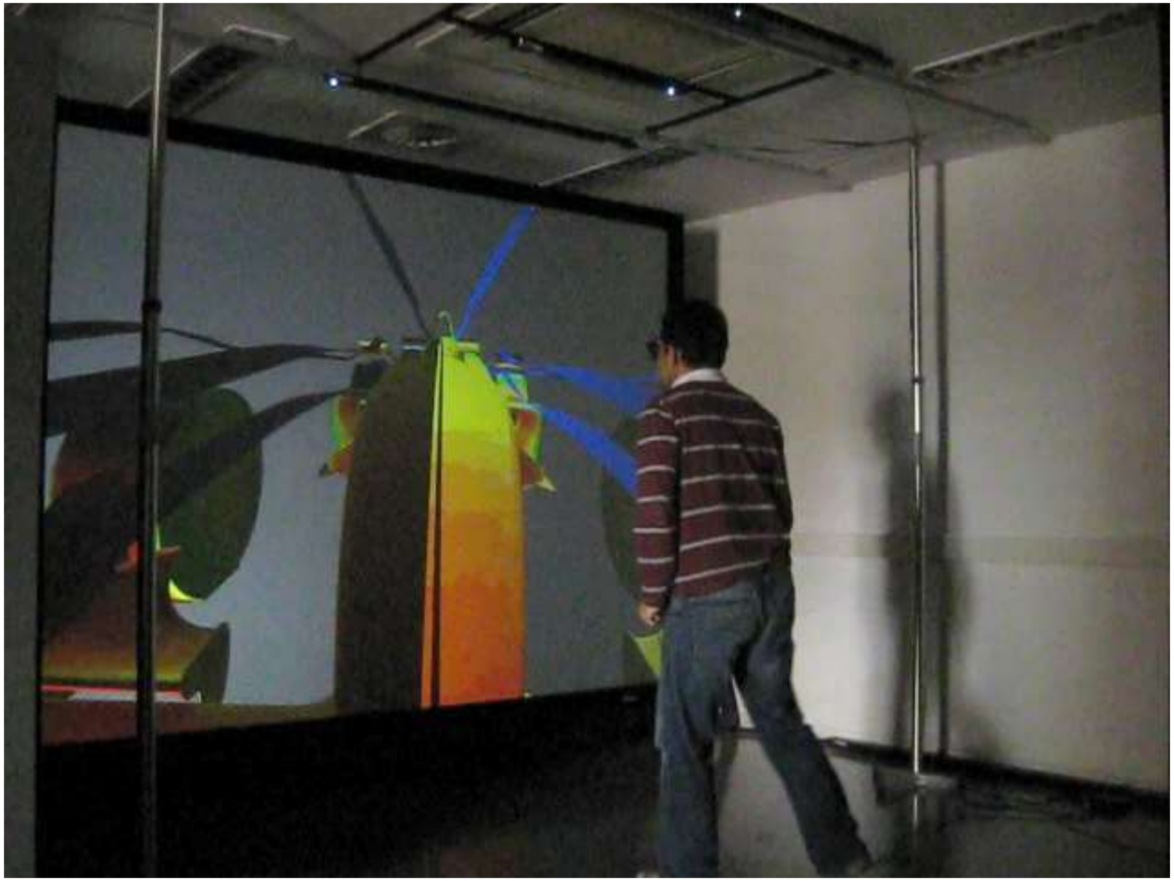
Goal of a navigation task?

- Continuous control of the virtual camera
  - Changes in the subjective view of the user

Example: Virtual Navigation

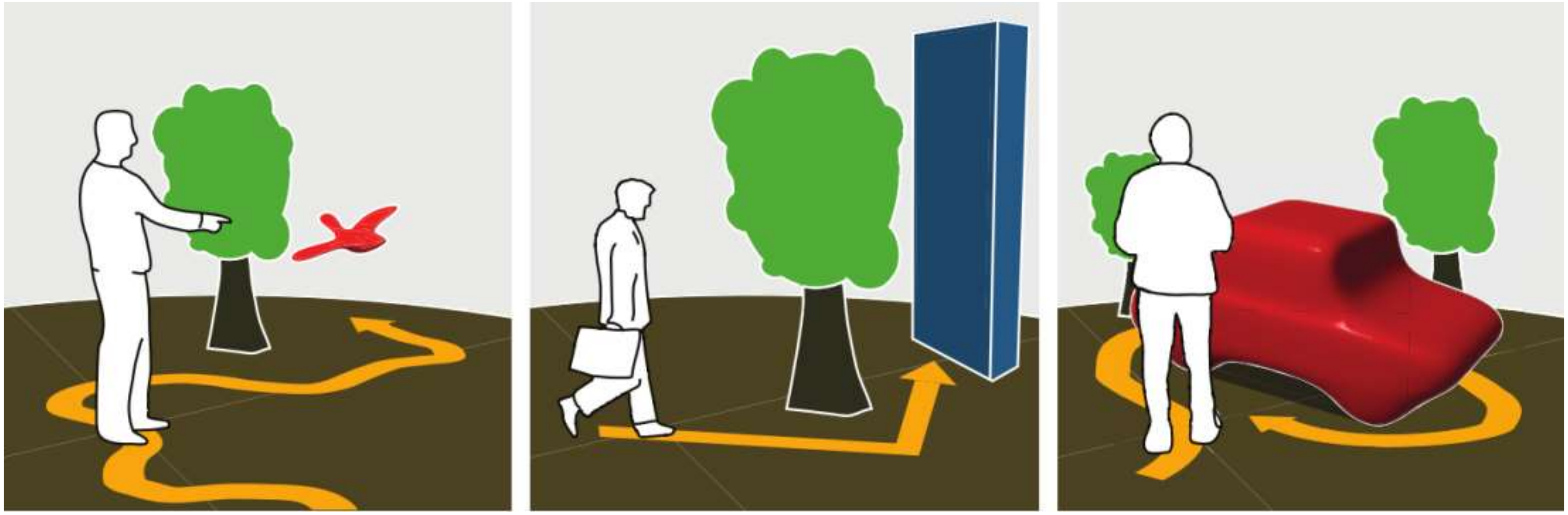


Example: Physical Navigation



Navigation Tasks

- Navigation involves two different **tasks**
  - Travel : motor component. Actions to move the user to a new target location or in the desired direction.
  - Wayfinding : cognitive component. Process of defining a path through a environment.



Exploration | Search | Maneuvering

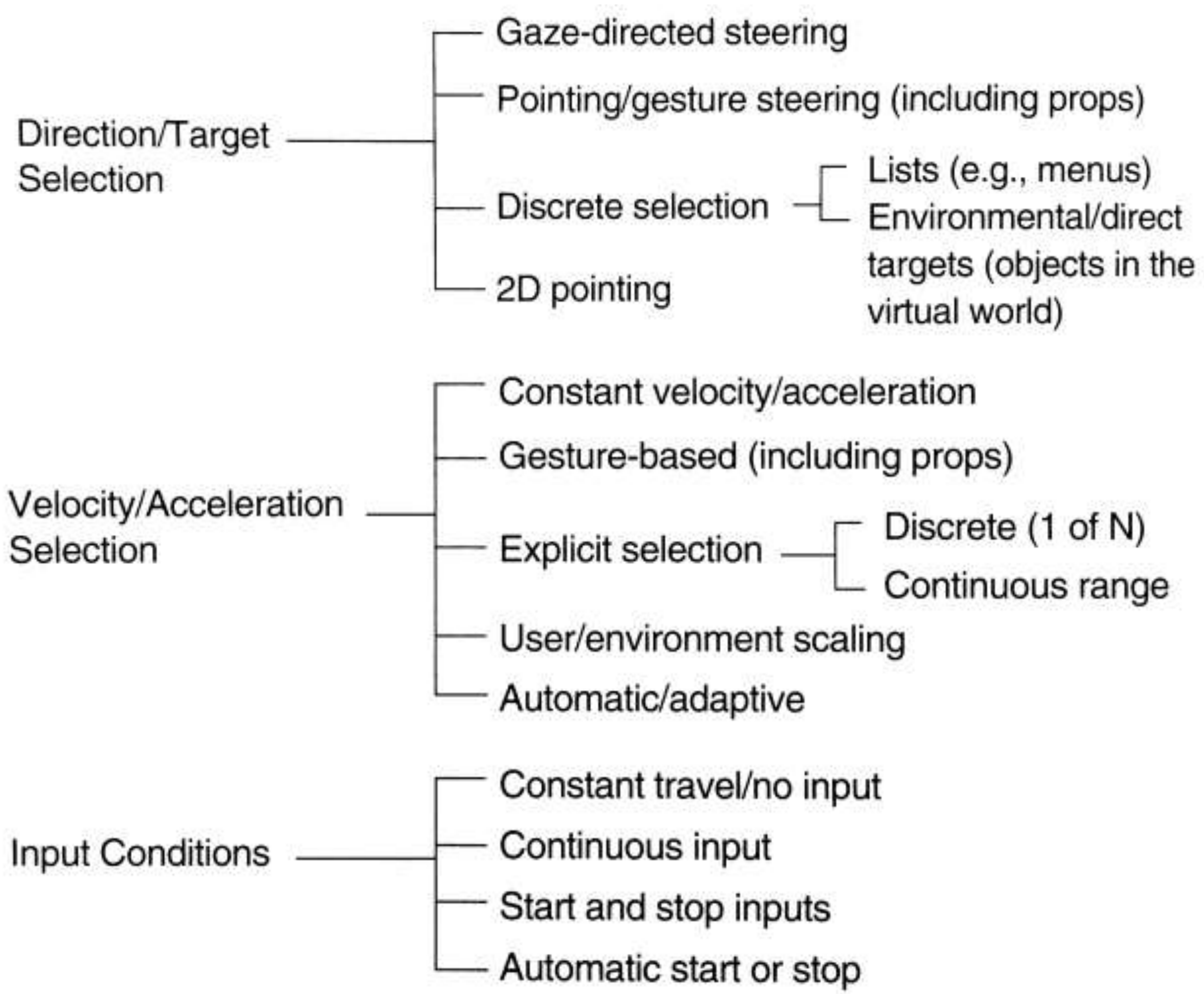
Kulik, A. (2009). Building on Realism and Magic for Designing 3D Interaction Techniques. IEEE Computer Graphics and Applications, 29(6), 22–33. https://doi.org/10.1109/MCG.2009.115

Navigation Tasks

- Navigation involves two different **tasks**
  - Travel : motor component. Actions to move the user to a new target location or in the desired direction.
  - Wayfinding : cognitive component. Process of defining a path through a environment.

- Travel tasks can be decomposed in three **sub-tasks**
  - Direction or target selection : *Where to move?*
  - Velocity and acceleration : *How fast?*
  - Conditions of input : *How travel is initiated, continued and terminated?*

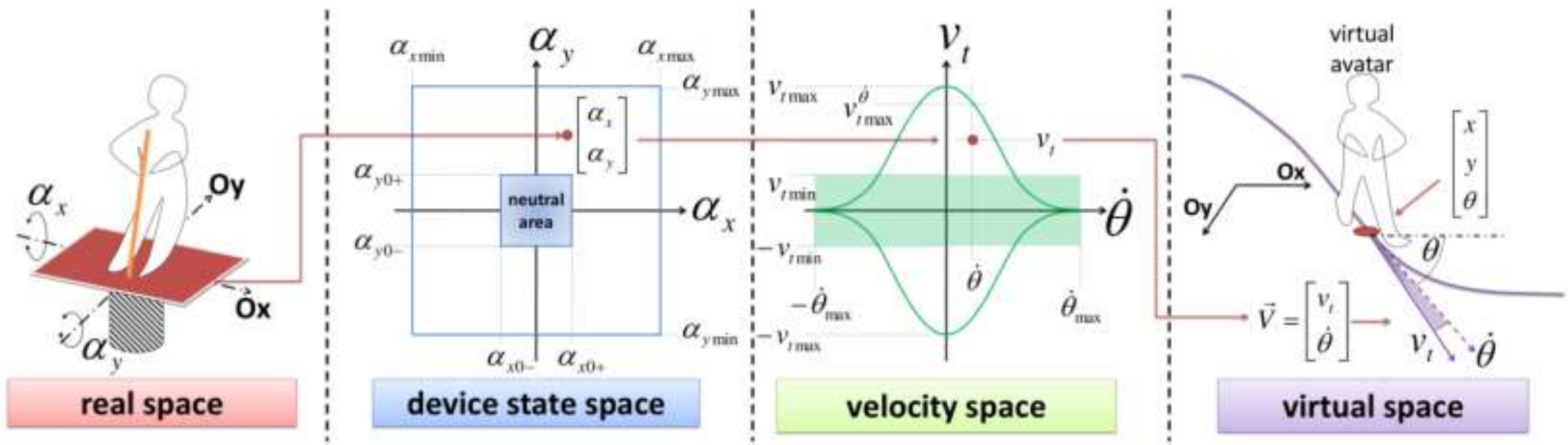
Travel Sub-tasks Overview



Bowman, D. A., Kruijff, E., LaViola, J. J., & Poupyrev, I. (2004). 3D User Interfaces: Theory and Practice. Addison Wesley.

Navigation Control Law

- The navigation control law interpretes users actions and updates the virtual camera motion accordingly



Marchal, M., Pettré, J., & Lécuyer, A. (2011). Joyman: A human-scale joystick for navigating in virtual worlds. In 2011 IEEE Symposium on 3D User Interfaces (3DUI) (pp. 19–26).

Classification of Navigation Techniques

1. User Control
2. User Motion
3. Metaphor-based
   - Locomotion techniques
   - Steering techniques
   - Manual manipulation techniques
   - Route-planning techniques

Travel Task Classification (I)

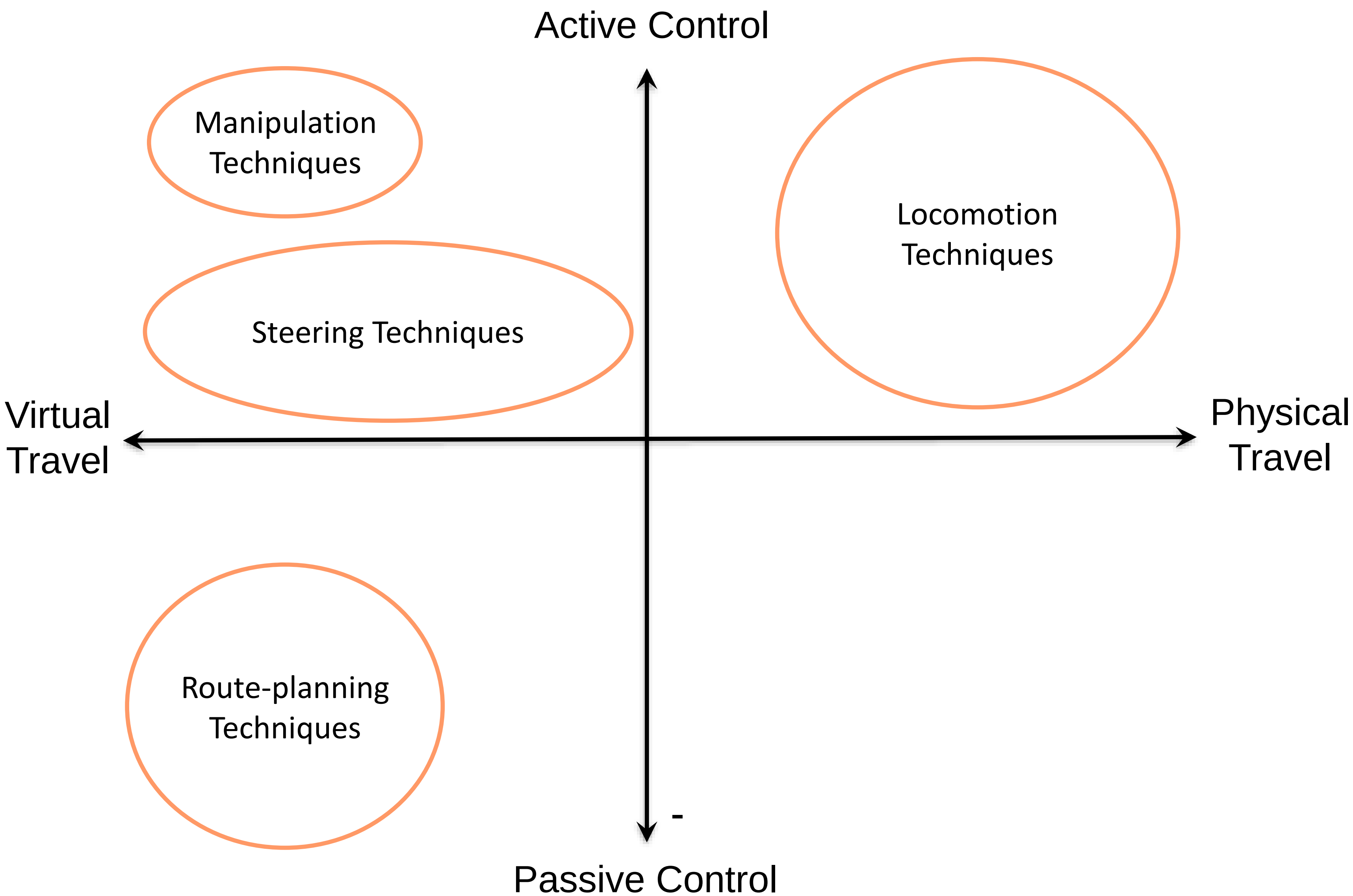
- User Control
  - **Active**: viewpoint movement is controlled by the user.
  - **Passive**: viewpoint movement is controlled by the system.
  - **Hybrid**: route planning
    - Users plan the path and the system follows it.

Travel Task Classification (II)

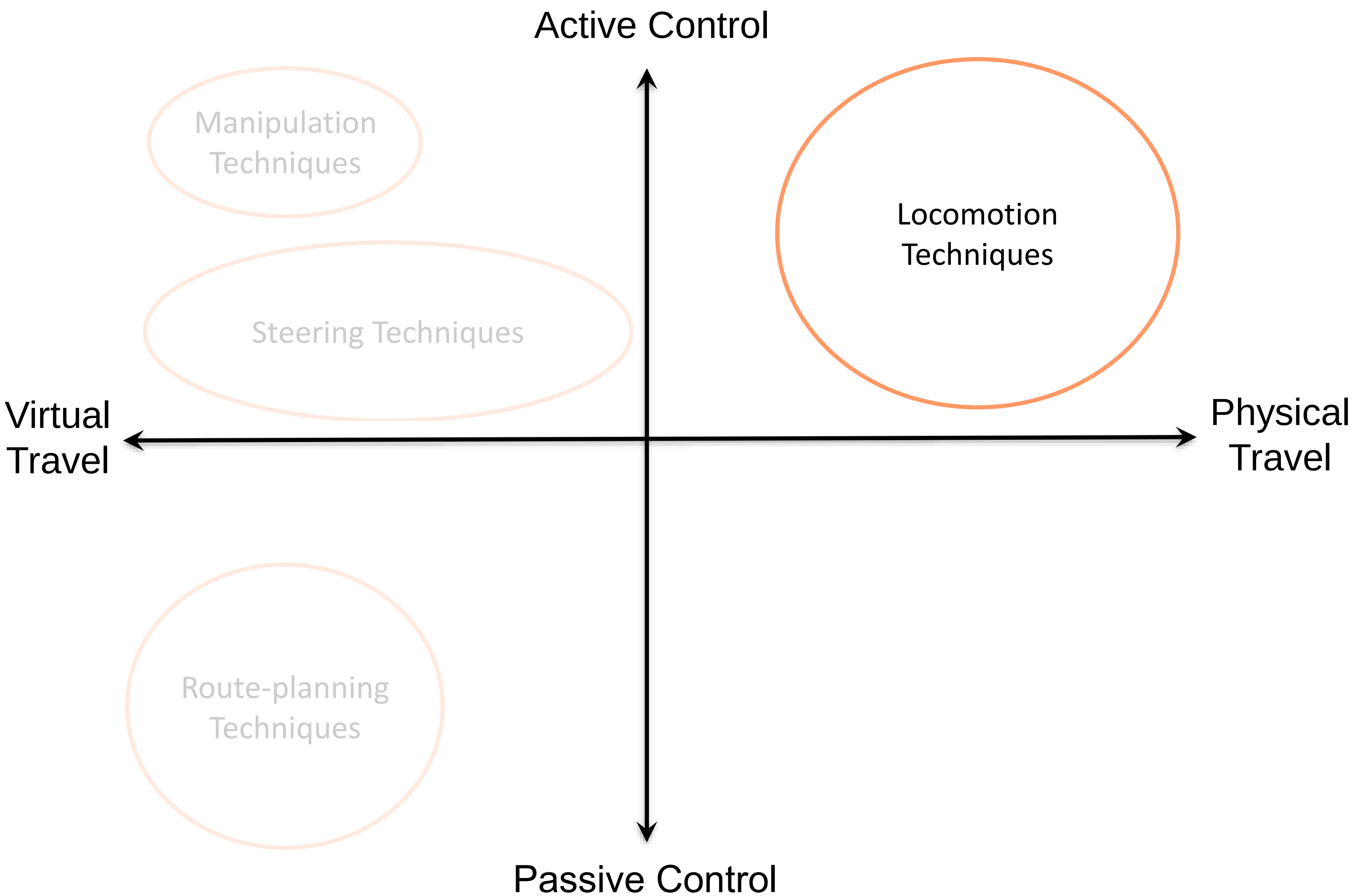
- User Motion
  - **Physical travel**: mimic the motions of the real world
    - The user's body physically translate or rotates
    - Travel is constrained by the tracked space
  - **Virtual travel**: the virtual environment moves
    - User's body remains stationary. Head motion and rotation is supported.
    - Visual motion cues are provided, but not vestibular cues

https://www.youtube.com/watch?v=8YB1NUSIGpk

Classification of Navigation Techniques



Classification of Navigation Techniques



Physical locomotion techniques

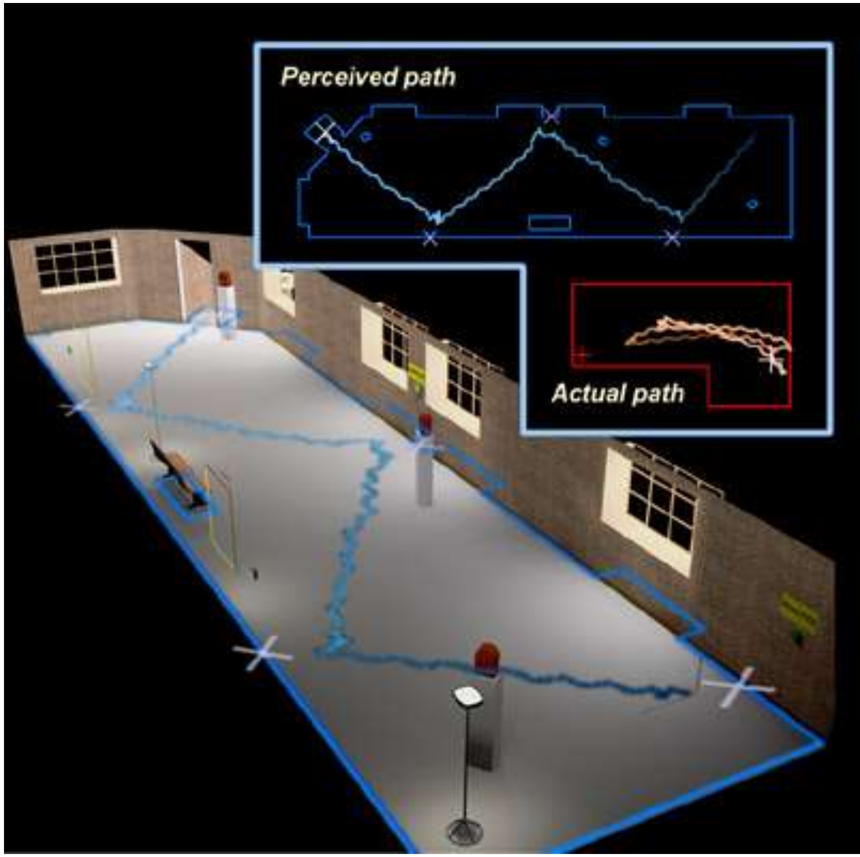
- Use the user's **physical exertion** to transport himself through the virtual world
- Mimic a **natural** method of locomotion and exploration in the real world
- Four main techniques
  - Walking
  - Redirected walking
  - Walking in place
  - Direct Manipulation

Walking

- **Interface** : User legs
- **Input mapping** : isomorphic
- **Degrees of Freedom** : 6 DoFs
- **Benefits**
  - Easy to use
  - Provides vestibular cues
- **Limitations**
  - Size of the real environment and the range of the tracking system must be greater than the virtual environment
  - Cables are an important issue
  - Users are lazy

Redirected Walking

- **Interface**: User legs
- **Input mapping**: Anisomorphic
- **Degrees of Freedom**: 6 DoFs
- **Benefits**
  - Easy to use
  - Provides vestibular cues
- **Limitations**
  - Still requires a large tracked area
  - Cables are an important issue
  - Users are lazy
  - Suited for HMD-based setups



Redirected Walking

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Redirected Walking

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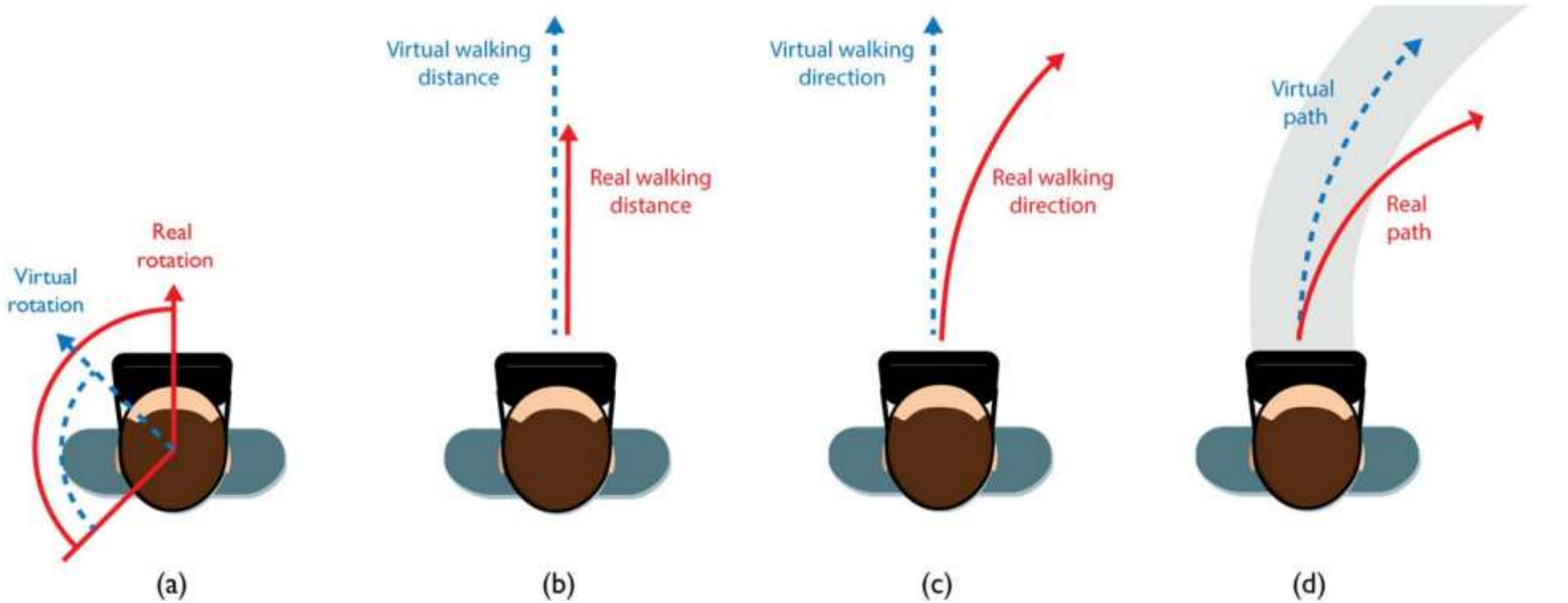
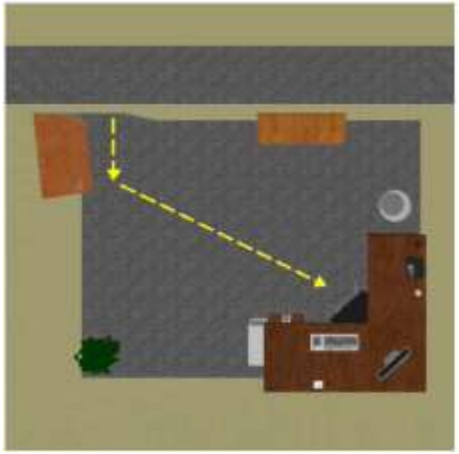
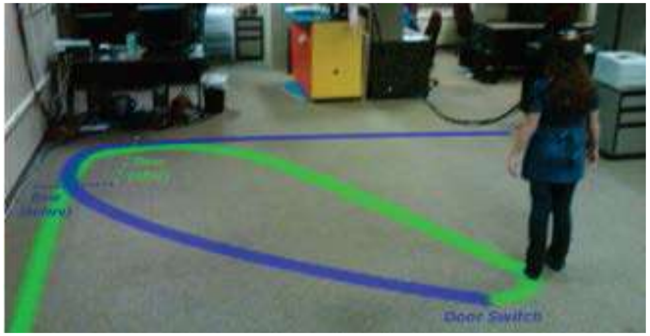


Impossible Spaces



- **Interface**: User legs
- **Input mapping**: Isomorphic
- **Degrees of Freedom**: 6 DoFs
- **Benefits**
  - Easy to use
  - Provides vestibular cues
- **Limitations**
  - Still requires a large tracked area
  - Cables are an important issue
  - Users are lazy
  - Suited only HMD-based setups
  - Users can perceive that the virtual environment is “impossible”



Walking in Place

- **Interface**: User legs
- **Input mapping**: Isomorphic /Anisomorphic
- **Degrees of Freedom**: 6 DoFs / constrained
- **Benefits**
  - No need for a large physical environment.
  - Moderate amount of vestibular cues
- **Limitations**
  - Not as effective as real walking
  - Users are lazy

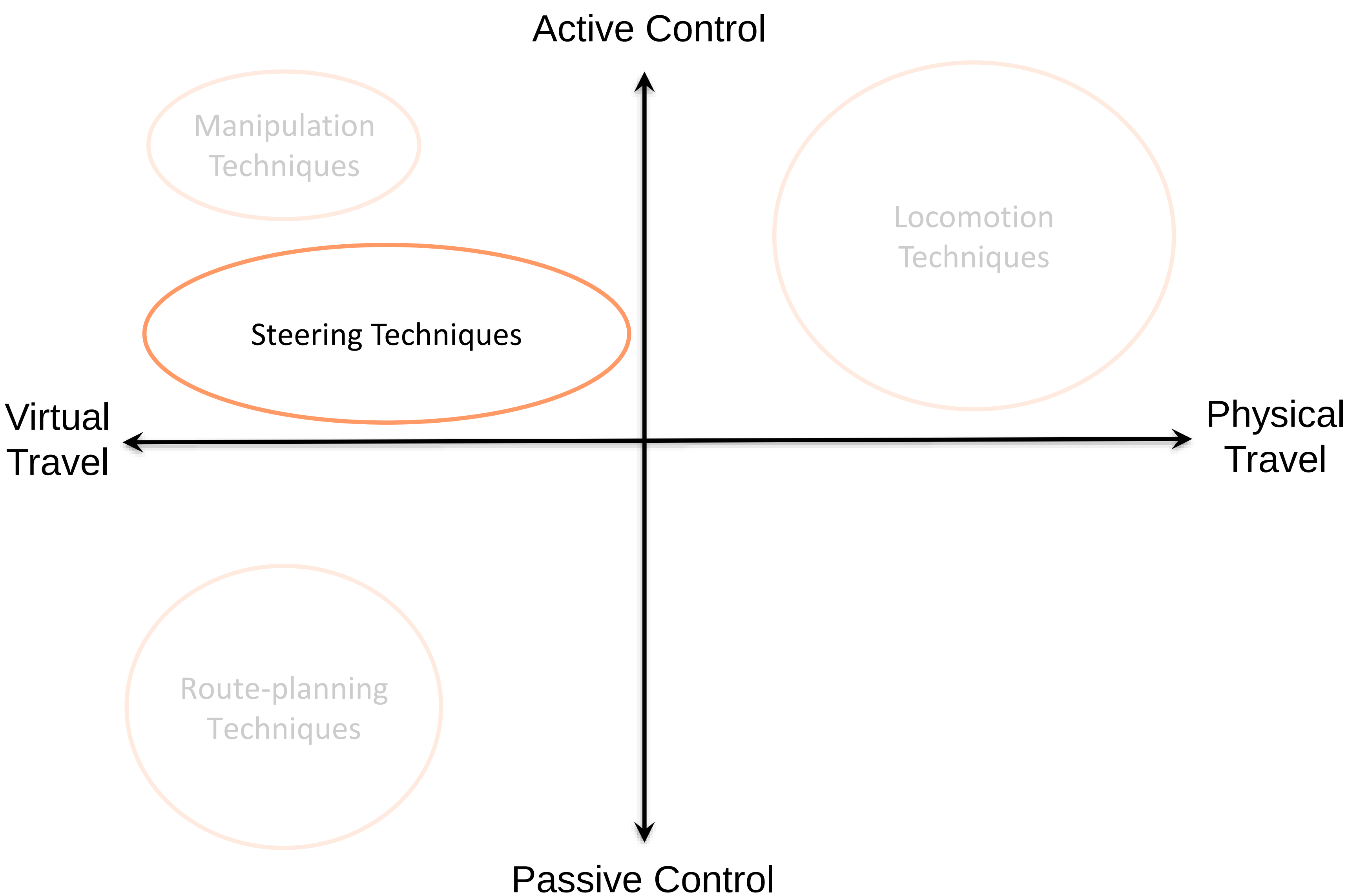
Walking in Place

- **Interface**: User legs
- **Input mapping**: Isomorphic /Anisomorphic
- **Degrees of Freedom**: 6 DoFs / constrained
- **Benefits**
  - No need for a large physical environment.
  - Moderate amount of vestibular cues
- **Limitations**
  - Not as effective as real walking
  - Users are lazy
  - **Need of an external device**

(Moon)Walking in Place

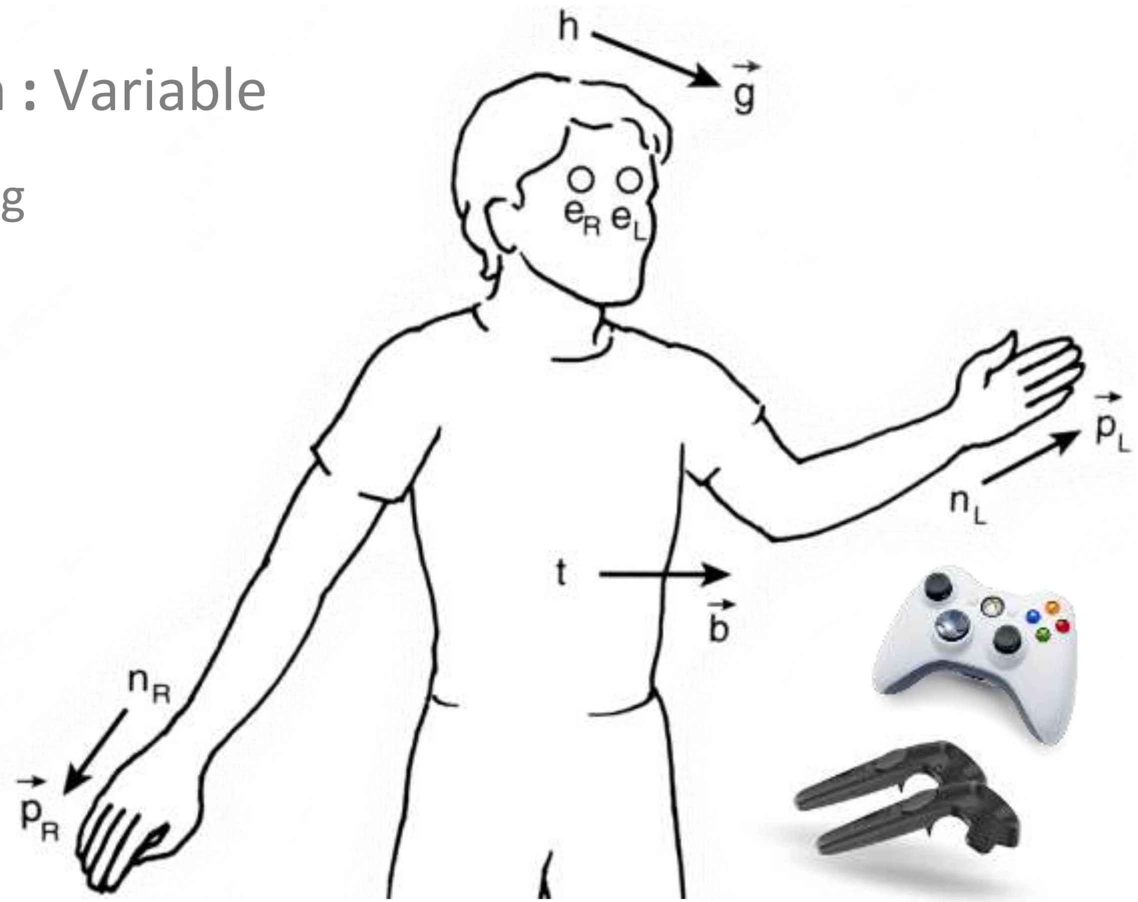
- **Interface**: User legs
- **Input mapping**: Isomorphic /Anisomorphic
- **Degrees of Freedom**: 6 DoFs / constrained
- **Benefits**
  - No need for a large physical environment.
  - Moderate amount of vestibular cues
- **Limitations**
  - Not as effective as real walking
  - Users are lazy
  - **Need of an external device**

Classification of Navigation Techniques



Steering Techniques

- **Interface:** Variable
- **Input Mapping**: Variable
- **Degrees of Freedom :** Variable
  - Gaze-Directed Steering
  - Pointing
  - Torso-Directed
  - Camera-in-Hand



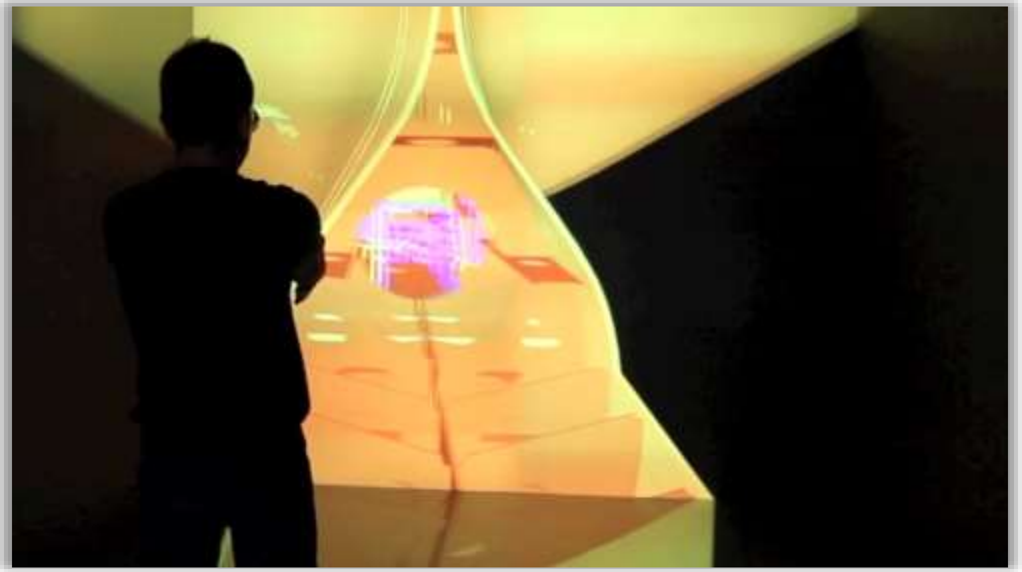
Steering Techniques

➢ Benefits

- No need for a large physical environment
- For lazy users
- No need for additional devices

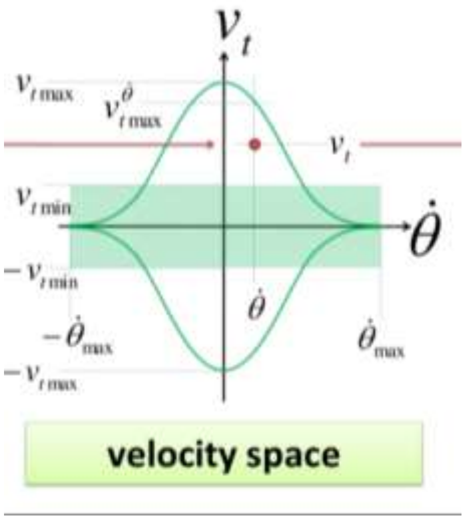
➢ Limitations

- Increased cue-conflict



Example: Joyman

- **Interface**: The Joyman
- **Degrees of Freedom** : 2DoF
- **Input Mapping**: Anisomorphic
  - Tangential speed dependent on the angular speed
  - Speed adjusted according usual human walking speeds.



Marchal, M., Pettré, J., & Lécuyer, A. (2011). Joyman: A human-scale joystick for navigating in virtual worlds. In 2011 IEEE Symposium on 3D User Interfaces (3DUI) (pp. 19–26).

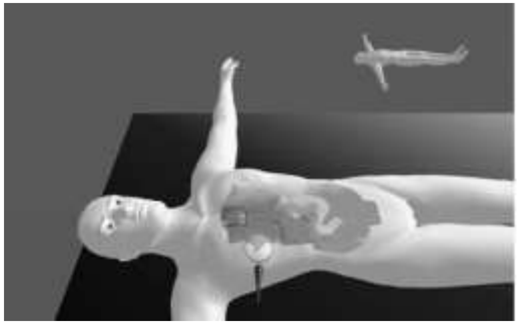
Example: Multi-Scale Navigation

- The **navigation speed** has to be adjusted to ensure that the user can freely navigate as efficient and comfortable as possible
  - Avoid simulation sickness due to fast motions
  - Avoid boredom due to slow motion

- The **relative size** of the user hast to be adjusted to ensure that the perception of the virtual environment is optimal:
  - Diplopia (e.g. when zooming in)
  - Diminished depth perception (e.g. when zooming out)

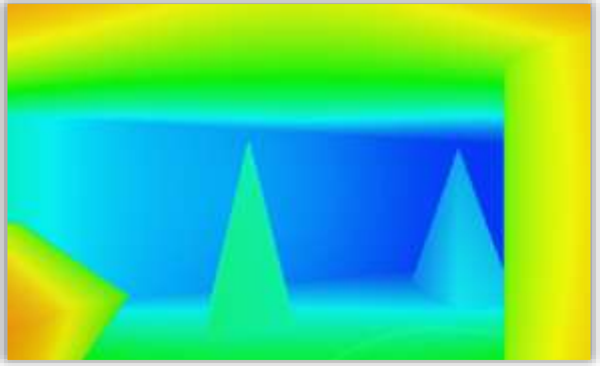
Navigation Speed Adaptation

- Discrete (*manual*) techniques
  - Magnifying glass metaphor
  - Landmark-based



Magnifying glass

- Continuous (*automatic*) Techniques
  - Depth-map
  - Depth-cubemap
  - Optical flow
  - Viewpoint quality

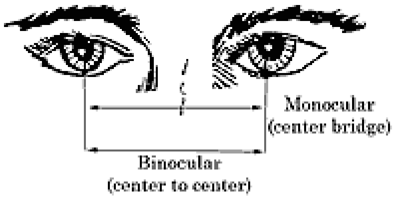


Optical Flow Map

WARE, C., AND FLEET, D. 1997. Context sensitive flying interface. In Symposium on Interactive 3D graphics (SI3D), 127–ff.
MCCRAE, J., MORDATCH, I., GLUECK, M., AND KHAN, A. 2009. Multiscale 3D navigation. In Symposium on Interactive 3D Graphics and Games, 7–14.
FREITAG, S., WEYERS, B., AND KUHLEN, T. W. 2016. Automatic speed adjustment for travel through immersive virtual environments based on viewpoint quality. In IEEE Symposium on 3D User Interfaces, 67–70.

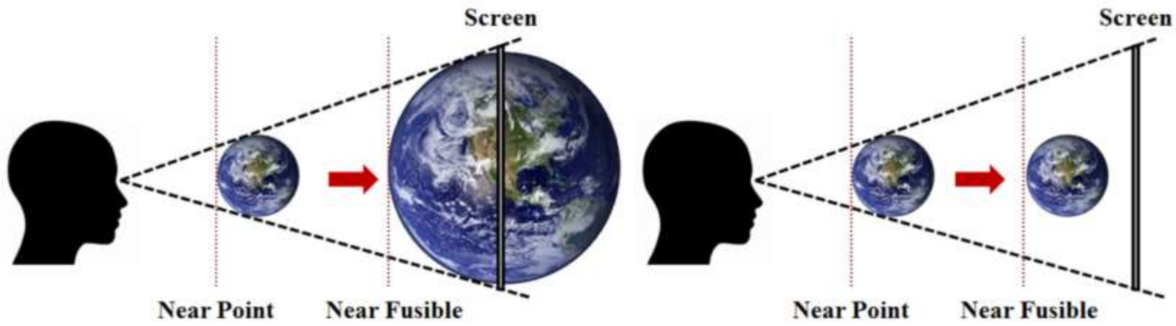
Users' Relative Size Adaptation

- IPD adjustment based on depth information



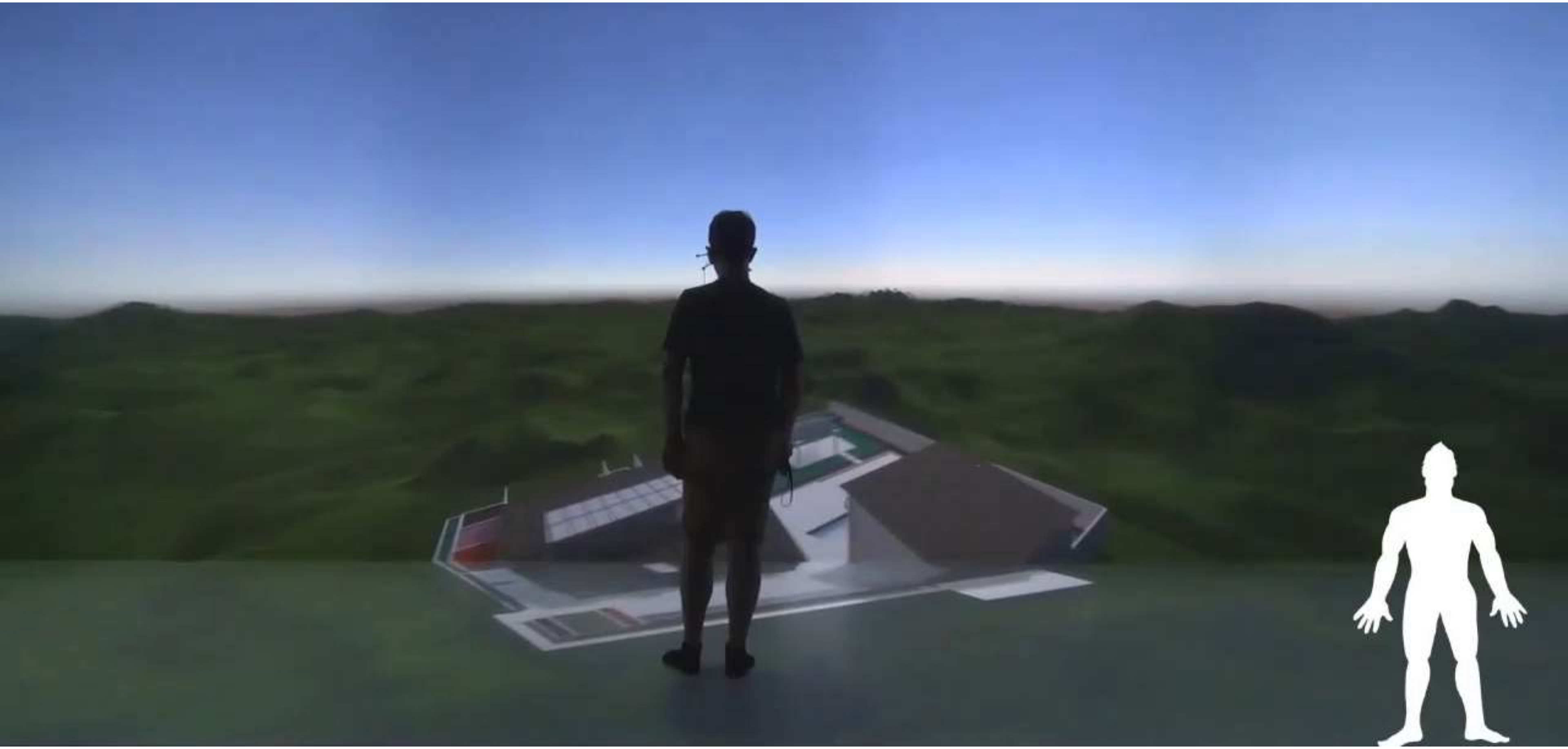
$$IPD = d_{min} \cdot k_{IPD}$$

- Depth range adjustment based on the distance between the user and the VE



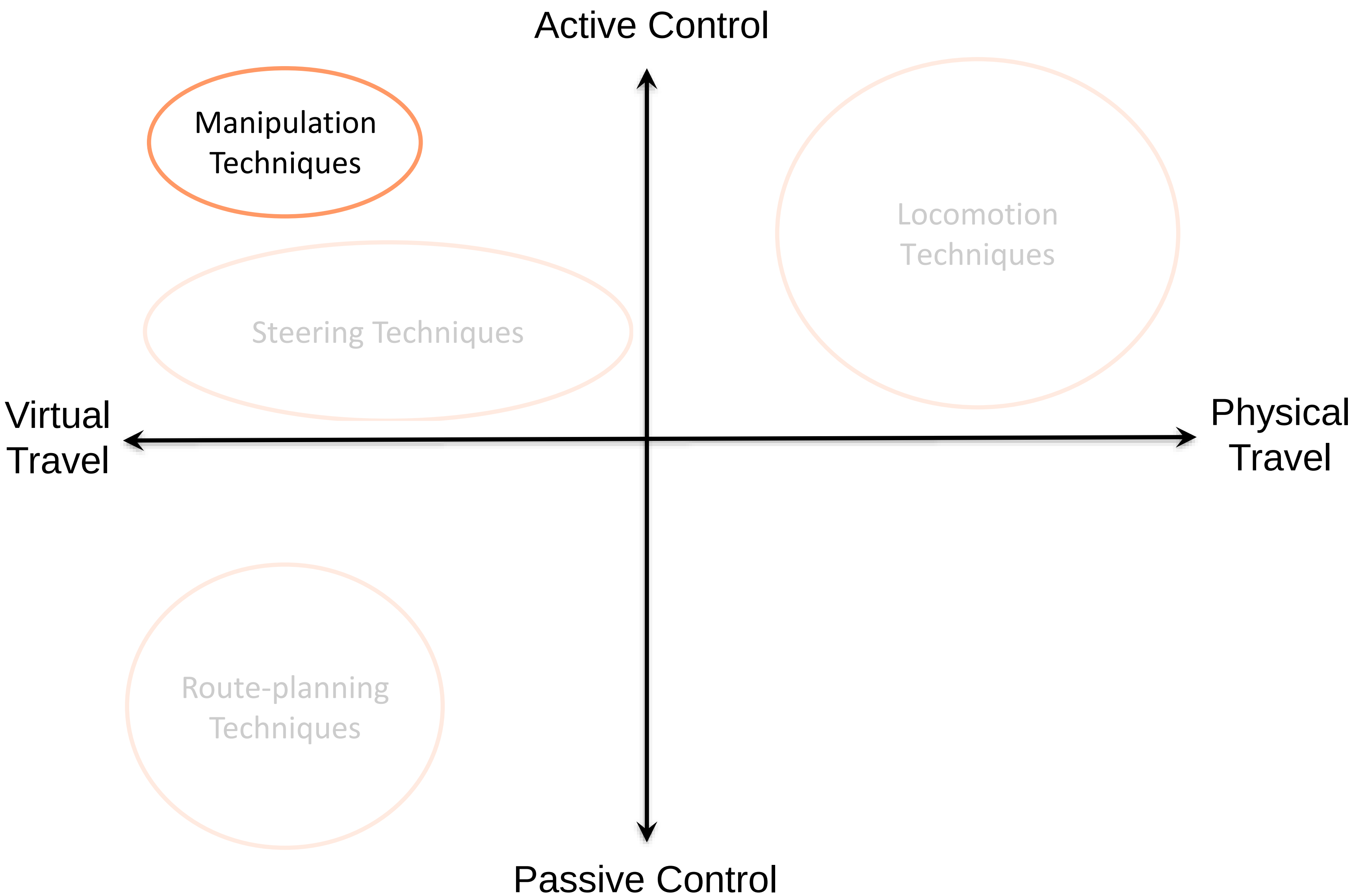
CHO, I., LI, J., AND WARTELL, Z. 2014. Evaluating dynamic adjustment of stereo view parameters in a multi-scale virtual environment. 91–98.

GiAnt Navigation



Argelaguet, F, and Maignant, M. "GiAnt: stereoscopic-compliant multi-scale navigation in VEs." *Proceedings of the 22nd ACM Conference on Virtual Reality Software and Technology*. ACM, 2016.

Classification of Navigation Techniques



Manipulation-Based Navigation

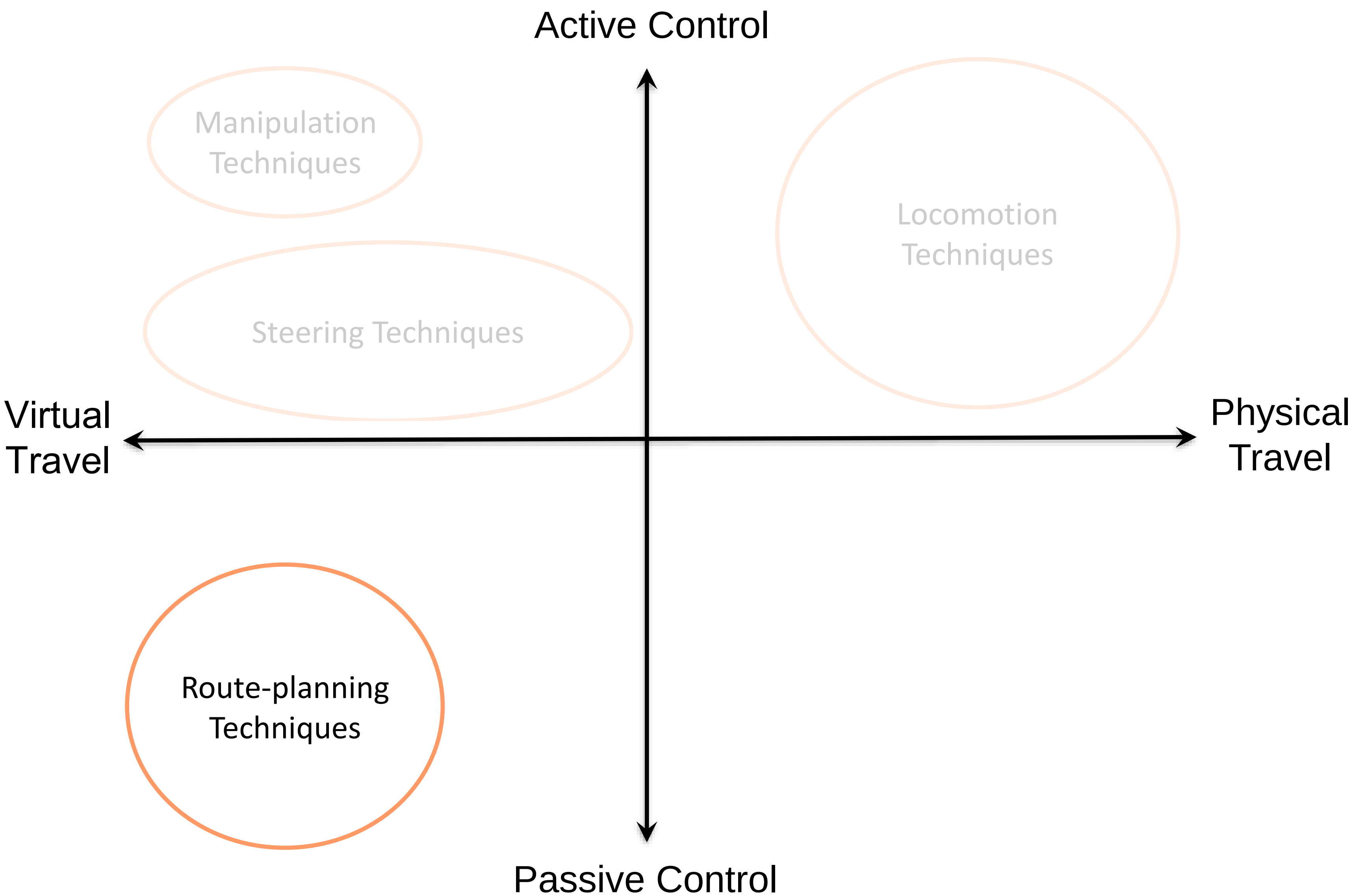
Use an object manipulation metaphor to control the viewpoint

- **Grabbing** the air (the entire world is viewed as an object to be manipulated.
- **Orbiting**. Fixed-object manipulation
  - The user selects an object
  - The viewpoint is moved relative to the object

Manipulation-Based Navigation

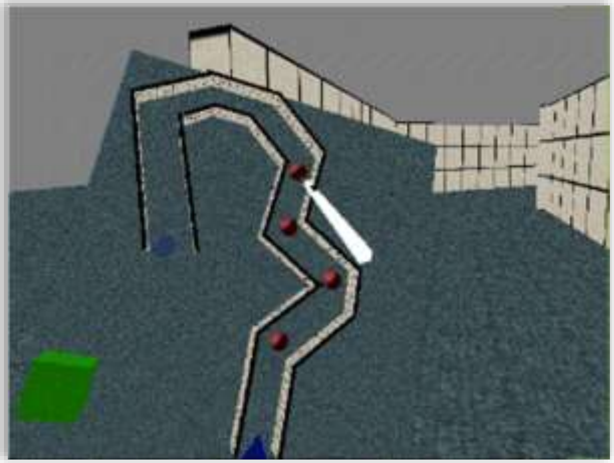
CHO, I., LI, J., AND WARTELL, Z. 2014. Evaluating dynamic adjustment of stereo view parameters in a multi-scale virtual environment. 91–98.
https://www.youtube.com/watch?v=GkirY8DPh84

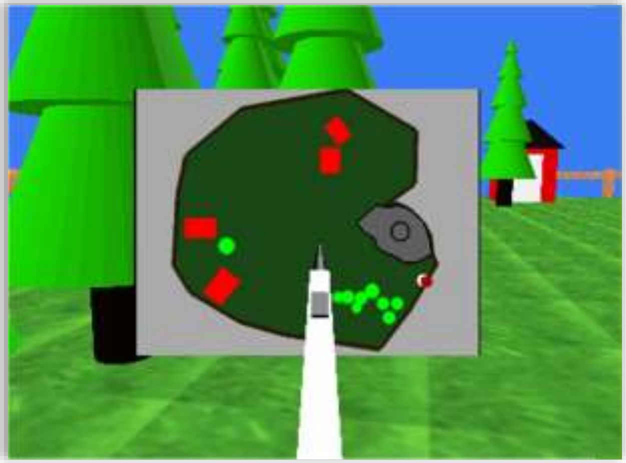
Classification of Navigation Techniques



Map Based Techniques

- Plan the **route** using a map
  - Drawing a path
  - Marking points along the path
- Select the desired **destination** in the map
- Requires an interface to manipulate a 2D map or a virtual replica





Design Guidelines

- **Distance** to be traveled
  - Short-range: using natural physical motion only
  - Medium-range: virtual travel technique
  - Large-range: speed adaptation and “teleportation”
- **DoFs** required for the movement (walk vs fly)
  - Required **accuracy** (exploration vs maneuvering)
- Use **multiple** travel techniques to support different travel tasks
  - E.g. precise maneuvering tasks will benefit from **head tracking**
- Other **primary tasks** that take place during the travel
  - Information gathering
  - Keep a low user cognitive load. The user would like to focus elsewhere.
- Visibility of the target **destination**

Wrap-up

Contents