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Design Lenses for 3D User Interface in Extended Reality

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“Any sufficiently advanced technology is indistinguishable from magic.”

- Arthur C. Clarke

My work presents a systematic and practical approach to the design and development of user interfaces and user interactions in XR that feel like Clarke’s magic.

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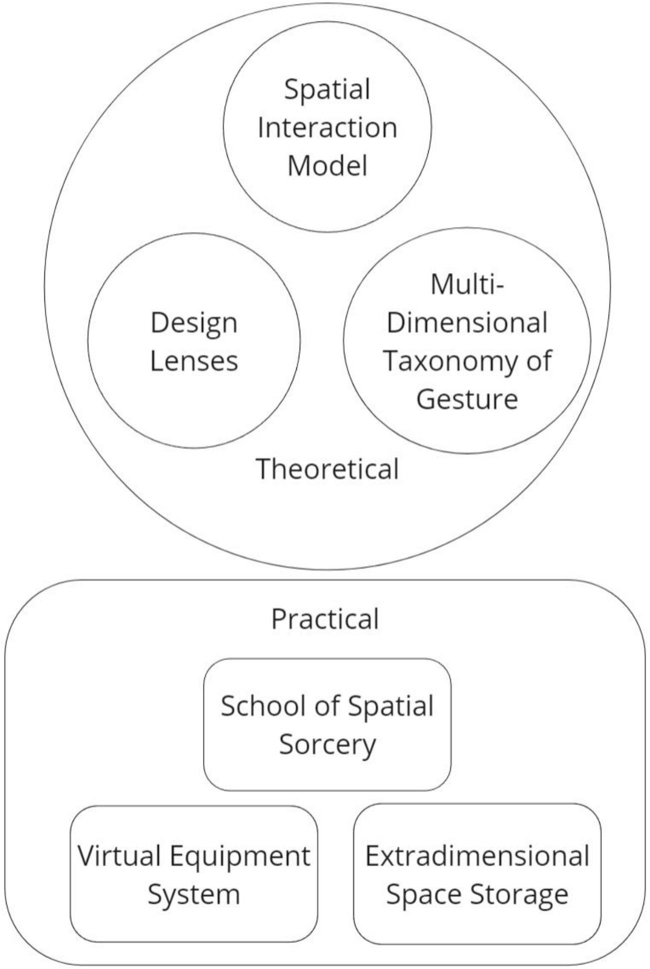
Body of Work



Introduction

- Extended Reality (XR)
- XR Qualities
- State of XR
- Existing Approach
- Problems
- Approach

Reality-Virtuality Continuum

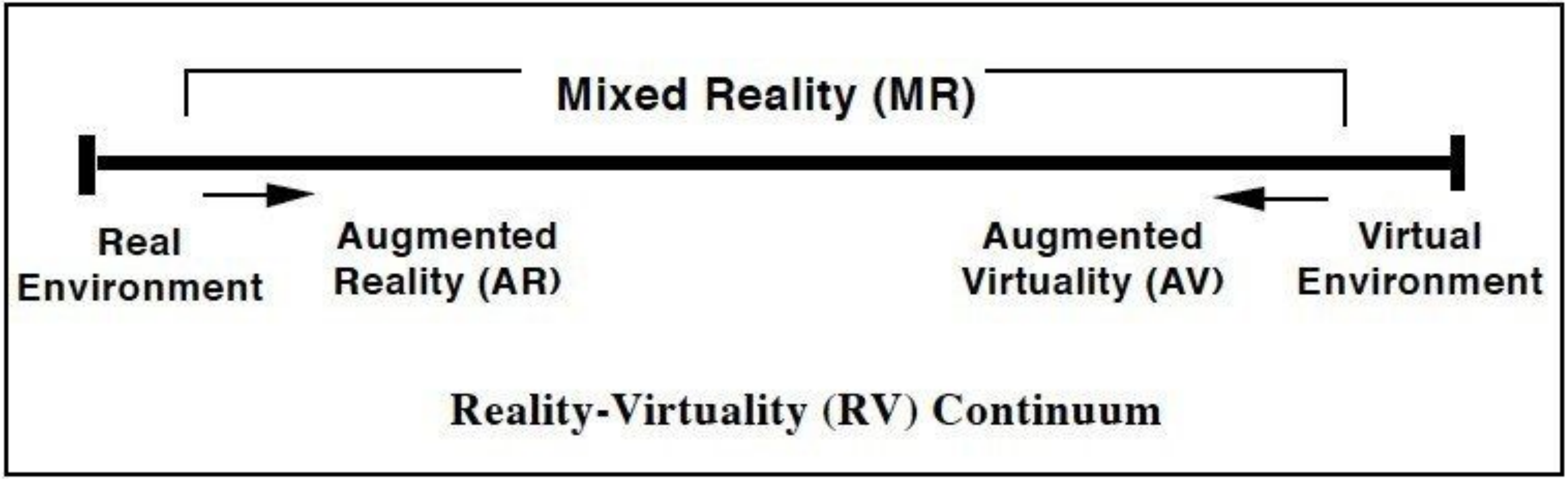


Figure: Reality-Virtuality (RV) Continuum diagram

P. Milgram, H. Takemura, A. Utsumi, and F. Kishino, “Augmented reality: A class of displays on the reality-virtuality continuum,” 1995, vol. 2351, pp. 282–292.

Extended Reality (XR)

AR

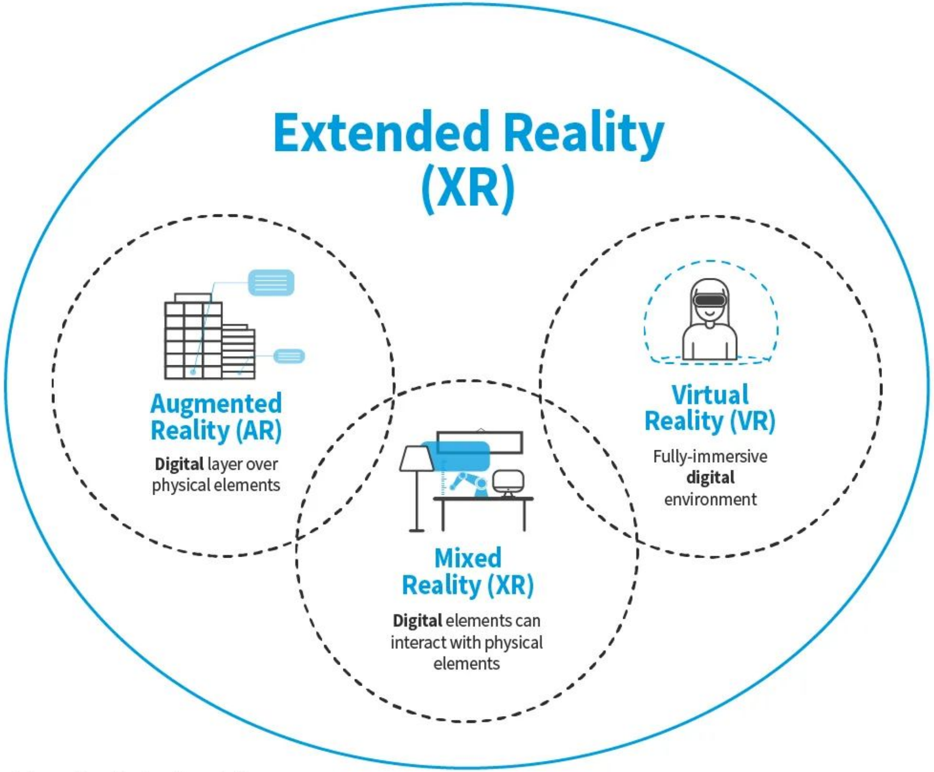
VR

MR

XR

Extended Reality (XR)

Umbrella term that encompasses any sort of technology that alters reality by addding digital elements to the physical or real-world environment by any extent.



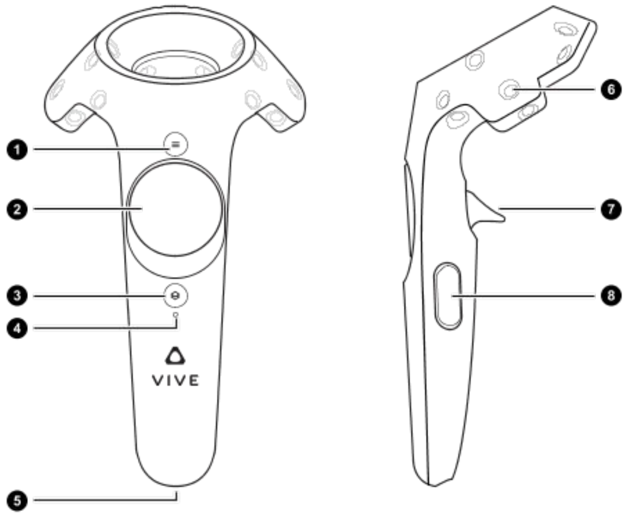
Interaction Design Foundation
interaction-design.org

XR Qualities

- 3D Spatial Interaction
- Objects are part of the interaction environment (as interactors or interactables)
- Users are part of the interaction environment
- Many Contexts

3D Spatial Interaction

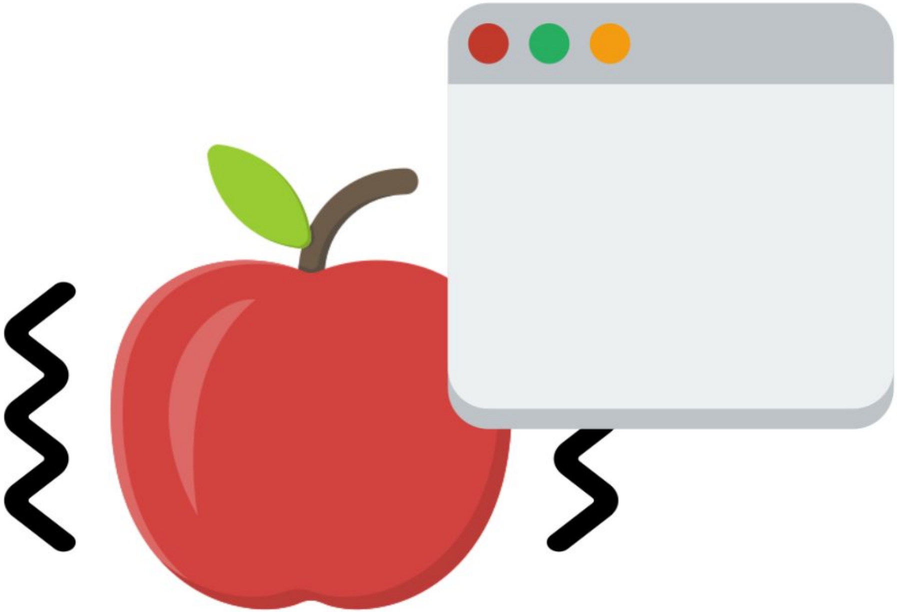
With Motion Controllers or technology to track the user's body, 3D spatial interaction is a staple in XR



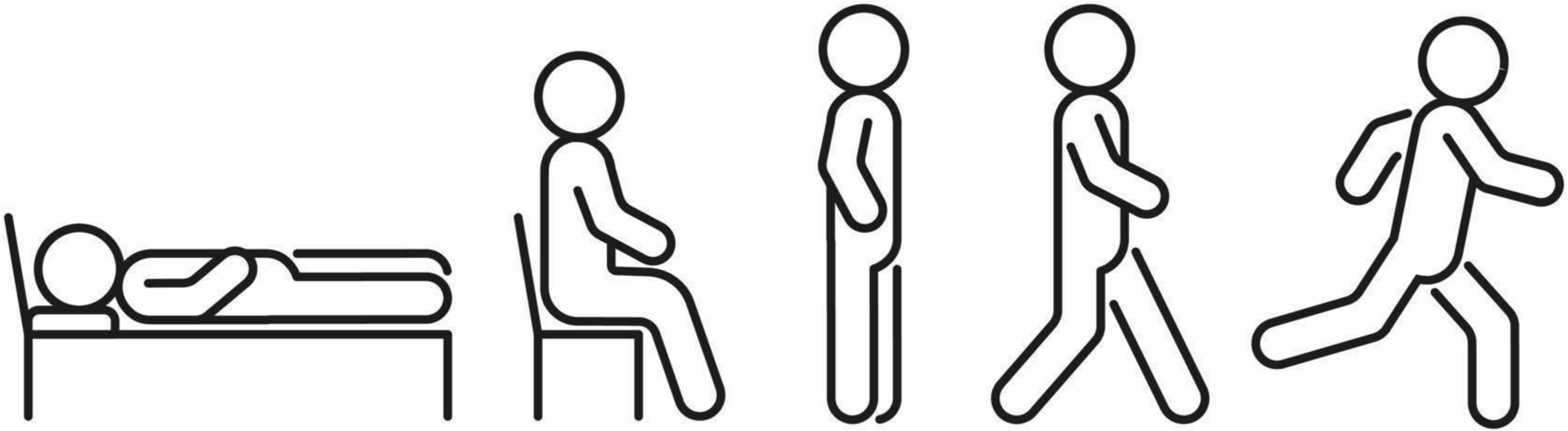
Objects are part of interaction environment (as Interactors or Interactables)

An object, whether physical or virtual, can be tracked in XR.

The apple can be an interactor.



User as part of the environment: Physical Space & Postures



Mobile Augmented Reality: Walking, Riding Vehicles, Driving Vehicles

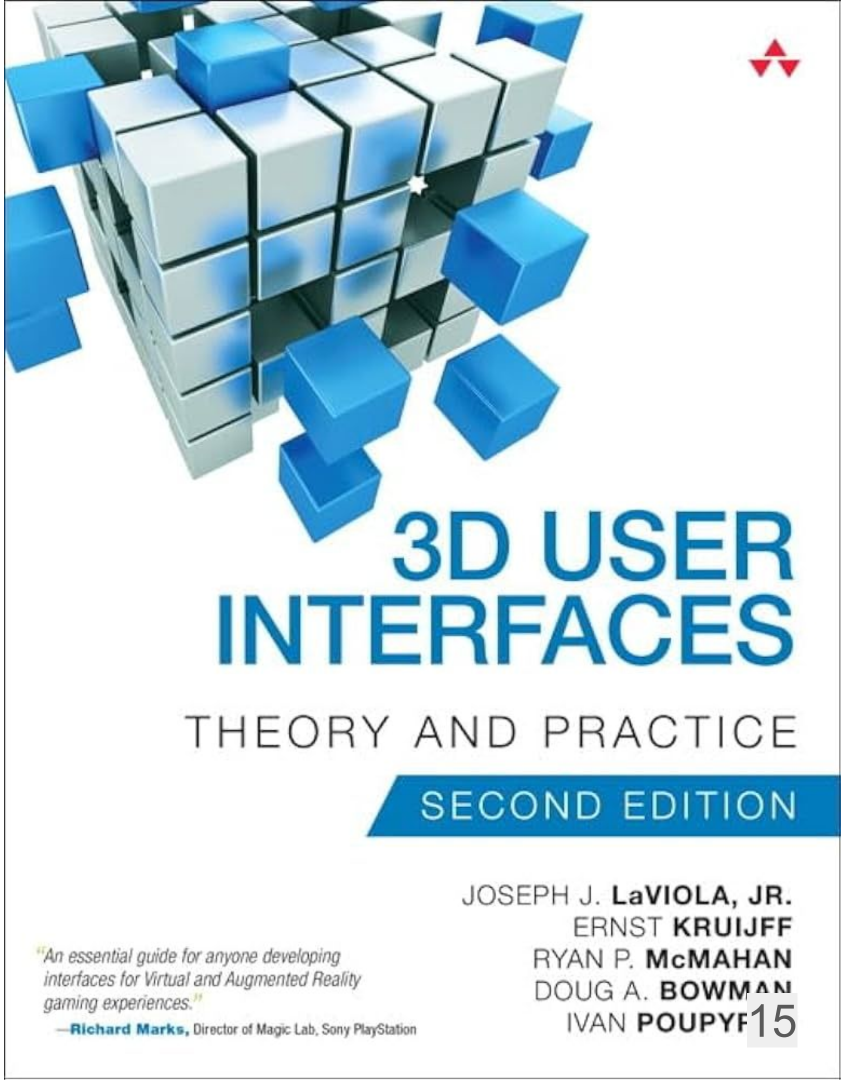
XR’s Many Contexts

Different Contents: Work, Sports, Training, Medical, Entertainment, Health, Social

Existing Approach

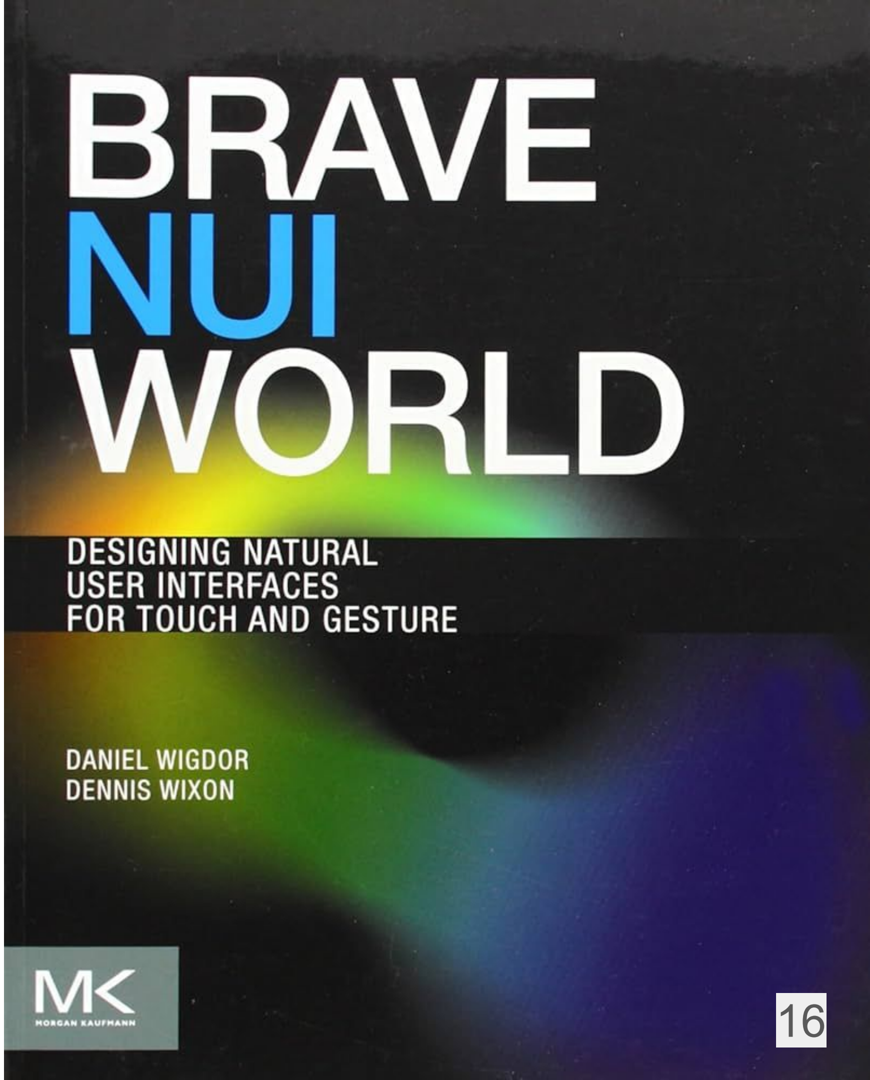
3D User Interface

A user interface that involves 3D interaction.



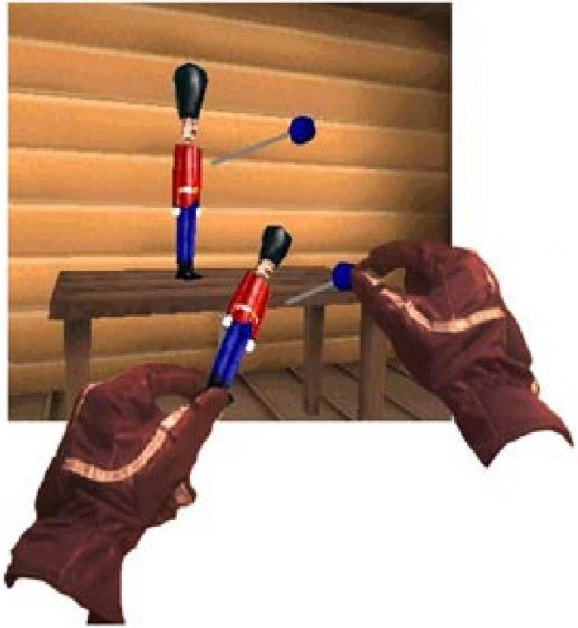
Natural User Interface

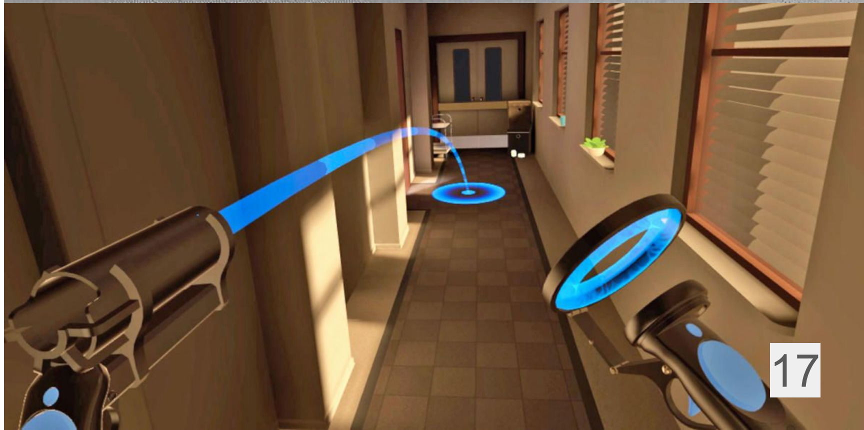
A natural user interface or natural interface is a user interface that is effectively invisible, and remains invisible as the user continuously learns increasingly complex interactions.



Hyperphysical User Interface

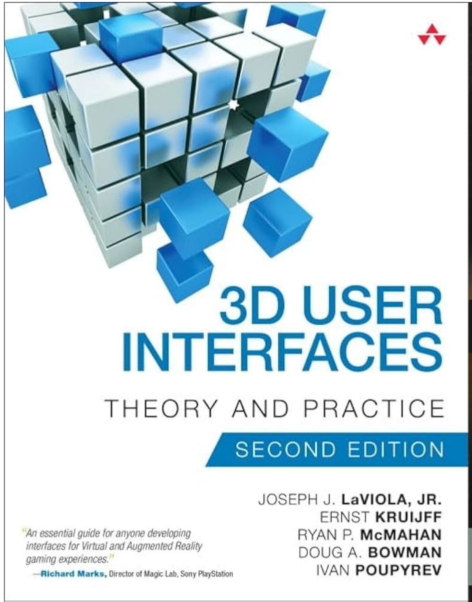
Hyperphysical User Interfaces do not follow the rules of real-world physics.

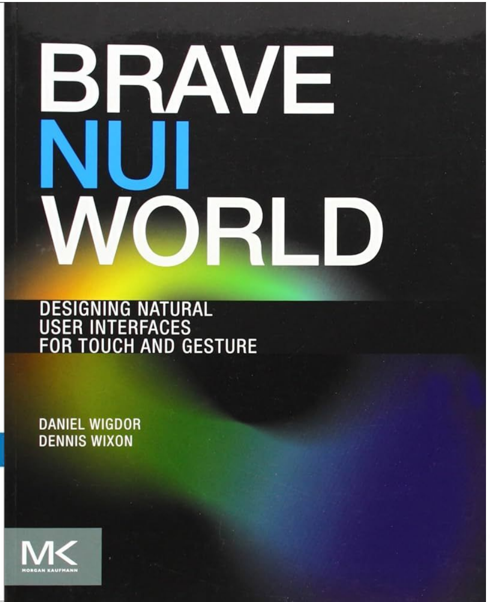


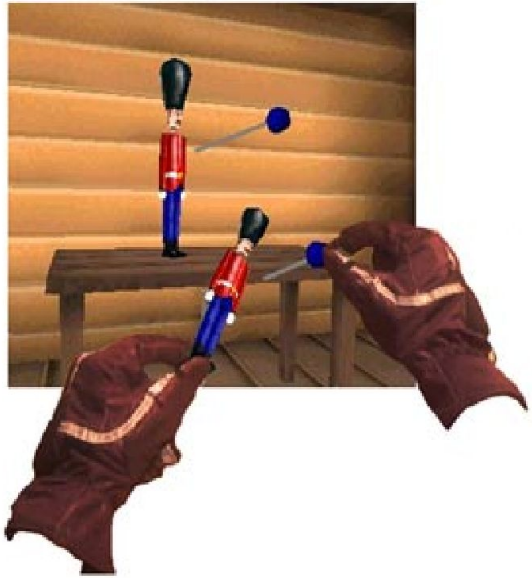


Many Interaction Techniques

Lots of interaction techniques were developed to address the many different needs.





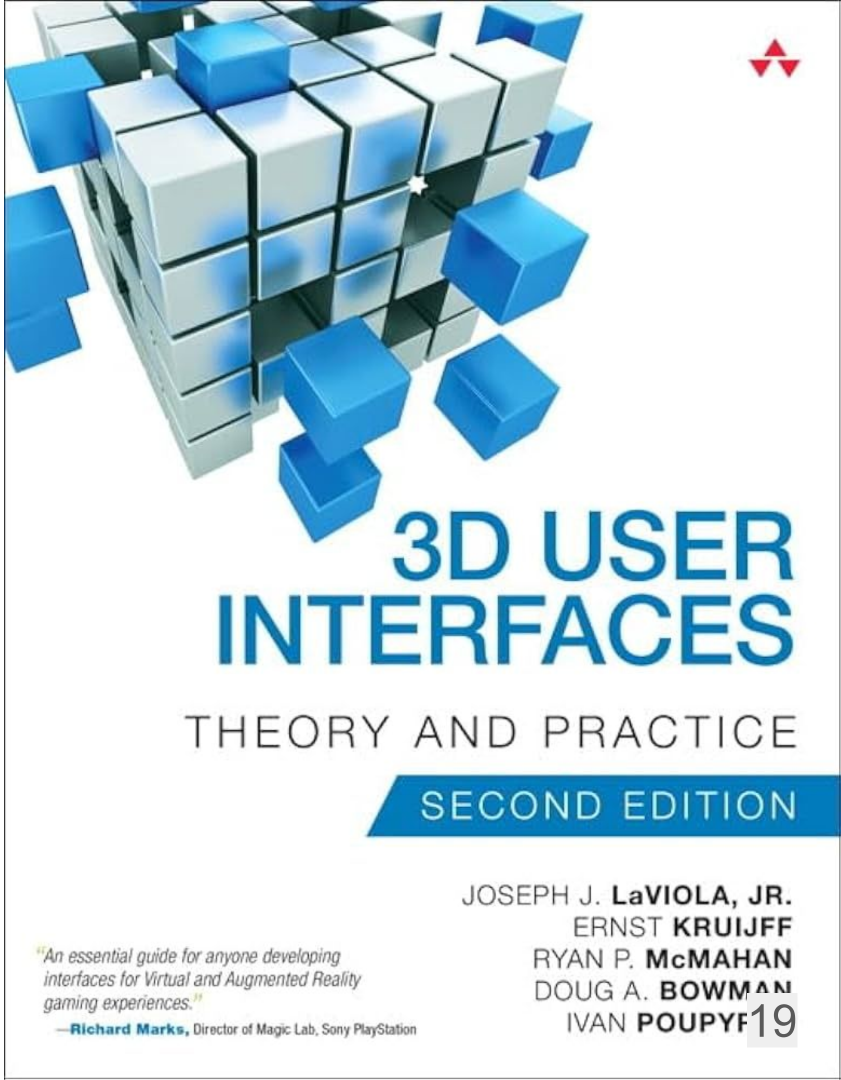


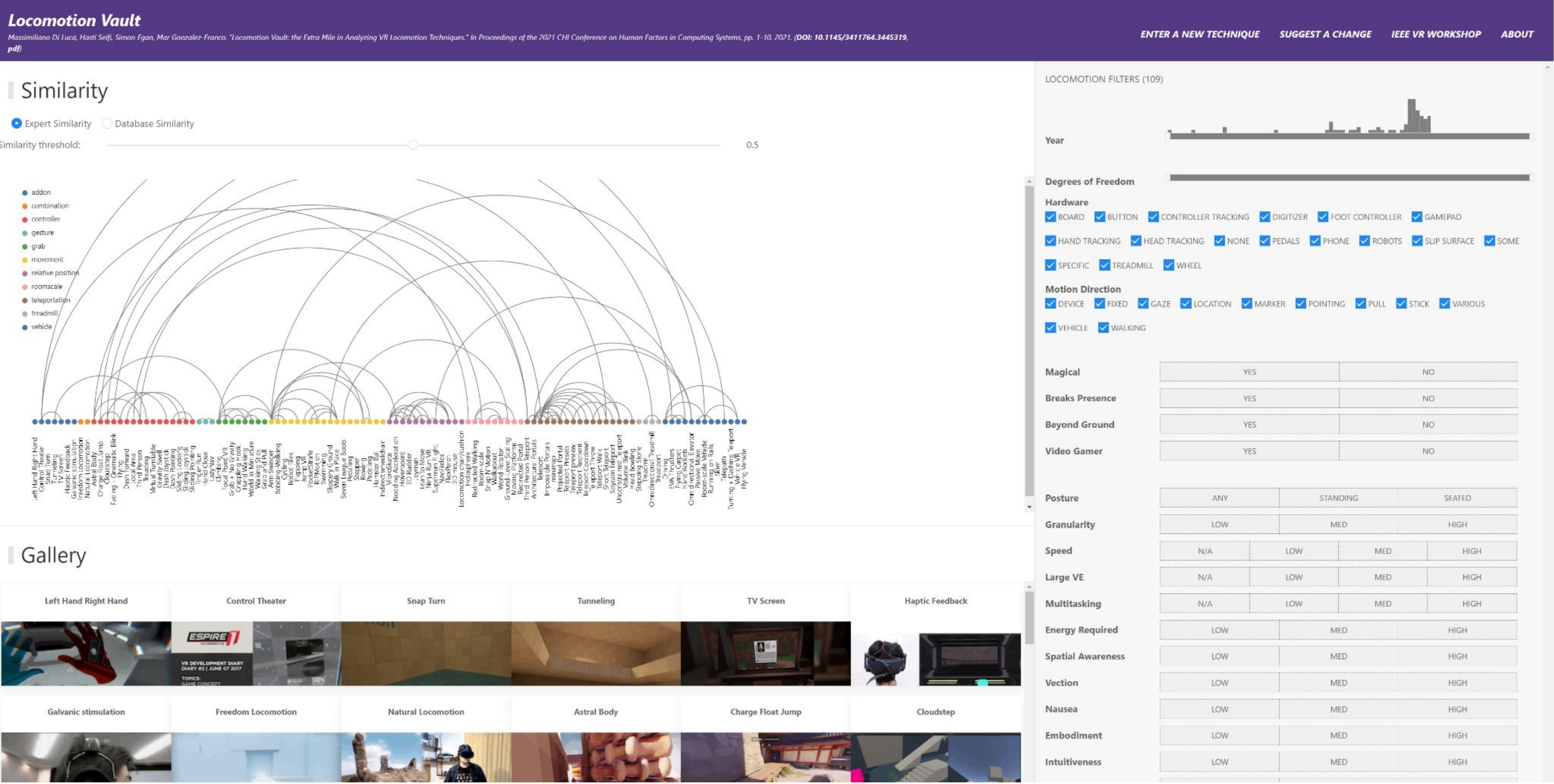
Many Interaction Techniques

In the 3D User Interfaces textbook, techniques are classified based on the type of user task

Let's look at one of the **most common** tasks

1) Selection and Manipulation
2) **Travel**
3) System Control





https://locomotionvault.github.io/

Challenges

Many different considerations such as contexts, scenarios, situations with the user as a part of the interaction environment

Many techniques to address the different contexts and scenarios, each with different strengths and weaknesses

Lack of a unified system control interface to allow the user to utilize the best technique for the situation at hand

Need for ways to **evaluate techniques** for different contexts

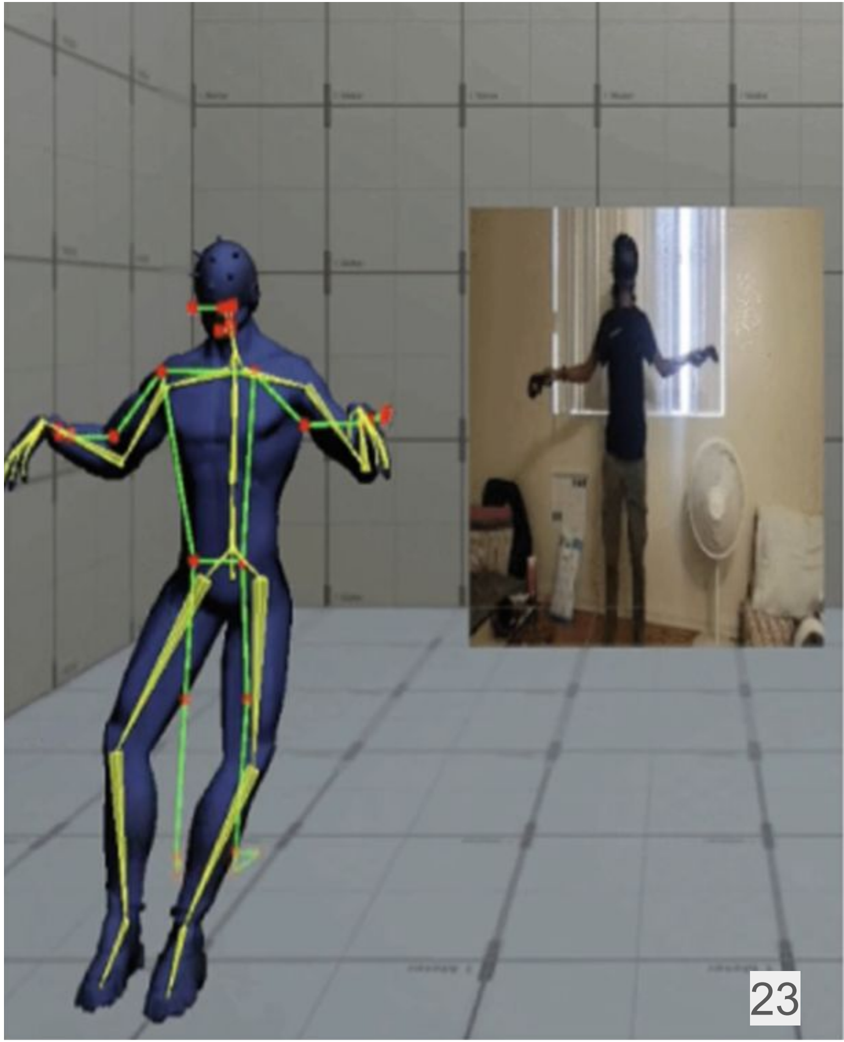
This Thesis's Approach

Assumptions

This thesis work applies primarily to 6 Degree of Freedom XR

The design presented also makes the following assumptions:

- The user’s body can eventually be fully tracked
- Physical objects, environment can be fully tracked and its context known



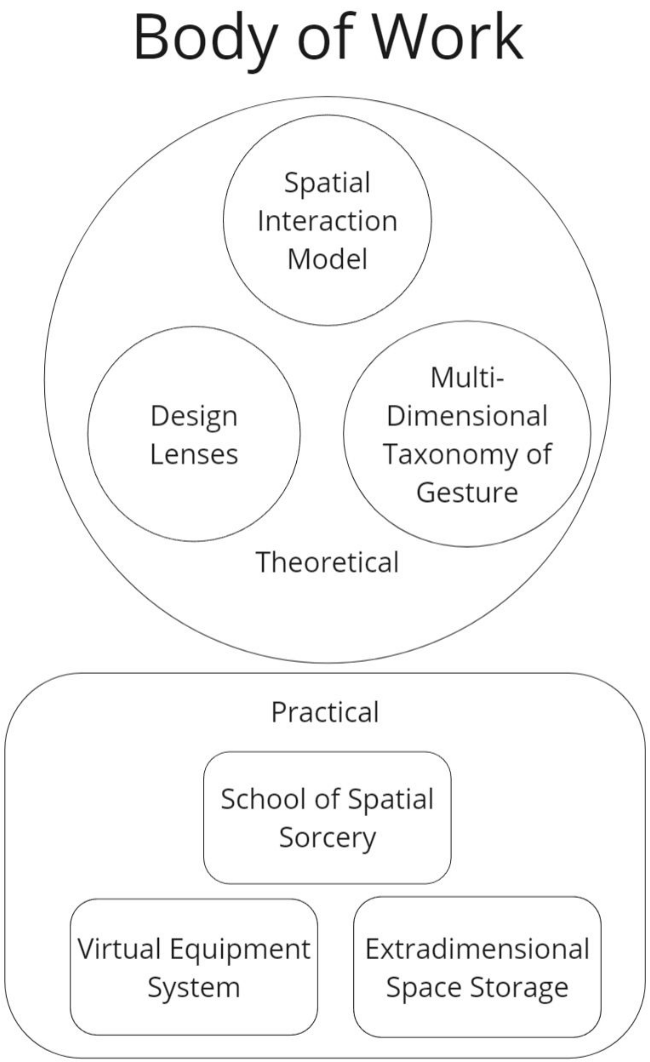
XR simulated in VR

Proof of concepts are built and tested in Virtual Reality to simulate Extended Reality with spatial awareness.

Problem	**Solution**	**Result**
Many qualities and contexts to design for in XR	Help **design** and **create** better interaction techniques	Implemented many interaction techniques in SSS, VES, and EDS
Have many interaction techniques but unable to **determine** the best interaction for the job	Help **discover** and **determine** the best interaction technique for the job	Created Spatial Interaction Model and the Design Lenses to use on the model. Expanded and adapted Gesture Taxonomy for XR
Have many interaction techniques but unable to **access** the best interaction for the job	Help manage and **access** the best interaction technique for the job	Interaction techniques that help manage repository of interactions, such as VES and EDS

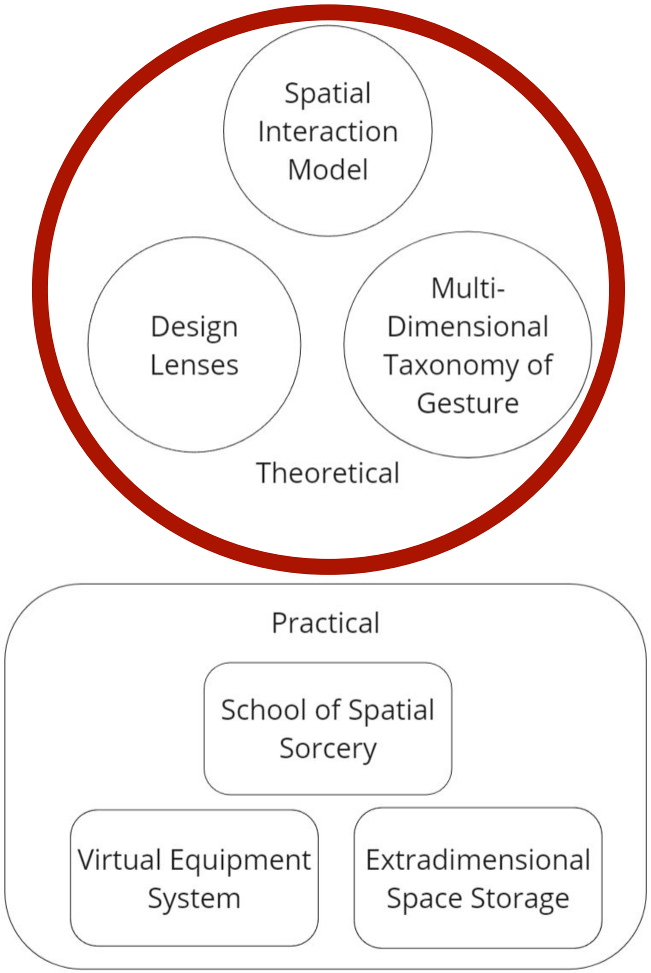
Approach

1. Identify and utilize **Design Lenses** for XR Interaction on the **Spatial Interaction Model**
2. Develop a **Multi-Dimensional Taxonomy** of Gesture as a design guide
3. **Explore and Prototype** different Interaction Techniques and Interaction Technique Management Solutions

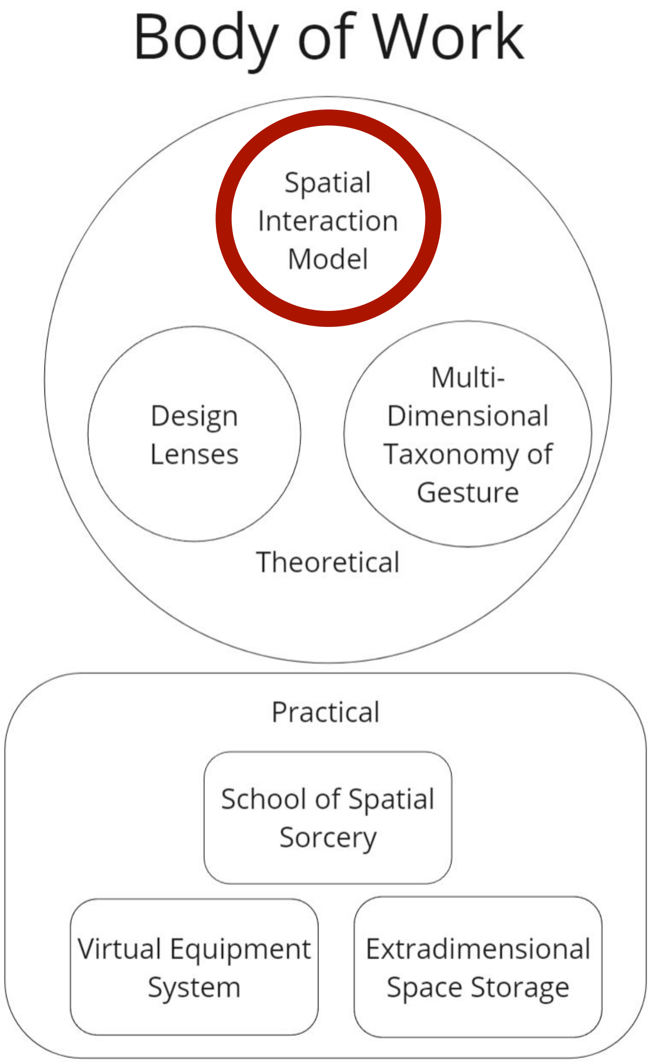


Theoretical Components

Body of Work



Spatial Interaction Model



What is Interaction?

“The term interaction is field-defining, yet surprisingly confused.”

Hornbæk, Kasper, and Antti Oulasvirta. "What is interaction?." CHI 2017

Concept	View of interaction	Key phenomena and constructs	Good interaction	Example support for evaluation and design
Dialogue	a cyclic process of communication acts and their interpretations	mappings between UI and intentions; feedback from the UI; turn taking	understandable; simple, natural; direct	methods/concepts for guessability, feedback, mapping; walkthroughs
Transmission	a sender sending a message over a noisy channel	messages (bits); sender and receiver; noisy channels	maximum throughput of information	metrics and models of user performance
Tool use	a human that uses tools to manipulate and act in the world	mediation by tools; directness of acting in the world; activity as a unit of analysis	useful and transparent tools; amplification of human capabilities	compatibility in instrumental interaction; break down analysis
Optimal behavior	adapting behavior to goals, task, UI, and capabilities	rationality; constraints; preferences; utility; strategies	improves or reaches maximum or satisfactory utility	models of choice, foraging, and adaptation
Embodiment	acting and being in situations of a material and social world	intentionality; context; coupling	provides resources for and supports fluent participation in the world	studies in the wild; thick description
Experience	an ongoing stream of expectations, feelings, memories	non-utilitarian quality; expectations; emotion	satisfies psychological needs; motivating	metrics of user experience; experience design methods
Control	interactive minimization of error against some reference	feedforward; feedback; reference; system; dynamics	rapid and stable convergence to target state	executable simulations of interactive control tasks

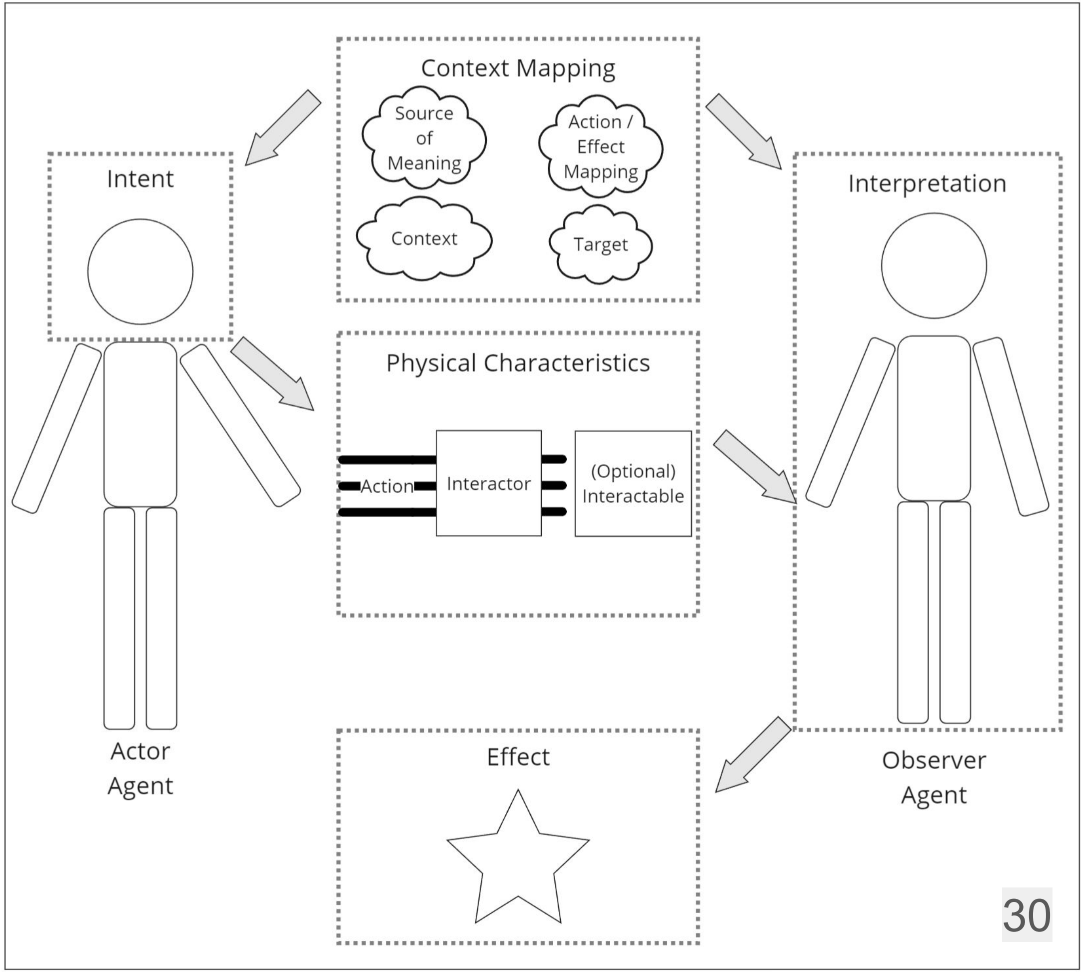
Table 1. Overview of some key concepts of interaction in HCI literature. The columns sum up the core view of what interaction is, the key phenomena that the view has helped see and their associated constructs, the notion of good interaction that follows from the view, and the key techniques and methods to help evaluating and designing user interfaces.

Spatial Interaction Model

A model based on XR qualities

A model to apply design lenses

Spatial Interaction Model



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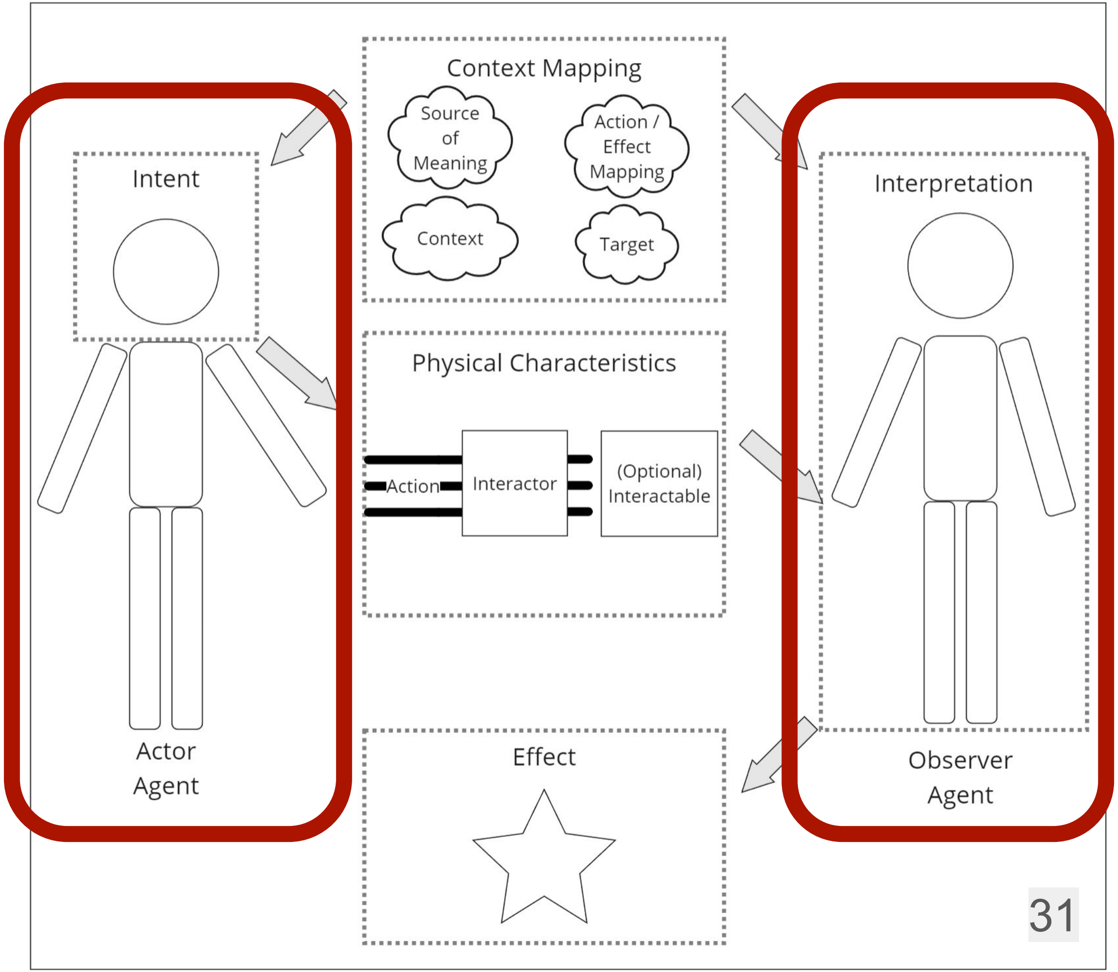

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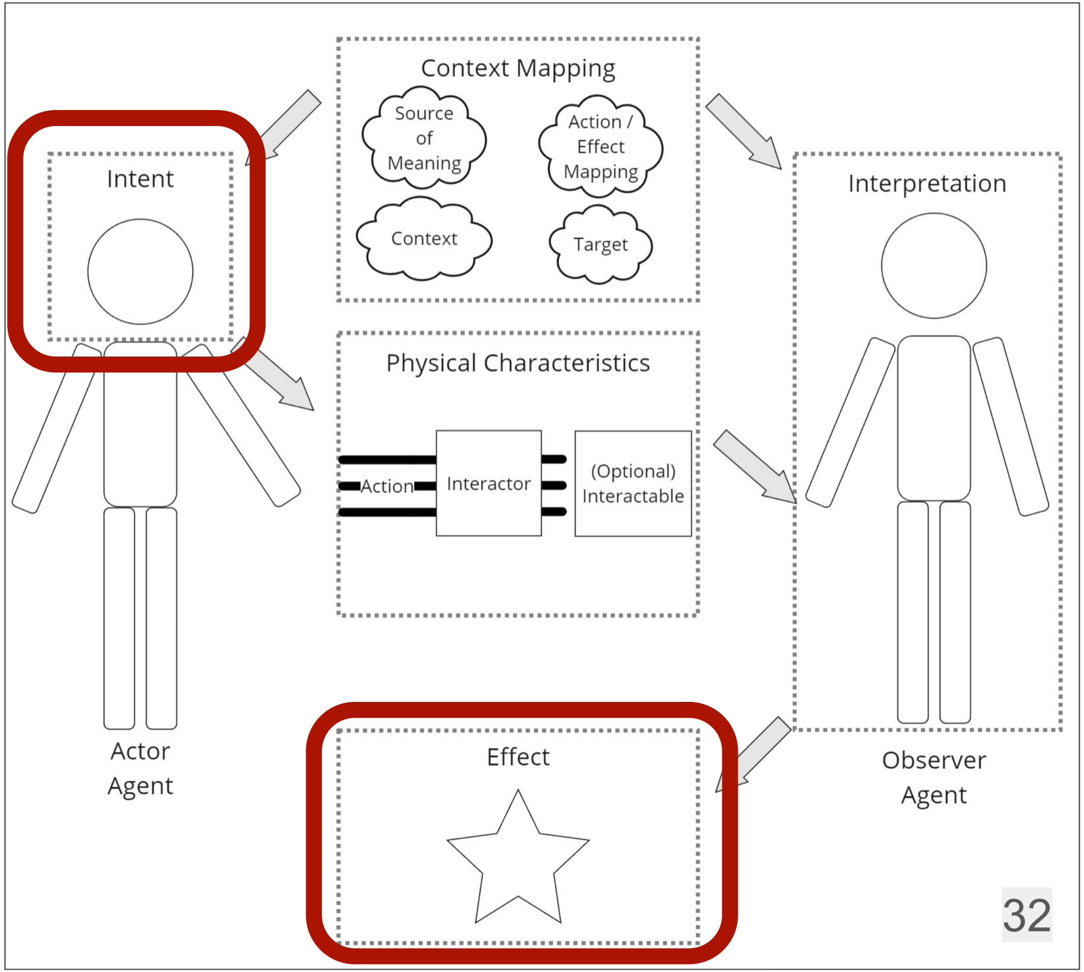

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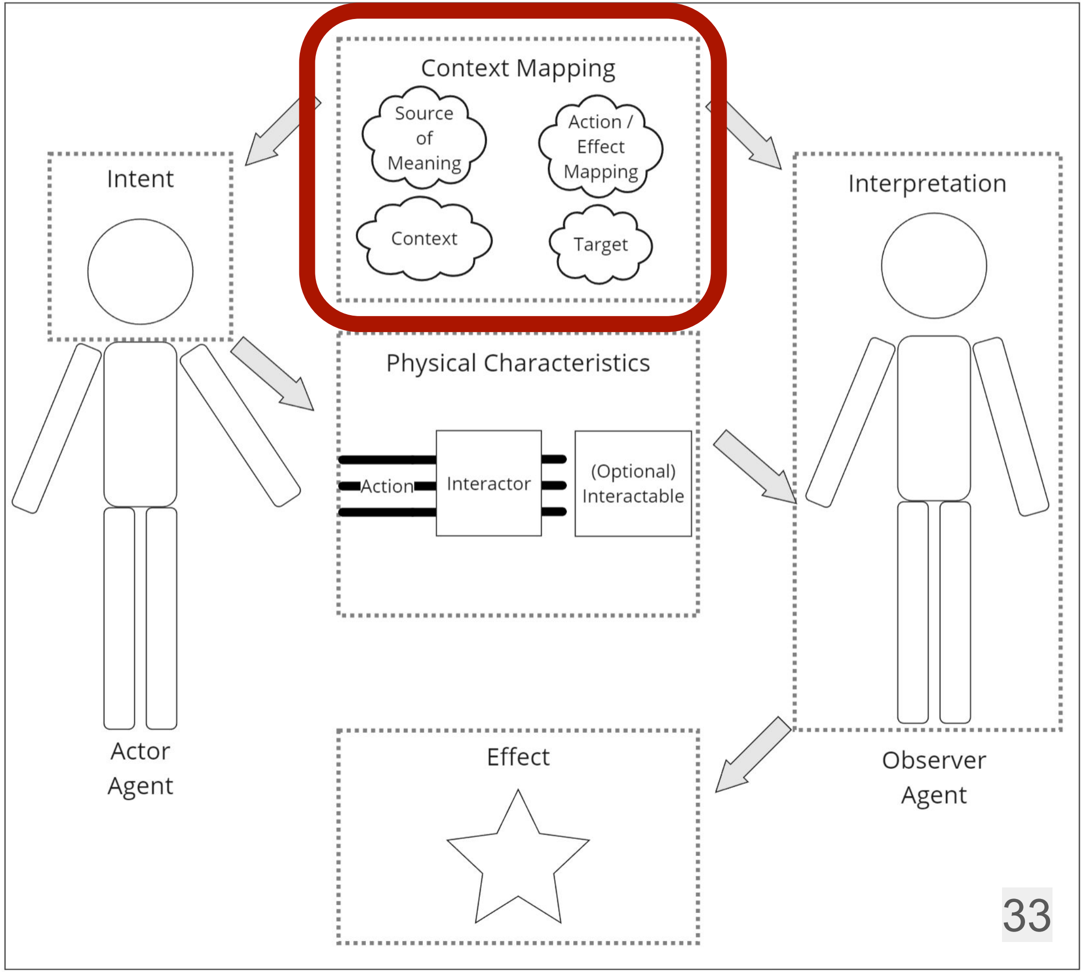

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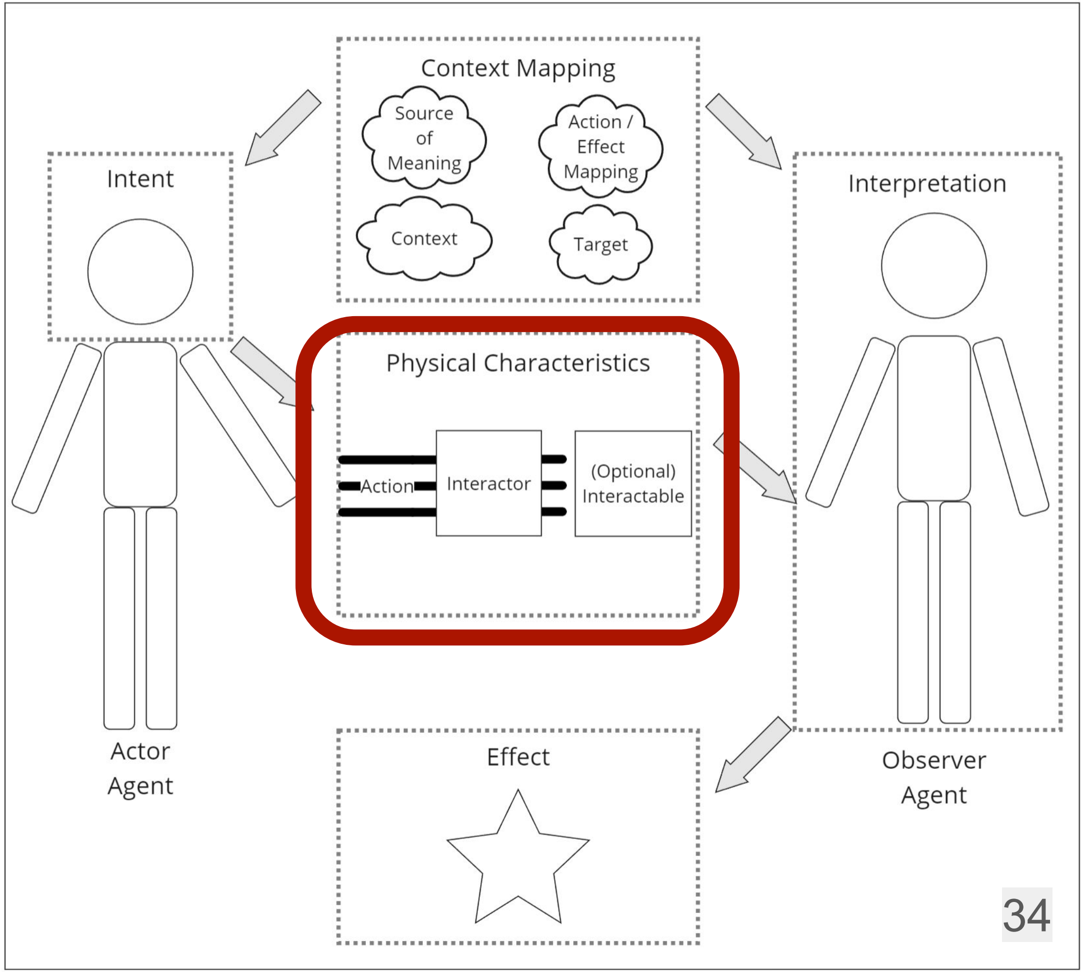

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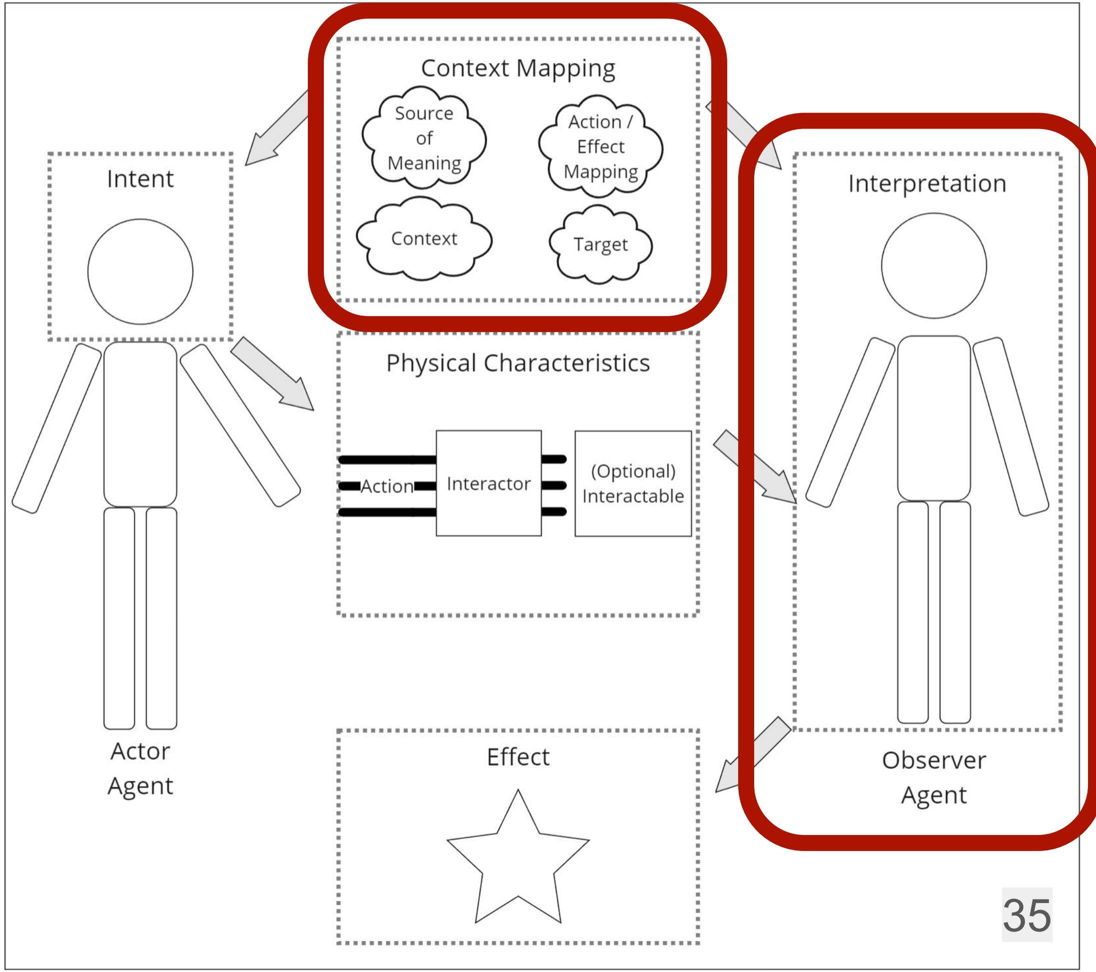

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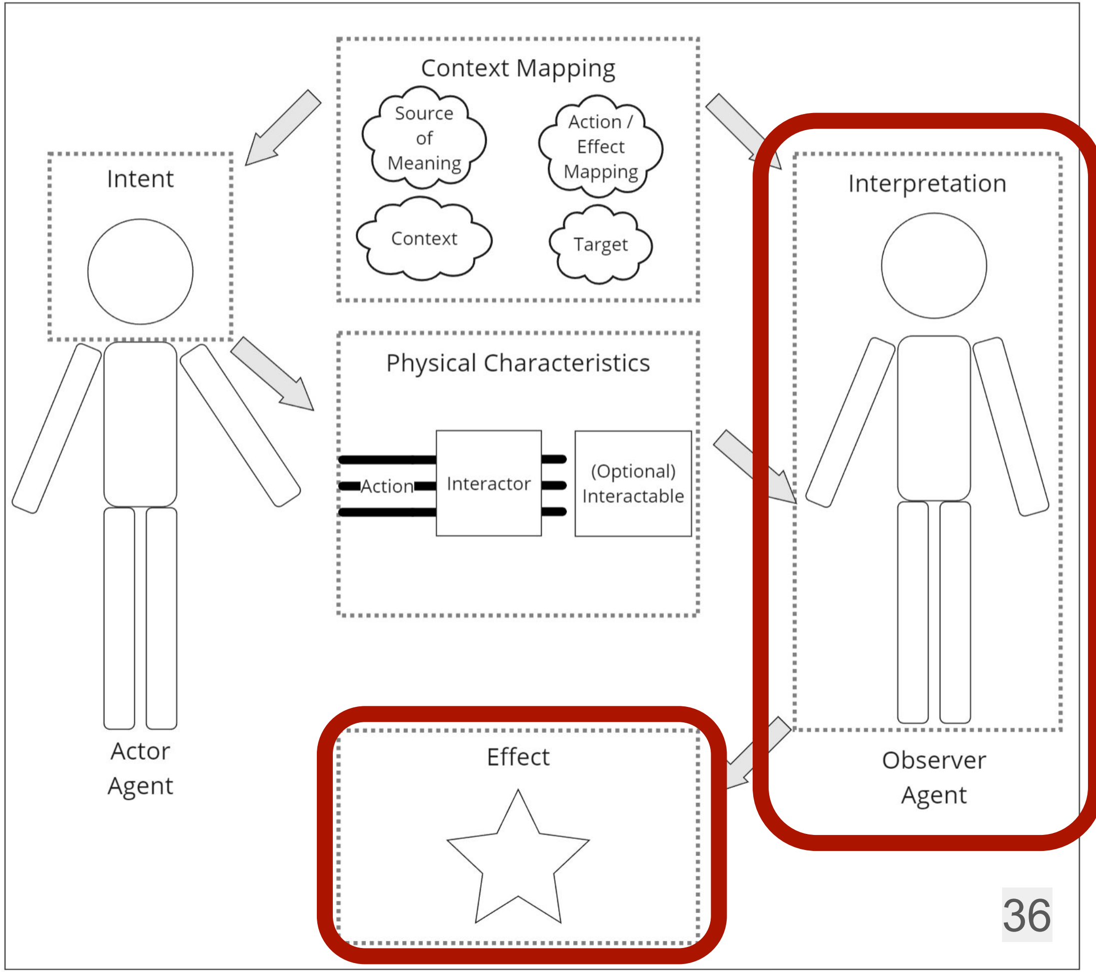

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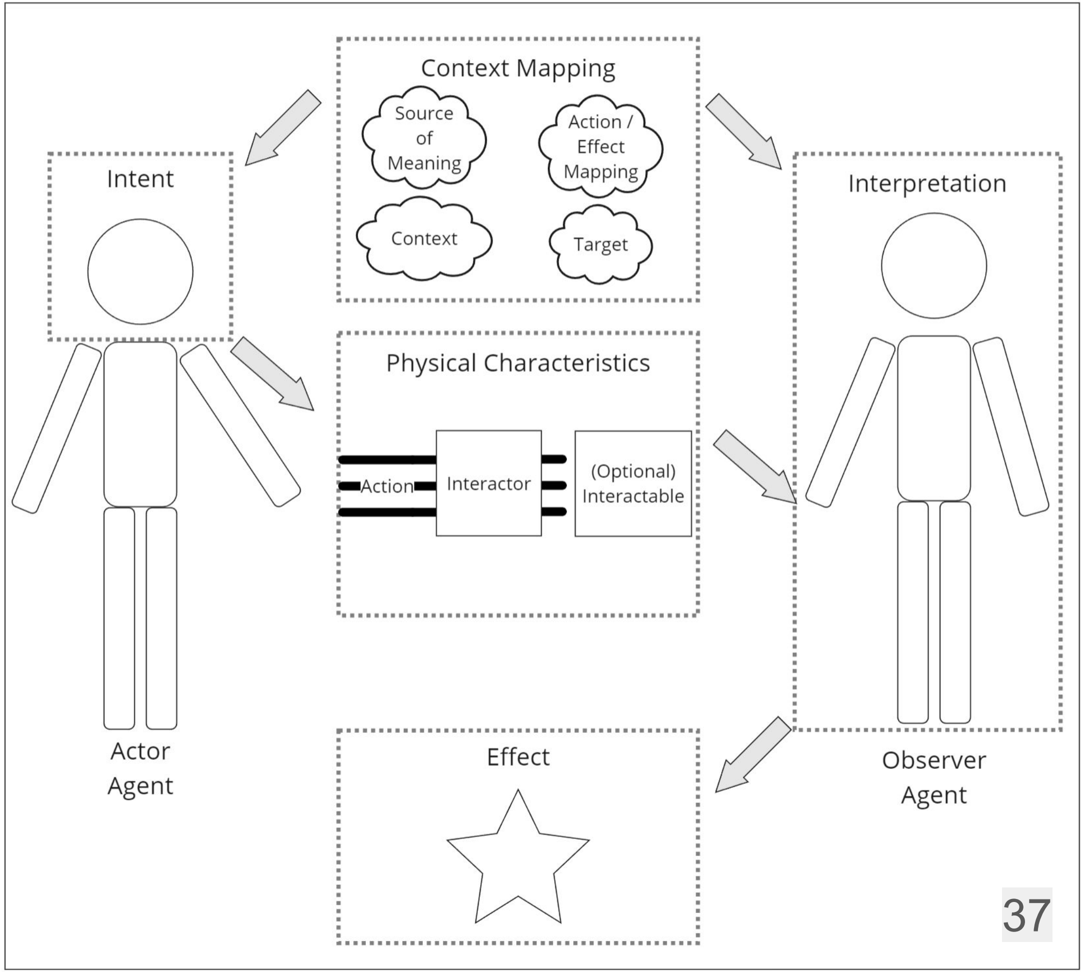
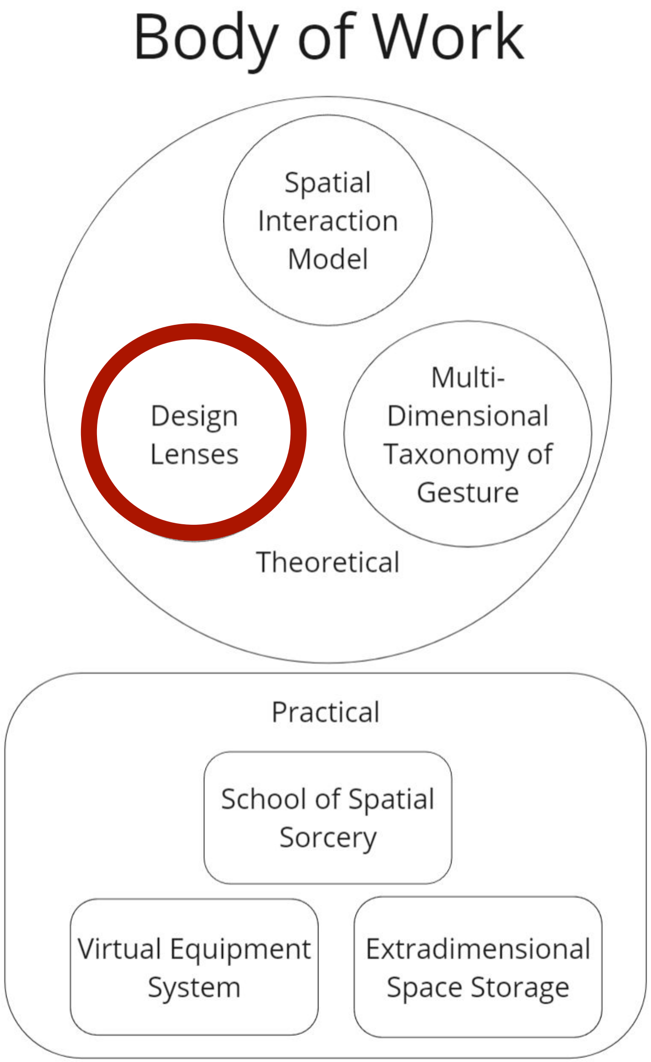


Design Lenses



Design Lenses

Hyperphysical User Interface

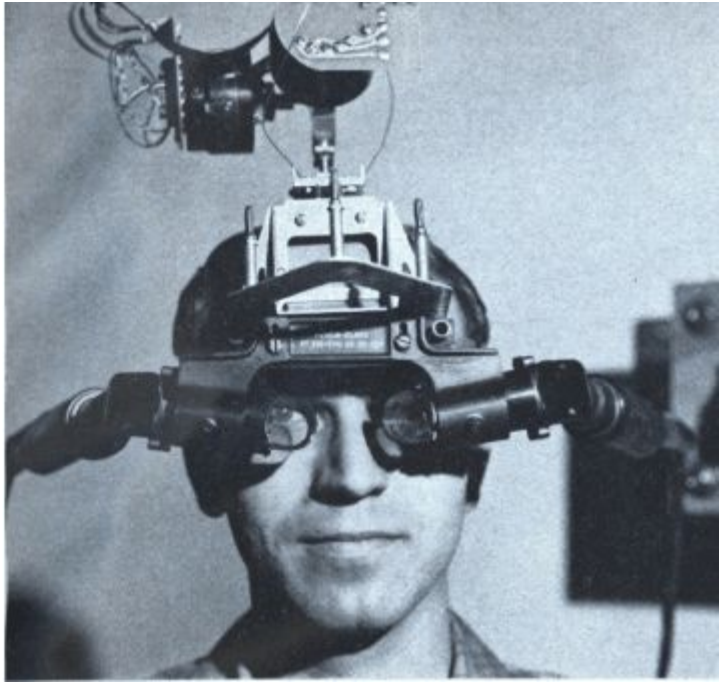
Whole-Body Interaction

Extradimensional Space

Design Lens
Hyperphysical User Interface

“The Ultimate Display”

In Ivan Sutherland’s classic article from 1965 “The Ultimate Display”, he stated **“There is no reason why the objects displayed by a computer have to follow the ordinary rules of physical reality with which we are familiar.”**



The Sword of Damocles by Ivan Sutherland

Aspects of Hyperphysicality

Manifestation -> Action -> Effect

Surrogate Object

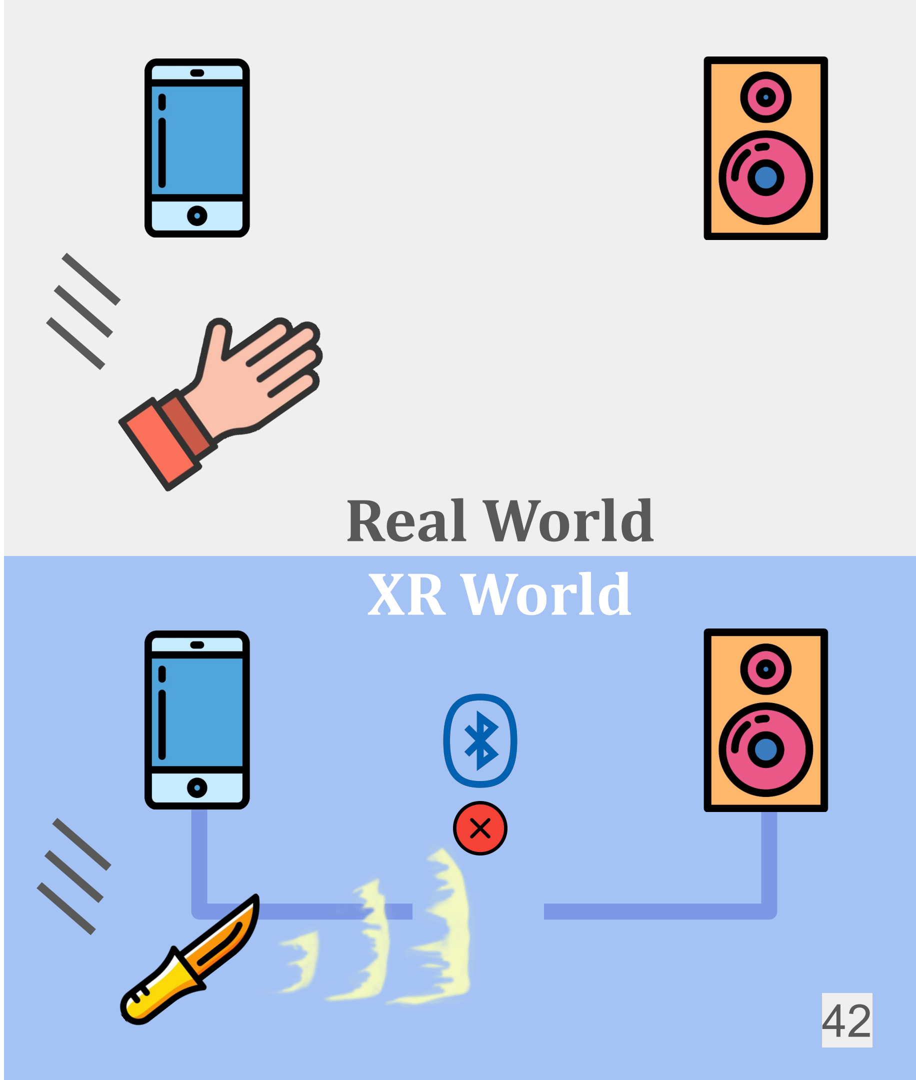
hand blade -> blade

Surrogate Action

chop -> disconnecting wave

Surrogate Effect

Chopped air-> disconnect)



Aspects of Hyperphysicality

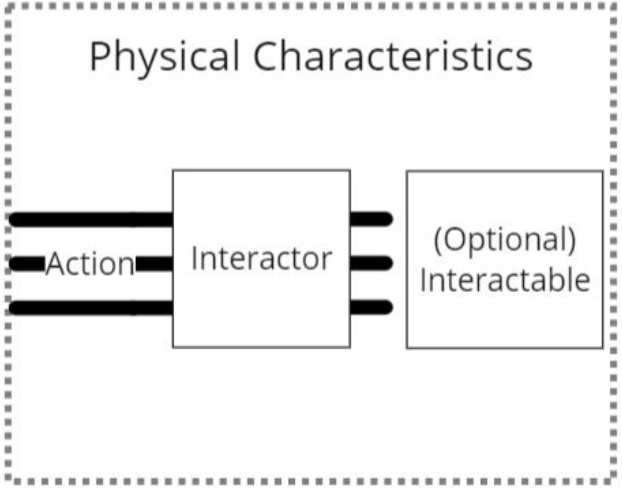
Manifestation -> Action -> Effect

Manifestation

- Interactor(s)
- Interactable(s)
- Environment

Action

Effect



Hyperphysicality in Manifestation

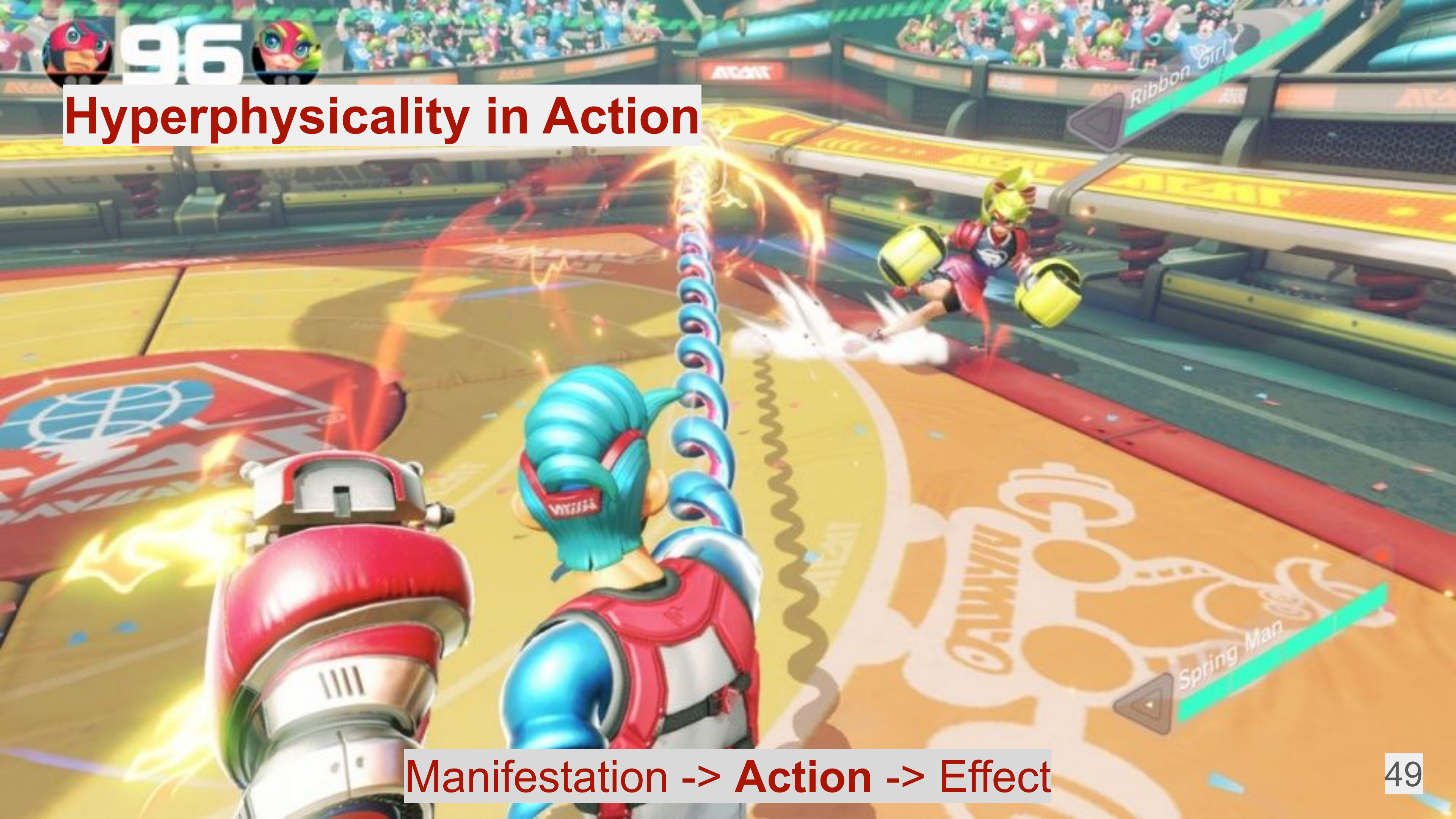
Manifestation -> Action -> Effect

Manifestation -> Action -> Effect

Manifestation -> Action -> Effect

Hyperphysicality in Action

Hyperphysicality in Action



Manifestation -> **Action** -> Effect

Hyperphysicality in Action

Manifestation -> **Action** -> Effect

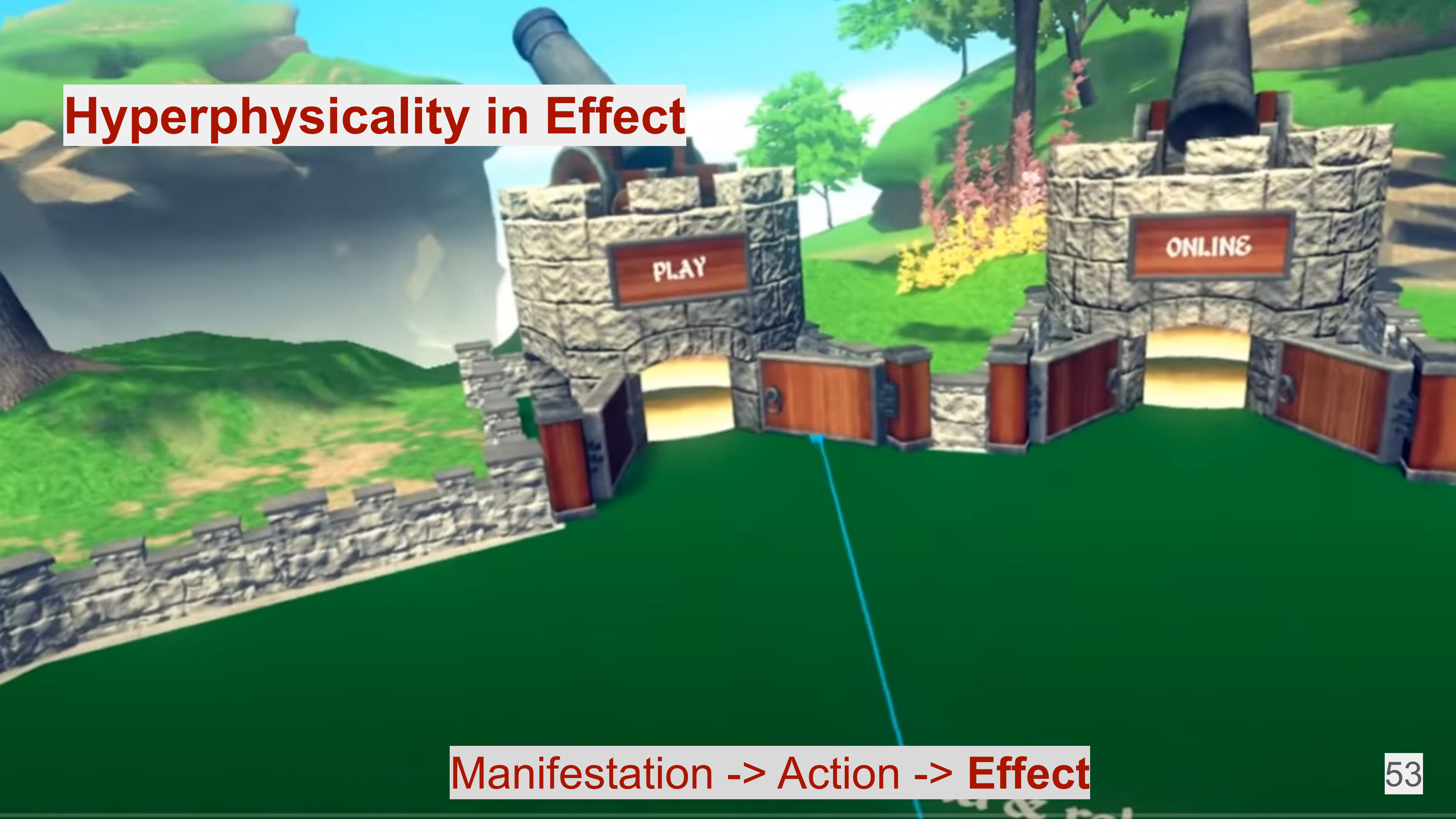
Other Examples in Hyperphysicality in Action

- Various Hand Gestures
  - Finger Gun
  - Stop (Block) Gesture
- Disembodied hand being controlled remotely
- Various Locomotion Techniques
  - Pull to Walk
  - Swing to Walk
  - Finger Walking

Manifestation -> **Action** -> Effect

Hyperphysicality in Effect

Hyperphysicality in Effect

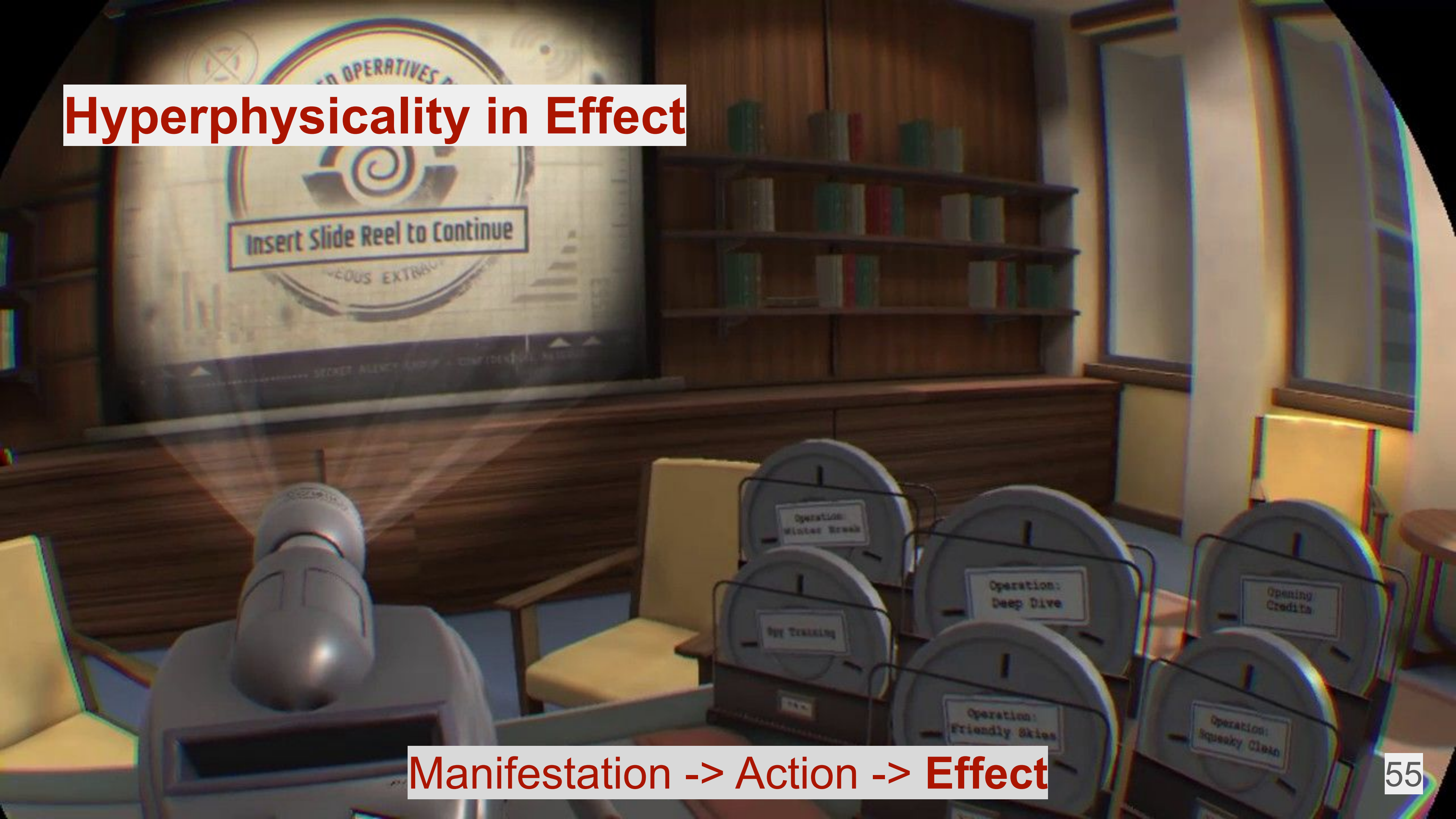


Manifestation -> Action -> **Effect**

Hyperphysicality in Effect

Manifestation -> Action -> **Effect**

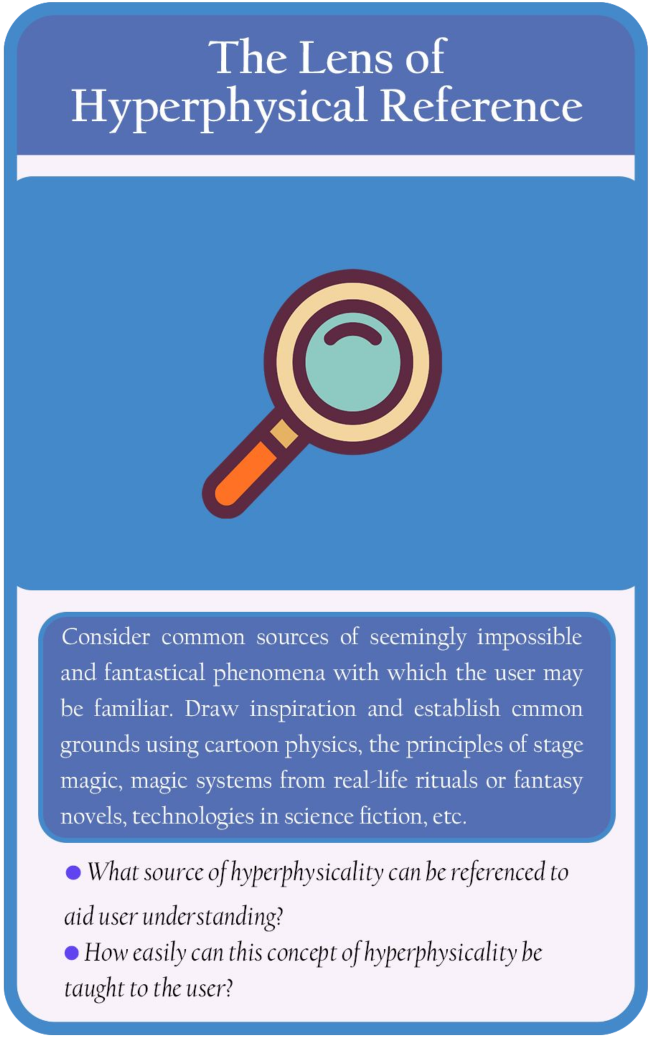
Hyperphysicality in Effect



Manifestation -> Action -> **Effect**

Hyperphysical Lenses

- Lens of Surrogate Manifestation
- Lens of Surrogate Action
- Lens of Surrogate Effect
- Lens of Hyperphysical References



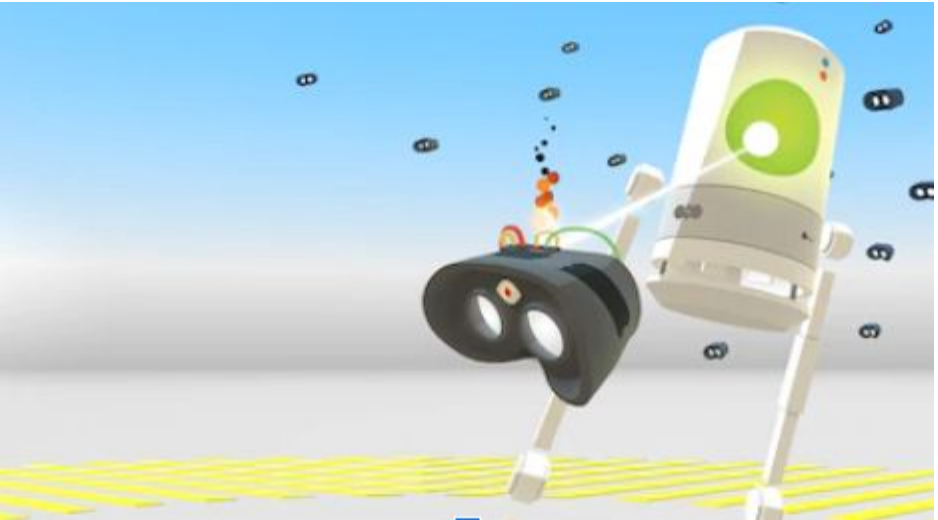
Design Lens
Whole-Body Interaction

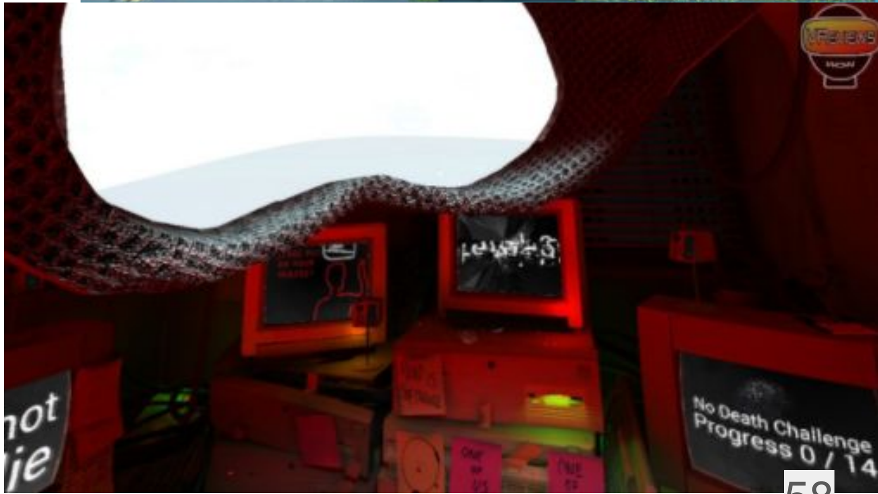
Head as an Interactor or Interactable

The Lab - Metaphor for Entering another World

Fantastic Contraption - Storage Space

Various VR Games - putting food next to the mouth to eat



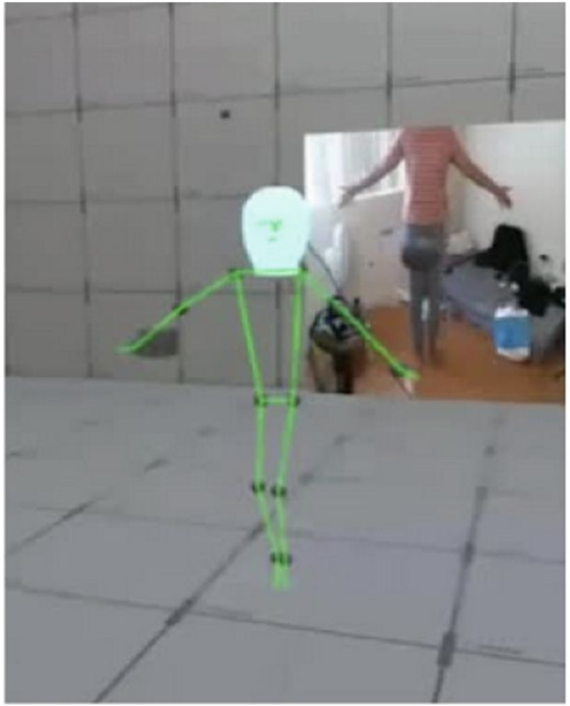


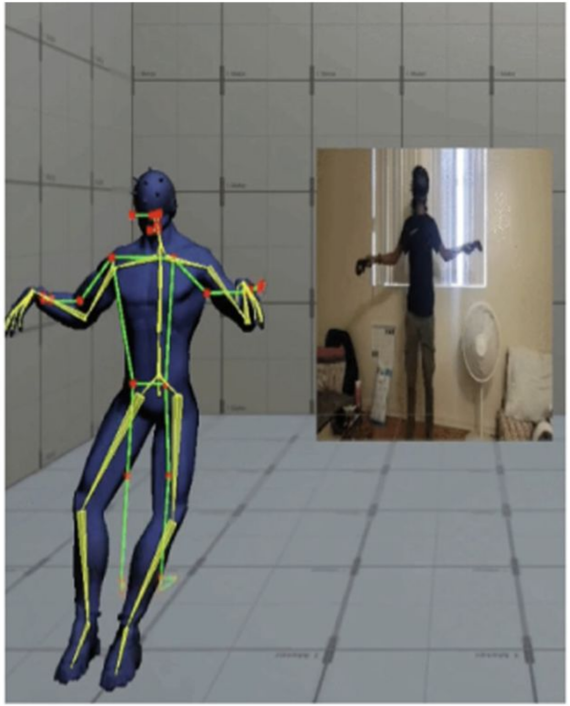
Hand as an Interactor or interactable

https://twitter.com/pushmatrix/status/1229781239445389315

By Daniel Beauchamp @pushmatrix

Other Body Parts Enabled by Advancing Technology



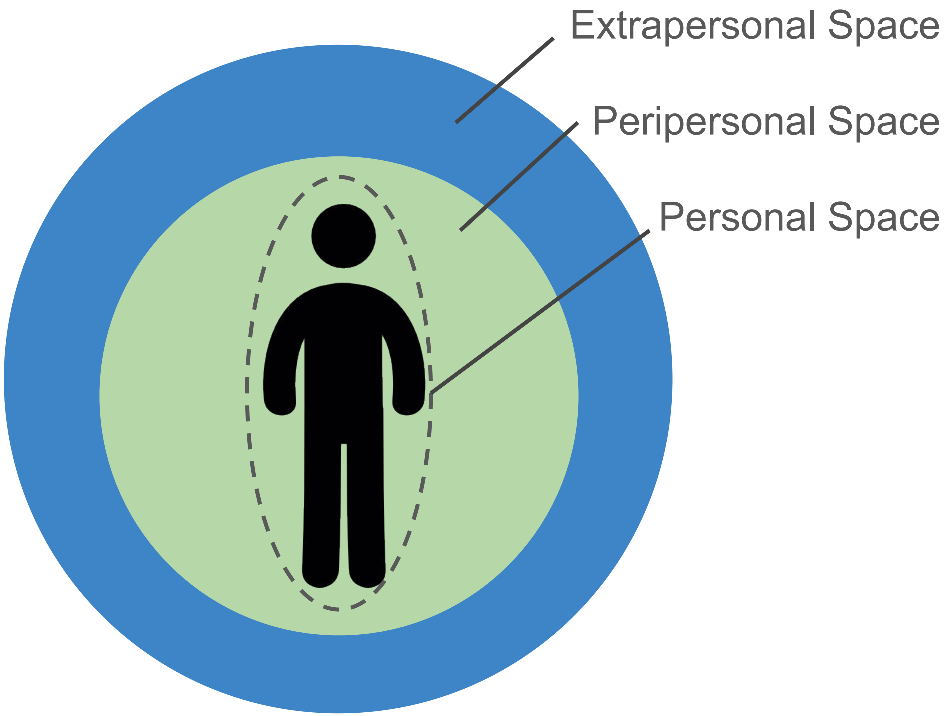


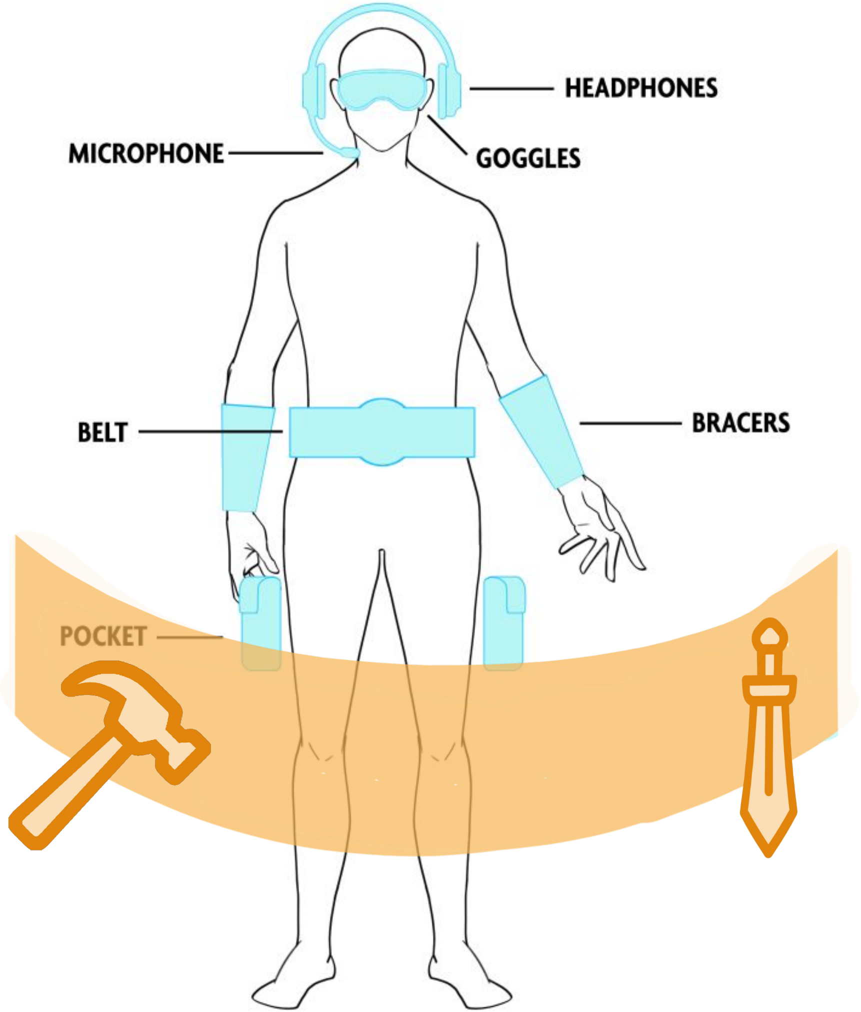
Personal, Peripersonal, and Extrapersonal Space

Personal space: the area immediately bordering the body

Peripersonal space: the area that is within the distance of the user's reach

Extrapersonal space: the area beyond the user's hand reach without help of tools




HEADPHONES
MICROPHONE
GOGGLES
BELT
BRACERS
POCKET

Whole-Body Interaction Lenses

Lens of Interaction Roles

Lens of Soma-Semantic

Lens of Body Capability

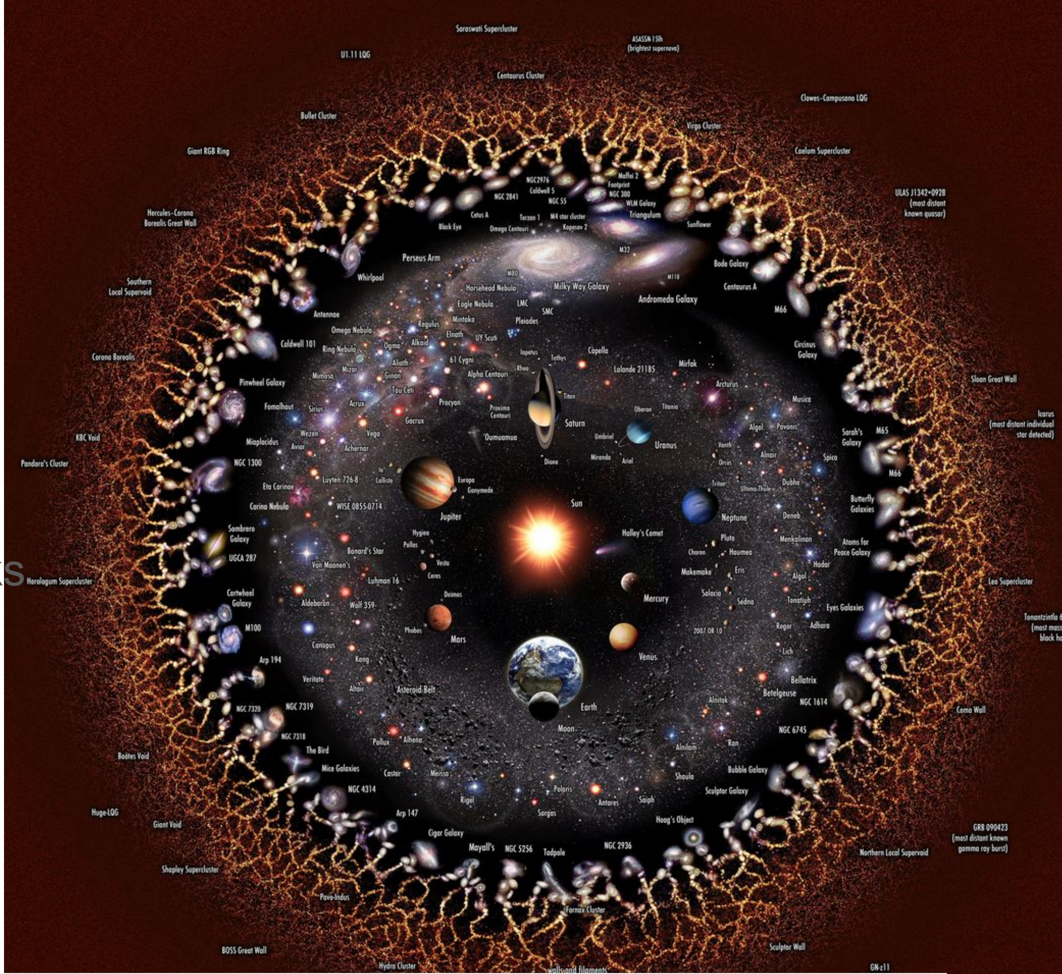
Design Lens
Extradimensional Space

Definition of Dimension

In Astrophysics, the term "universe" describes the **sum of all space and time that we live in.**

Universe, dimension, plane, world, space, or reality are often used in works of fiction interchangeably without a clear distinction or definition for each.

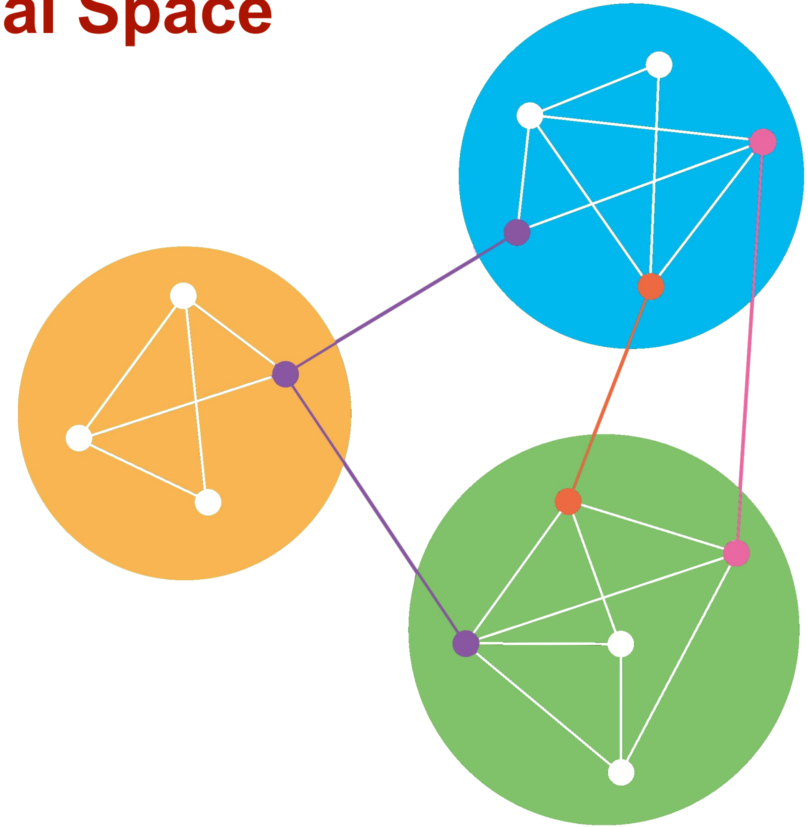
A dimension is the sum of all space and time that are connected physically.



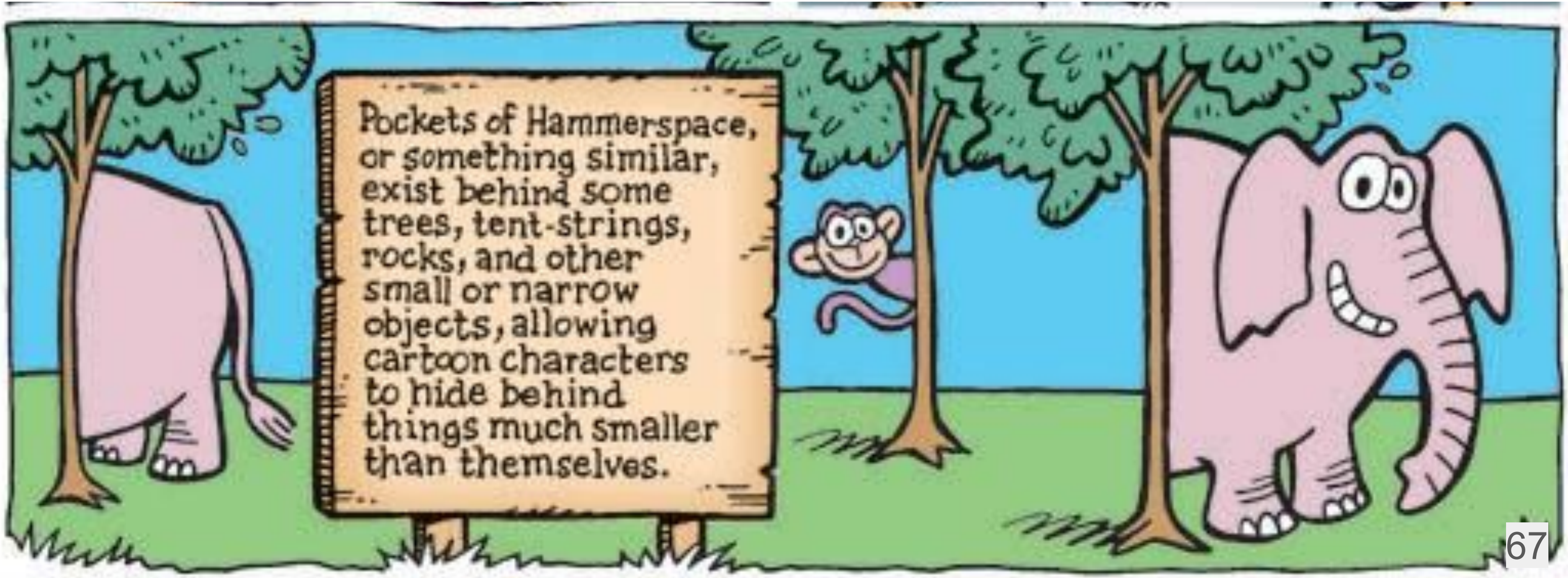
https://commons.wikimedia.org/wiki/File:Extended_universe_logarithmic_illustration_(English_annotated).png

Definition of Extradimensional Space

Fiction work posits that there are **other distinct and separate sums of space and time that are not connected physically with our own**. This may be described using terms such as alternate, another, **extradimensional**, or parallel to refer to a dimension other than our own.



Hammerspace in Pop Culture



Extradimensional Space Lenses

Lens of Permission

Lens of Relevancy

Lens of Dimension Shift

Lens of Dimensional Sight

The Lens of Permission

Consider what are the restrictions when performaing an interaction. Ask yourself these questions

- *Can this interaction technique access entities in extradimensional space?*
- *If not, should this interaction technique be an extradimensional interaction technique?*
- *What are the criteria to access entities in this extradimensional space?*

Extradimensional Space Lenses

Lens of Permission

Lens of Relevancy

Lens of Dimension Shift

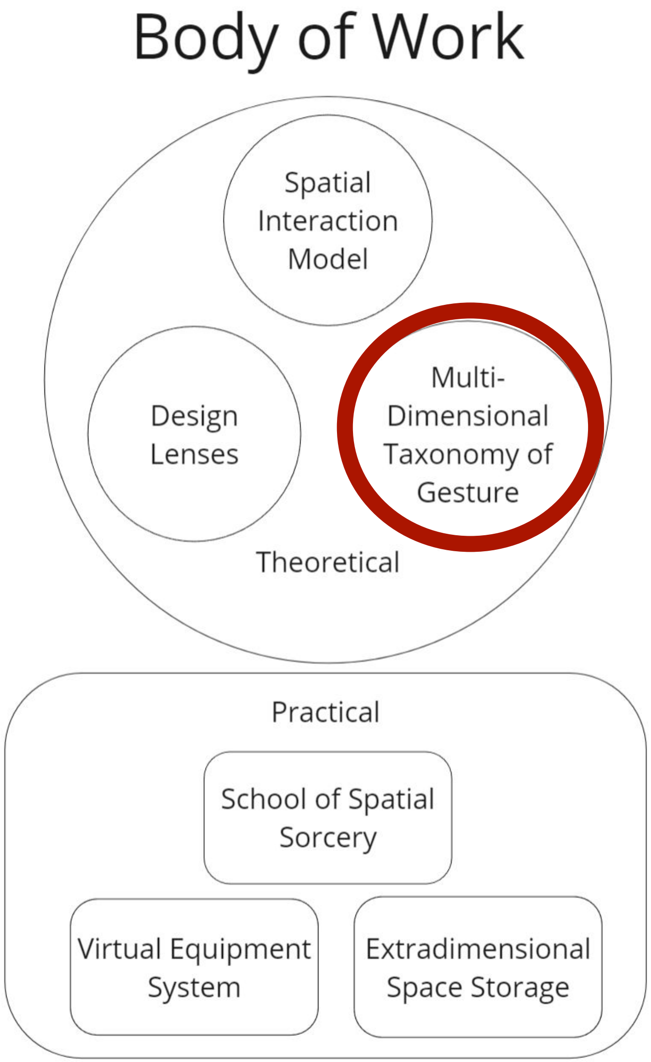
Lens of Dimensional Sight

The Lens of Relevancy

Consider what matters the most during an interaction. Ask yourself these questions

- *Is this entity relevant to the current interaction?*
- *Should it be stored in another dimension for later use?*

Multi-Dimensional Taxonomy of Gesture



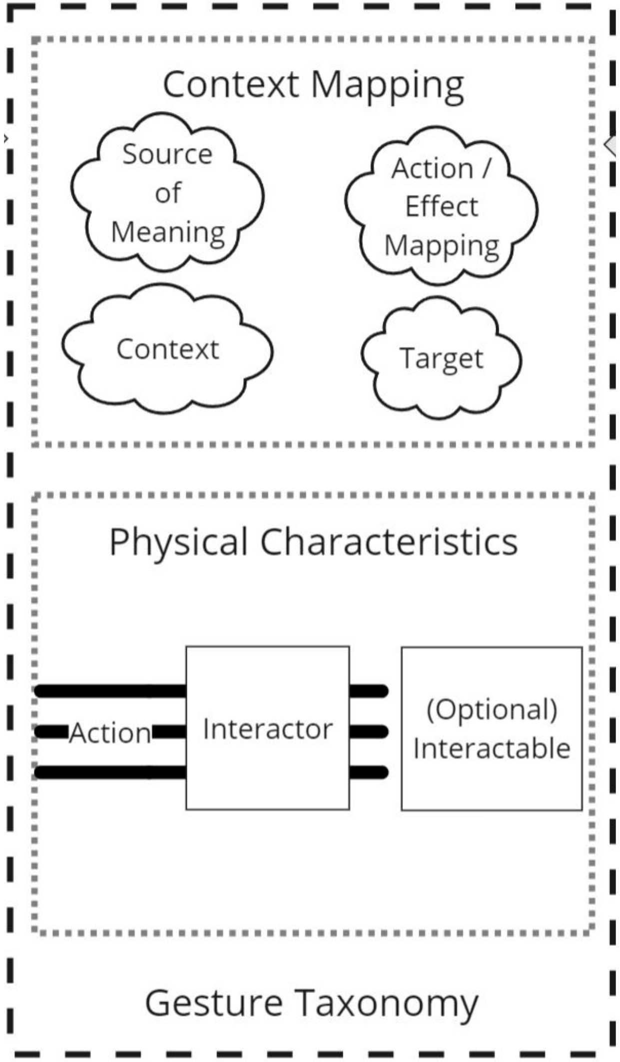
Powen Yao, Tian Yang, and Michael Zyda "Toward a Gesture System Architecture in Extended Reality Based on a Multi-dimensional Taxonomy of Gestures" HCII 2023

Introduction

Multi-Dimensional Taxonomy of Gesture for Extended Reality

Based on Spatial Interaction Model and the Design Lenses

Two classes of dimensions. **Gesture Mapping** and **Physical Characteristics**.



Prior Works in Taxonomy

Linguistics

Efron 1941, Kendon 1988, McNeill 1992

Human-Computer Interaction

Quek et al. 1994, Pavlovic 1997, Cassell 1998

Multi-Dimensional Gesture Taxonomy

Poggi 2001, Karam 2005, Wobbrock 2009 (Surface Gestures), Ruiz 2011 (Motion Gestures), Vafaei 2013 (VR and mid-air hand gestures)

Key Points

- Inclusion of emergent qualities in XR

- Break down of the "Nature" Dimension

- System Architecture based on the Taxonomy

Physical Characteristics

Physical Characteristics

Physical Characteristics can be viewed as **properties of the interactor and the action performed by the interactor**.

Put simply, Physical Characteristics are about the properties of the interactor and its actions.

Dimensions	Sub-dimensions	Categories	Sub-categories	Description
Position	***x***	*Relevant*		Gesture involves the x-axis of position
		Irrelevant		Gesture ignores the x-axis of position
	y	*Relevant*		Gesture involves the y-axis of position
		Irrelevant		Gesture ignores the y-axis of position
	z	*Relevant*		Gesture involves the z-axis of position
		Irrelevant		Gesture ignores the z-axis of position
Rotation	***x***	*Relevant*		Gesture involves the roll-axis of rotation
		Irrelevant		Gesture ignores the roll-axis of rotation
	y	*Relevant*		Gesture involves the pitch-axis of rotation
		Irrelevant		Gesture ignores the pitch-axis of rotation
	z	*Relevant*		Gesture involves the yaw-axis of rotation
		Irrelevant		Gesture ignores the yaw-axis of rotation
Form		*Static*		No motion/change is in gesture
		Dynamic		Motion/change occurs in gesture
Interactor		*User Body*	*Hand*	Arm is fixed, but palm or fingers move
			Arm	Arm moves (hand moves as well)
			Head	Gesture is performed by head movement
			Shoulder	Gesture is performed by shoulder movement
			Foot	Gesture is performed by foot movement
			Eyes	Gesture is performed by pupil movement
			Mouth	Gesture is performed by lip movement
			Other body parts	Gesture is performed by other body part
		Input Device		Gesture utilizes Input Device as an interactor
		In-Environment Object		Gesture utilizes In-Environment Object as an interactor
Multiplicity		*Simple*		Gesture utilizes only one interactor
		Multiple		Gesture utilizes multiple interactors
Action Symmetry		*Symmetric*		Gesture utilizes multiple interactors performing similar motion
		Asymmetric		Gesture utilizes multiple interactors doing performing different motion
Interactor Homogeniety		*High*		Interactors are very similar in its form and function
		Medium		Interactors are only somewhat similar in its form and function
		Low		Interactors are not similar in its form and function
Complexity		*Simple*		Gesture involves an atomic gesture
		Compound		Gesture involves multiple atomic gestures
Motion Threshold		*None*		Gesture does not involve changes in position or rotation
		Position / Angle		Gesture involves changes in position/angle
		Velocity		Gesture involves changes in velocity/angular velocity
		Acceleration		Gesture involves changes in acceleration/angular acceleration
		Jerk		Gesture involves changes in jerk/angular jerk

Physical Characteristics - Interactor

Form	*Static*		No motion/change is in gesture
	Dynamic		Motion/change occurs in gesture
Interactor	*User Body*	*Hand*	Arm is fixed, but palm or fingers move
		Arm	Arm moves (hand moves as well)
		Head	Gesture is performed by head movement
		Shoulder	Gesture is performed by shoulder movement
		Foot	Gesture is performed by foot movement
		Eyes	Gesture is performed by pupil movement
		Mouth	Gesture is performed by lip movement
		Other body parts	Gesture is performed by other body part
	Input Device		Gesture utilizes Input Device as an interactor
	In-Environment Object		Gesture utilizes In-Environment Object as an interactor
Multiplicity	*Simple*		Gesture utilizes only one interactor
	Multiple		Gesture utilizes multiple interactors
Action Symmetry	*Symmetric*		Gesture utilizes multiple interactors performing similar motion

Physical Characteristics - Additional Emergent Quality

	Input Device	Gesture utilizes Input Device as an interactor
	In-Environment Object	Gesture utilizes In-Environment Object as an interactor
Multiplicity	*Simple*	Gesture utilizes only one interactor
	Multiple	Gesture utilizes multiple interactors
Action Symmetry	*Symmetric*	Gesture utilizes multiple interactors performing similar motion
	Asymmetric	Gesture utilizes multiple interactors doing performing different motion
Interactor Homogeniety	*High*	Interactors are very similar in its form and function
	Medium	Interactors are only somewhat similar in its form and function
	Low	Interactors are not similar in its form and function
Complexity	*Simple*	Gesture involves an atomic gesture
	Compound	Gesture involves multiple atomic gestures
	None	Gesture does not involve changes in position or rotation

Physical Characteristics - Additional Emergent Quality

	Input Device	Gesture utilizes Input Device as an interactor
	In-Environment Object	Gesture utilizes In-Environment Object as an interactor
Multiplicity	*Simple*	Gesture utilizes only one interactor
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Complexity	*Simple*	Gesture involves an atomic gesture
	Compound	Gesture involves multiple atomic gestures
	None	Gesture does not involve changes in position or rotation
	Position / Angle	Gesture involves changes in position/angle

Gesture Mapping

Gesture Mapping

Gesture Mapping can be viewed as **any quality that can be used as context to map an action to a different effect**

Put simply, Gesture Mapping is the context to decipher the physical characteristics within a gesture to determine the effect.

it's the **'how'** and **'what else'** to consider.

Dimensions	Sub-dimensions	Categories	Description
Source of Meaning		*Physical*	Gesture derives its meaning from laws of physics
		Hyperphysical	Gesture derives its meaning from an alternate laws of physics
		Universal	Gesture derives its meaning from a generally universal set of values
		Cultural	Gesture derives its meaning from shared cultural values
		None	Gesture does not derives its meaning from any particular source; its arbitrary
Target		*Has Target*	Gesture has at least a target to interact with
		No Target	Gesture has no target to interact with
Action Mapping		*Direct*	Direct Relationship between Intent and Action
		Indirect	Indirect Relationship to Gesture between Intent and Action
Effect Mapping		*Direct*	Direct Relationship between Intent and Effect
		Indirect	Indirect Relationship to Gesture between Intent and Effect
Coordinate System		*Object / Interactable*	Coordinate system to process the gesture is based on an object
		Region	Coordinate system to process the gesture is based on a region
		World	Coordinate system to process the gesture is based on the world
		User	Coordinate system to process the gesture is based on the user
		Interactor	Coordinate system to process the gesture is based on the interactors
		Independent	No particular coordinate system is needed to process the gesture
		Mixed Dependencies	Use combination of coordinate system
Interaction Context		*Object*	Gestures require interaction with specific objects
		Region	Gestures require interaction with region-specific context
		World	Gesture require interaction with the world
		User	Gestures require interaction with the user
		Mixed Interaction Context	Gestures require interaction with multiple kinds of above components
		No Context	Gestures do not require interaction within any context
Temporal		*Continuous*	Action/task is performed during gesture
		Discrete	Action/task is performed after completion of gesture
Environment	***Region***	*Region-Associated*	Effect of gesture is relevant to which region it is performed in
		Region-Independent	Effect of gesture is independent from region
Social Context		*Private*	Only me
		Personal	My friends
		Social Groups	My teammates
		Public	Anyone else
User	***Proximity***	*Personal Space*	Gesture is performed in user's Personal Space
		Peripersonal Space	Gesture is performed in user's Peripersonal Space
		Extrapersonal Space	Gesture is performed in user's Extrapersonal Space
		Not Relevant	Gesture is performed in any space
	Posture	*Standing*	Gesture is based on User in the standing posture
		Sitting	Gesture is based on User in the sitting posture
		Lying Down	Gesture is based on User in the lying posture
		Other postures	Gesture is based on User in other postures not listed above
	Mobility	*Stationary*	Gesture is based on if the User is stationary
		Mobile	Gesture is based on if the User is travelling
		Mobile/Transportation Method	Gesture is based on the User's transportation method, e.g. bicycle, bus, car
Audience		*Human*	Gesture has human as the audience
		Rigid System	Gesture has a rule-based program as the audience
		Intelligent Agent	Gesture has an intelligent agent similar to human

Gesture Taxonomy
Breaking down the “Nature Dimension”

“Nature” Dimension in Previous Taxonomies

The definition of Nature is **"the mapping from gestures to their meaning"**

Nature

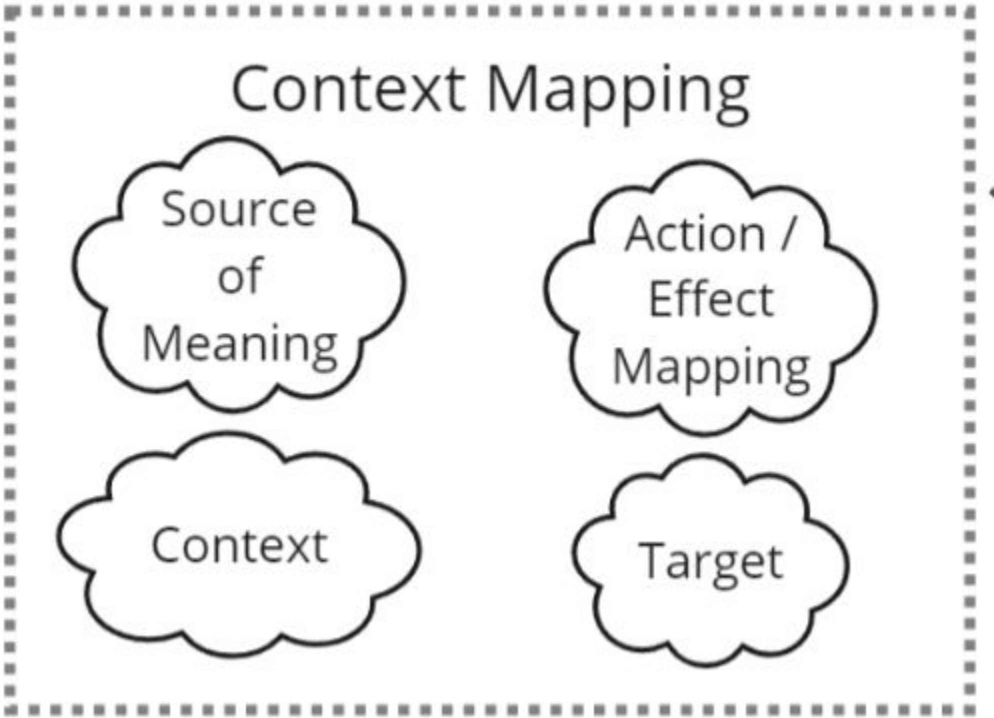
- Physical: Gesture acts physically on objects.
- Metaphorical: Gesture indicates a metaphor.
- Symbolic: Gesture visually depicts a symbol.
- Abstract: Gesture-referent mapping is arbitrary.

Additional Dimensions

We propose the addition of these dimensions to replace Nature:

- **Source of Meaning**
- **Target**
- **Action Mapping**
- **Effect Mapping**

These are included in the Spatial Interaction Model.



Gesture Mapping

Dimensions	Sub-dimensions	Categories	Description
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		Indirect	Indirect Relationship to Gesture between Intent and Action
Effect Mapping		*Direct*	Direct Relationship between Intent and Effect
		Indirect	Indirect Relationship to Gesture between Intent and Effect
Coordinate System		[illegible]	[illegible]
		Region	Coordinate system to process the gesture is based on a region
		World	Coordinate system to process the gesture is based on the world
		User	Coordinate system to process the gesture is based on the user
		[illegible]	[illegible]

Source of Meaning Dimension

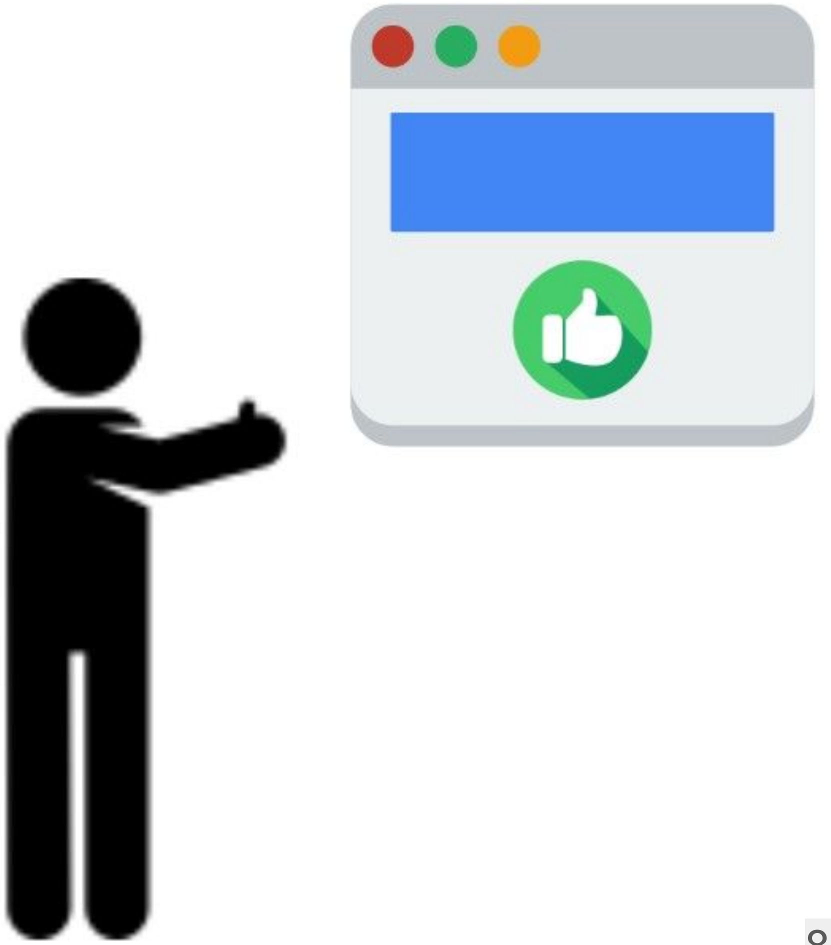
Nature is transformed to Source of Meaning dimension

Dimensions	Sub-dimensions	Categories	Description
	Source of Meaning	*Physical*	Gesture derives its meaning from laws of physics
		Hyperphysical	Gesture derives its meaning from an alternate laws of physics
		Universal	Gesture derives its meaning from a generally universal set of values
		Cultural	Gesture derives its meaning from shared cultural values
		None	Gesture does not derives its meaning from any particular source; its arbitrary
	Target	*Has Target*	Gesture has at least a target to interact with
		No Target	Gesture has no target to interact with
	Action Mapping	*Direct*	Direct Relationship between Intent and Action
		Indirect	Indirect Relationship to Gesture between Intent and Action
	Effect Mapping	*Direct*	Direct Relationship between Intent and Effect
		Indirect	Indirect Relationship to Gesture between Intent and Effect
		Object / Interactable	Coordinate system to process the gesture is based on an object
		[illegible]	[illegible]

Target Dimension

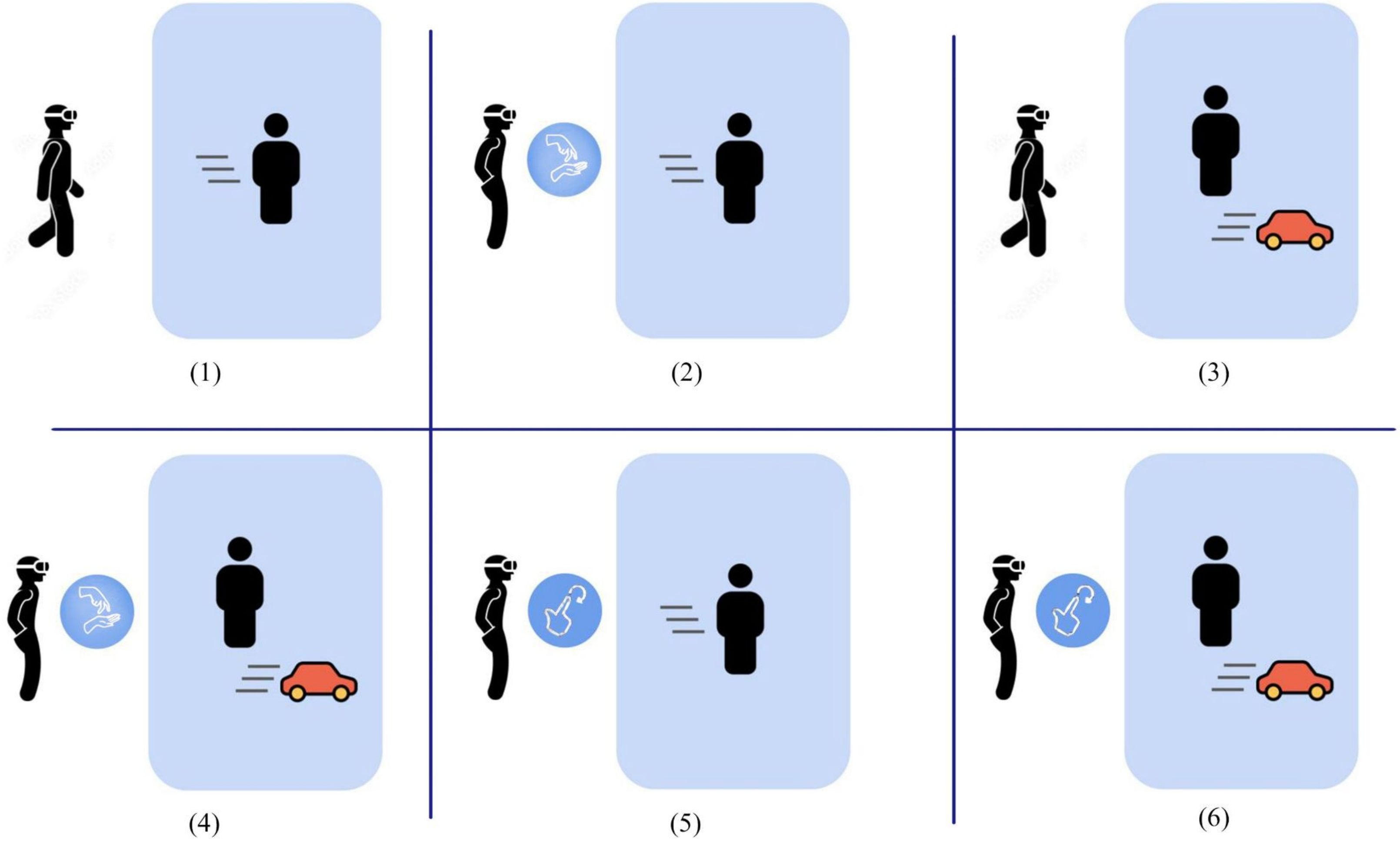
In the previous taxonomies' Nature dimension, physical is the only category with a target.

However, consider a thumbs up at a User Interface to show approval.



Action Mapping and Effect Mapping Dimension

Dimensions	Sub-dimensions	Categories	Description
Source of Meaning		*Physical*	Gesture derives its meaning from laws of physics
		Hyperphysical	Gesture derives its meaning from an alternate laws of physics
		Universal	Gesture derives its meaning from a generally universal set of values
		Cultural	Gesture derives its meaning from shared cultural values
		None	Gesture does not derives its meaning from any particular source; its arbitrary
Target		*Has Target*	Gesture has at least a target to interact with
		No Target	Gesture has no target to interact with
Action Mapping		*Direct*	Direct Relationship between Intent and Action
		Indirect	Indirect Relationship to Gesture between Intent and Action
Effect Mapping		*Direct*	Direct Relationship between Intent and Effect
		Indirect	Indirect Relationship to Gesture between Intent and Effect
Coordinate System		[illegible]	[illegible]
		Region	Coordinate system to process the gesture is based on a region
		World	Coordinate system to process the gesture is based on the world
		User	Coordinate system to process the gesture is based on the user
		[illegible]	[illegible]


(1)
(2)
(3)
(4)
(5)
(6)

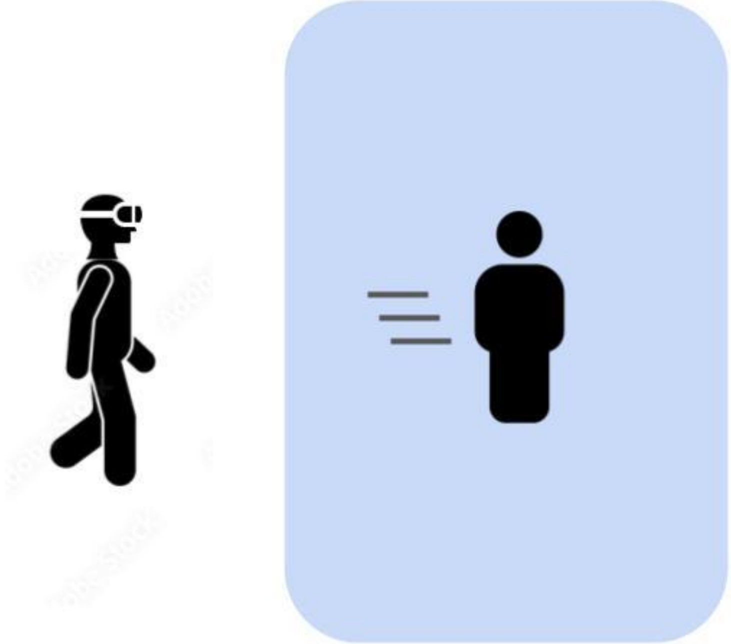
Case 1

User avatar moves when the user's legs move.

Nature: Physical

vs.

Source of Meaning:	Physical
Action Mapping:	Direct
Effect Mapping:	Direct
Target:	None (self)



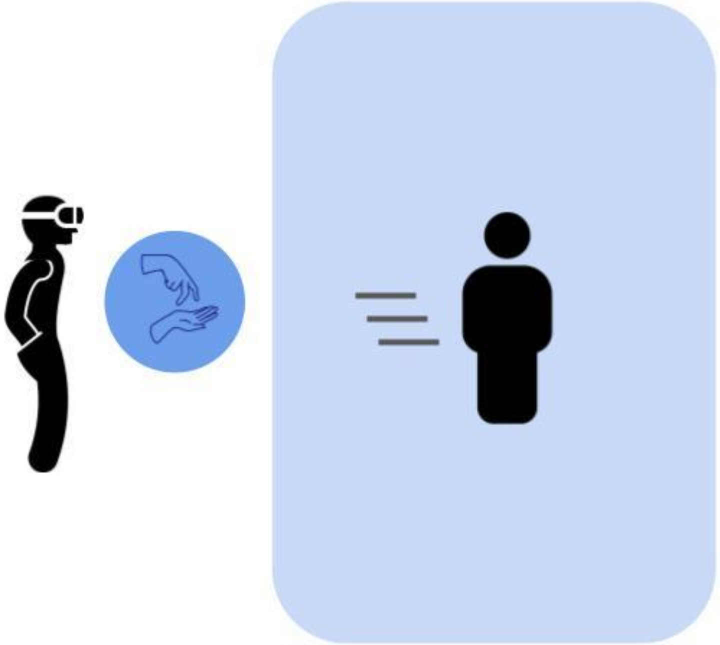
Case 2

User avatar moves when the user's fingers mimic legs and move.

Nature: Metaphor

vs.

Source of Meaning:	Physical
Action Mapping:	Indirect
Effect Mapping:	Direct
Target:	None (self)



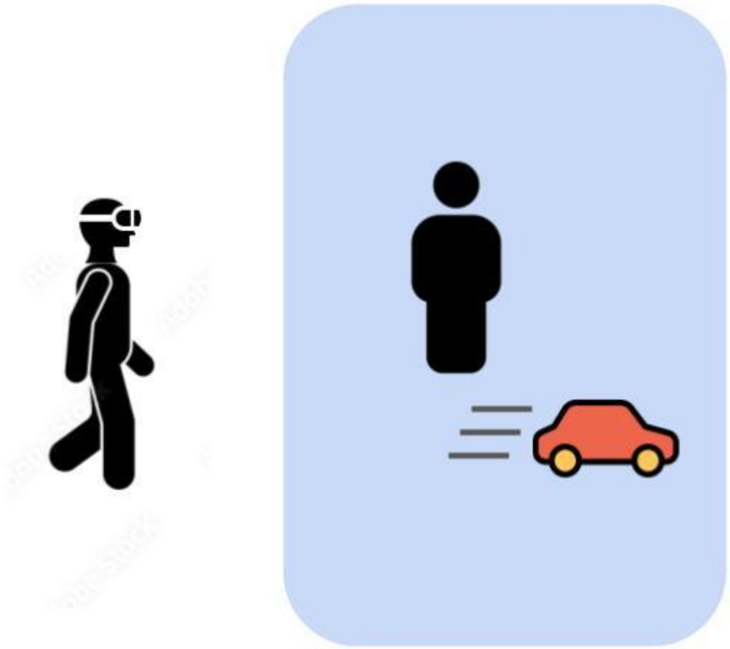
Case 3

A car moves when the user's legs move

Nature: Arbitrary

vs.

Source of Meaning:	Physical
Action Mapping:	Direct
Effect Mapping:	Indirect
Target:	Car



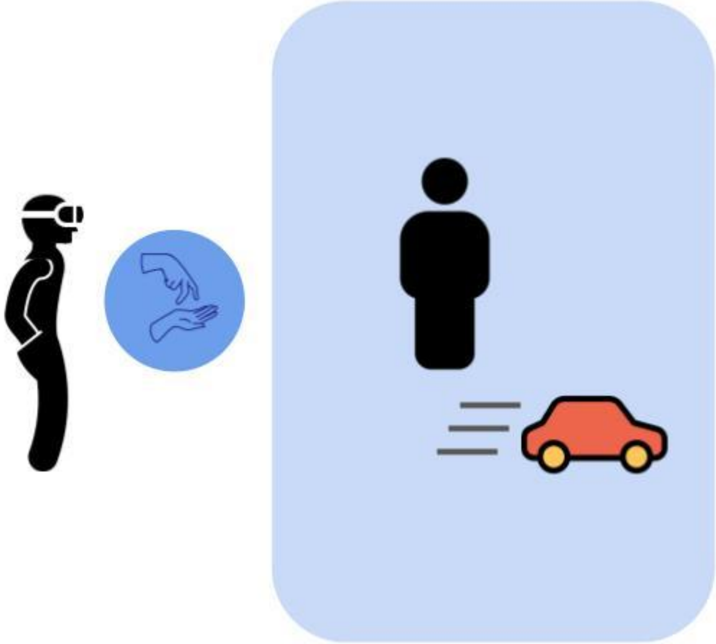
Case 4

A car moves when the user's fingers mimic legs and move

Nature: Arbitrary

vs.

Source of Meaning:	Physical
Action Mapping:	Indirect
Effect Mapping:	Indirect
Target:	Car



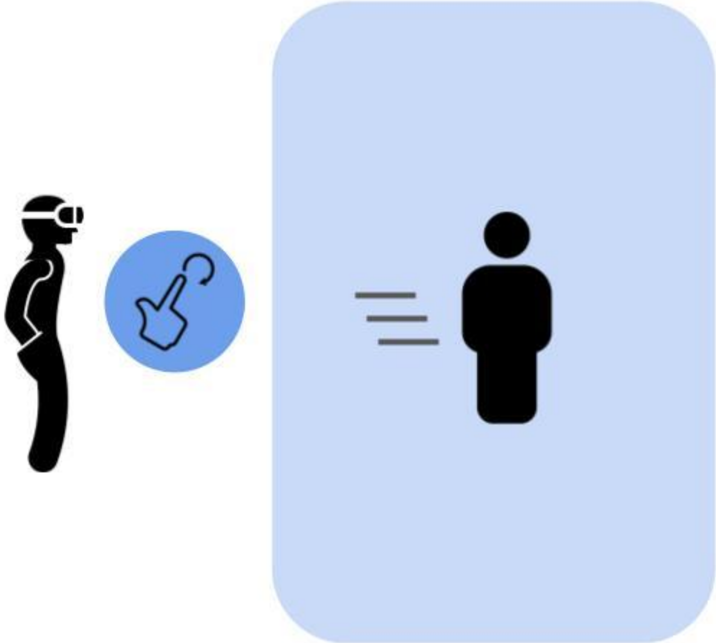
Case 5

User avatar moves when the user draws a symbol (wheel) to represent run

Nature: Metaphor

vs.

Source of Meaning:	Cultural
Action Mapping:	Indirect
Effect Mapping:	Direct
Target:	None (Self)



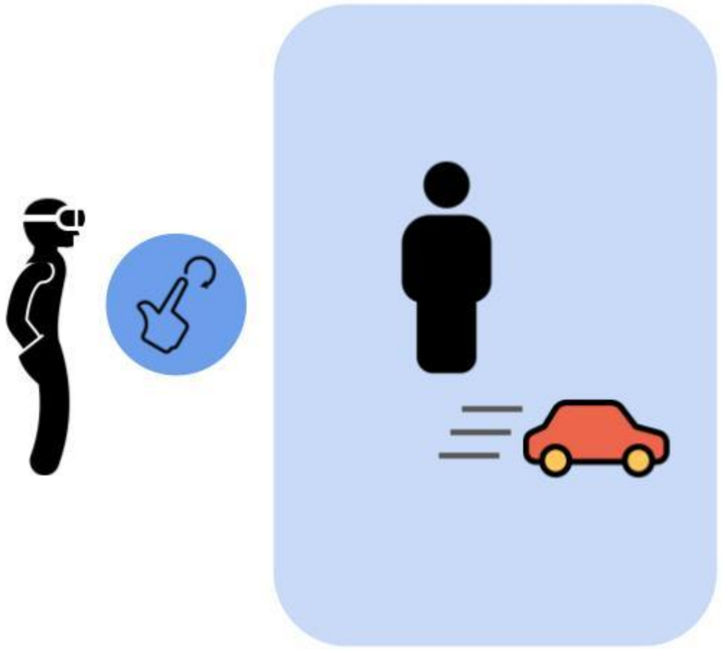
Case 6

A car moves when the user draws a symbol (wheel) to represent run.

Nature: Arbitrary.

vs.

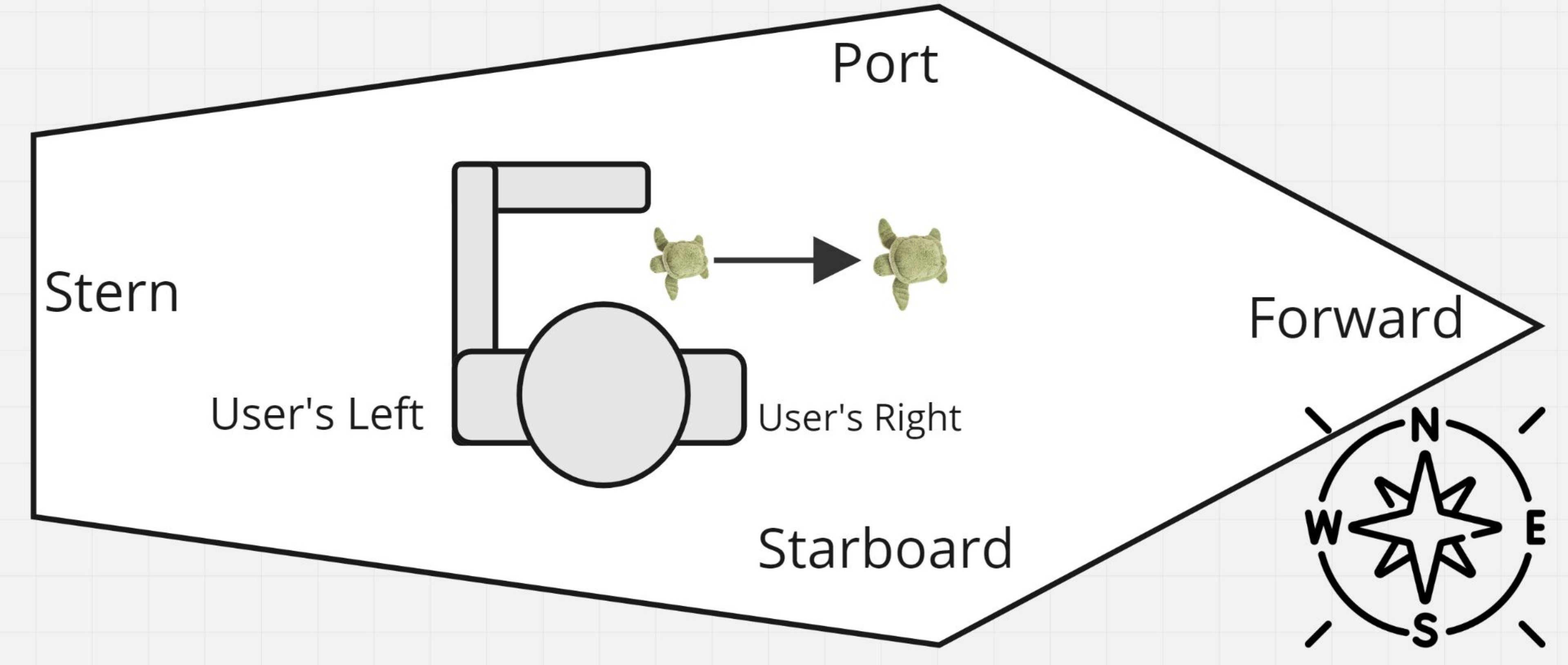
Source of Meaning:	Cultural
Action Mapping:	Indirect
Effect Mapping:	Indirect
Target:	Car

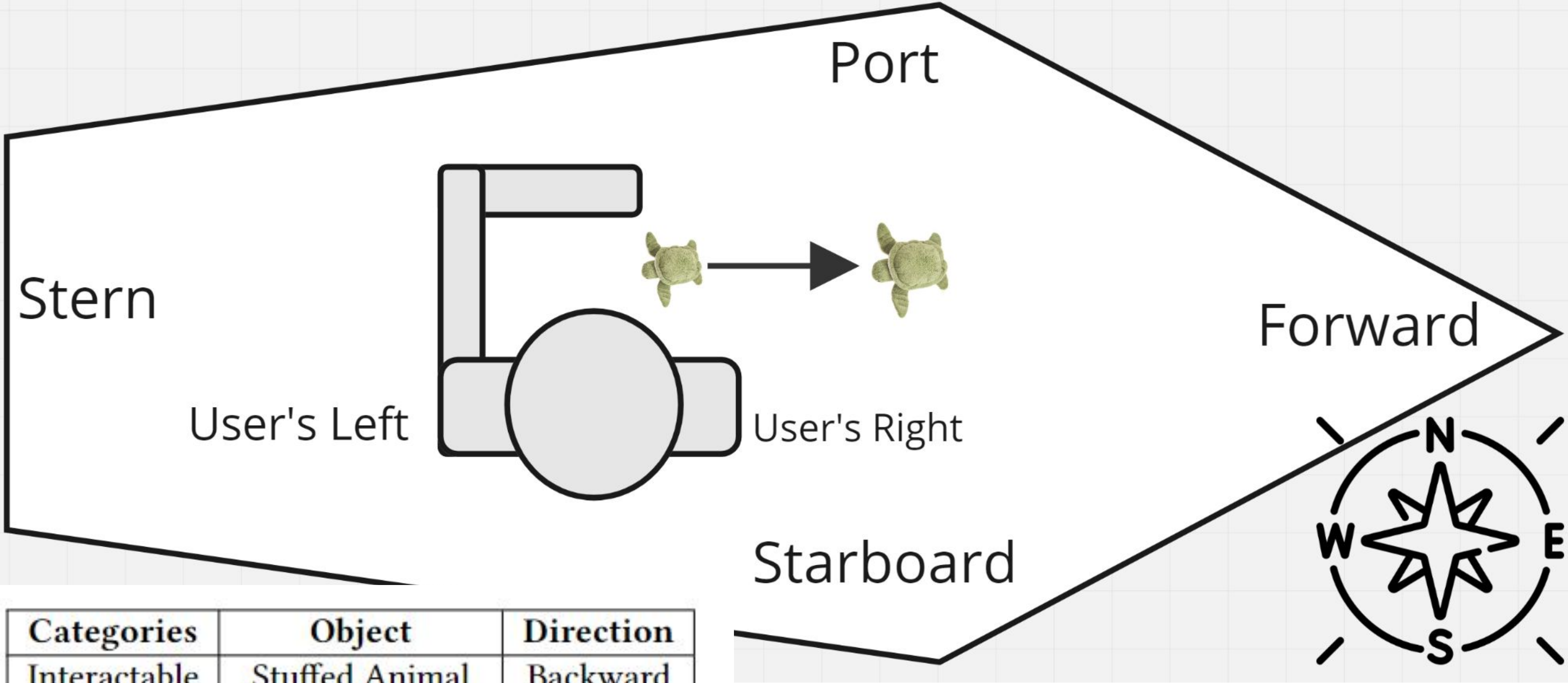


Gesture Mapping Continued

Gesture Mapping

Effect Mapping	*Direct*	Direct Relationship between Intent and Effect
	Indirect	Indirect Relationship to Gesture between Intent and Effect
Coordinate System	*Object / Interactable*	Coordinate system to process the gesture is based on an object
	Region	Coordinate system to process the gesture is based on a region
	World	Coordinate system to process the gesture is based on the world
	User	Coordinate system to process the gesture is based on the user
	Interactor	Coordinate system to process the gesture is based on the interactors
	Independent	No particular coordinate system is needed to process the gesture
	Mixed Dependencies	Use combination of coordinate system
Interaction Context	*Object*	Gestures require interaction with specific objects
	Region	Gestures require interaction with region-specific context
	World	Gesture require interaction with the world
	User	Gestures require interaction with the user
	Mixed Interaction Context	Gestures require interaction with multiple kinds of above components


Port
Stern
Forward
User's Left
User's Right
Starboard
N
W
E
S



Categories	Object	Direction
Interactable	Stuffed Animal	Backward
Interactor	User's Left Hand	Forward
User	User	Right
Region	Ship	Forward
World	World	East

Gesture Mapping - Interaction Context

		Independent	No particular coordinate system is needed to process the gesture
		Mixed Dependencies	Use combination of coordinate system
Interaction Context		*Object*	Gestures require interaction with specific objects
		Region	Gestures require interaction with region-specific context
		World	Gesture require interaction with the world
		User	Gestures require interaction with the user
		Mixed Interaction Context	Gestures require interaction with multiple kinds of above components
		No Context	Gestures do not require interaction within any context
Temporal		*Continuous*	Action/task is performed during gesture
		Discrete	Action/task is performed after completion of gesture
Environment	***Region***	*Region-Associated*	Effect of gesture is relevant to which region it is performed in
		Region-Independent	Effect of gesture is independent from region
Social Context		*Private*	Only me
		Personal	My friends
		Social Groups	My teammates
		Public	Anyone else

Gesture Mapping - Environmental, Social Contexts

Interaction Context		*Object*	Gestures require interaction with specific objects
		Region	Gestures require interaction with region-specific context
		World	Gesture require interaction with the world
		User	Gestures require interaction with the user
		Mixed Interaction Context	Gestures require interaction with multiple kinds of above components
		No Context	Gestures do not require interaction within any context
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		Region-Independent	Effect of gesture is independent from region
Social Context		*Private*	Only me
		Personal	My friends
		Social Groups	My teammates
		Public	Anyone else
		Personal Space	Gesture is performed in user's Personal Space

“OK” Sign

OK (America)

Money (Japan)

Mudra (seal of consciousness in yoga)

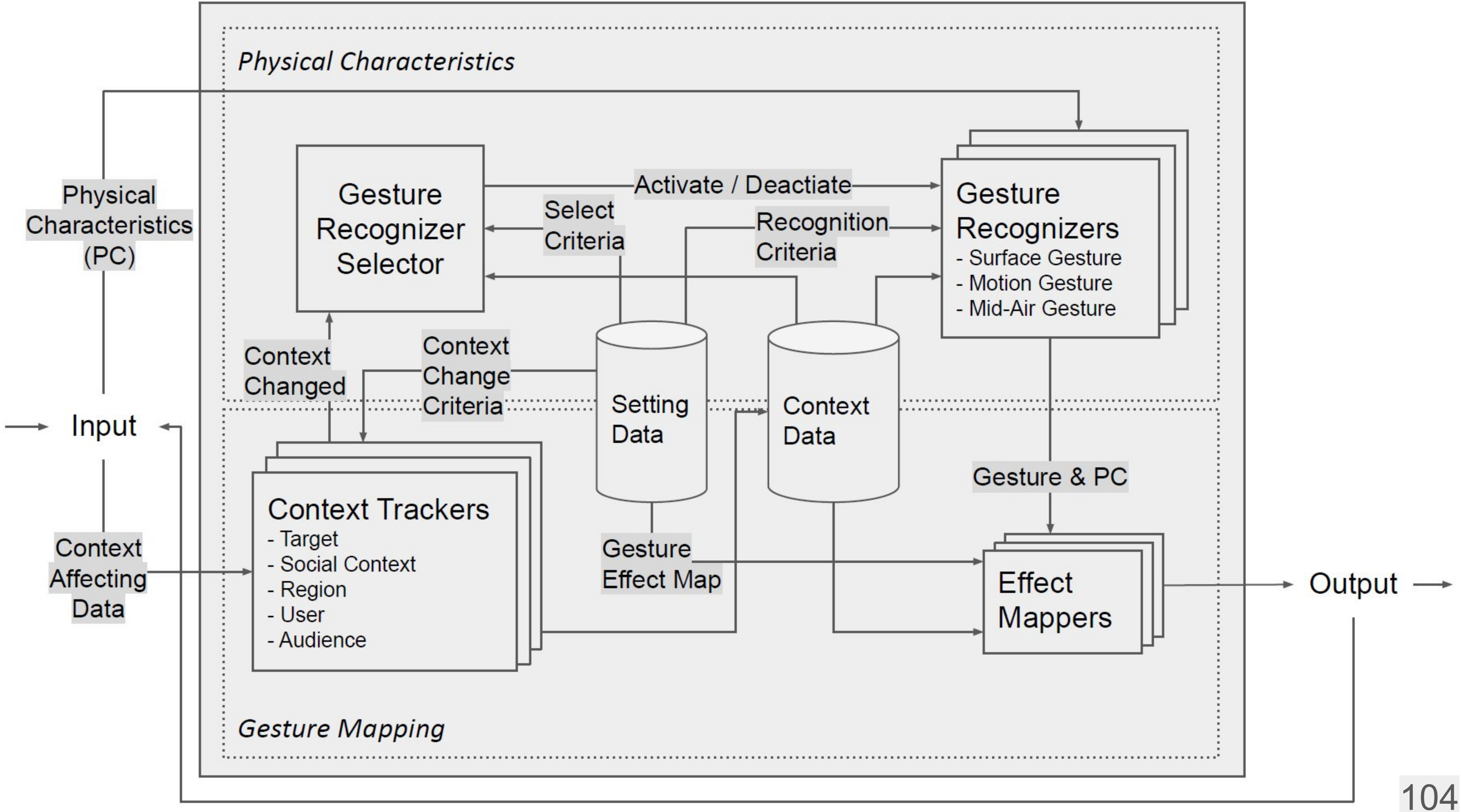
Sun (North American Plains Indian Sign Language)

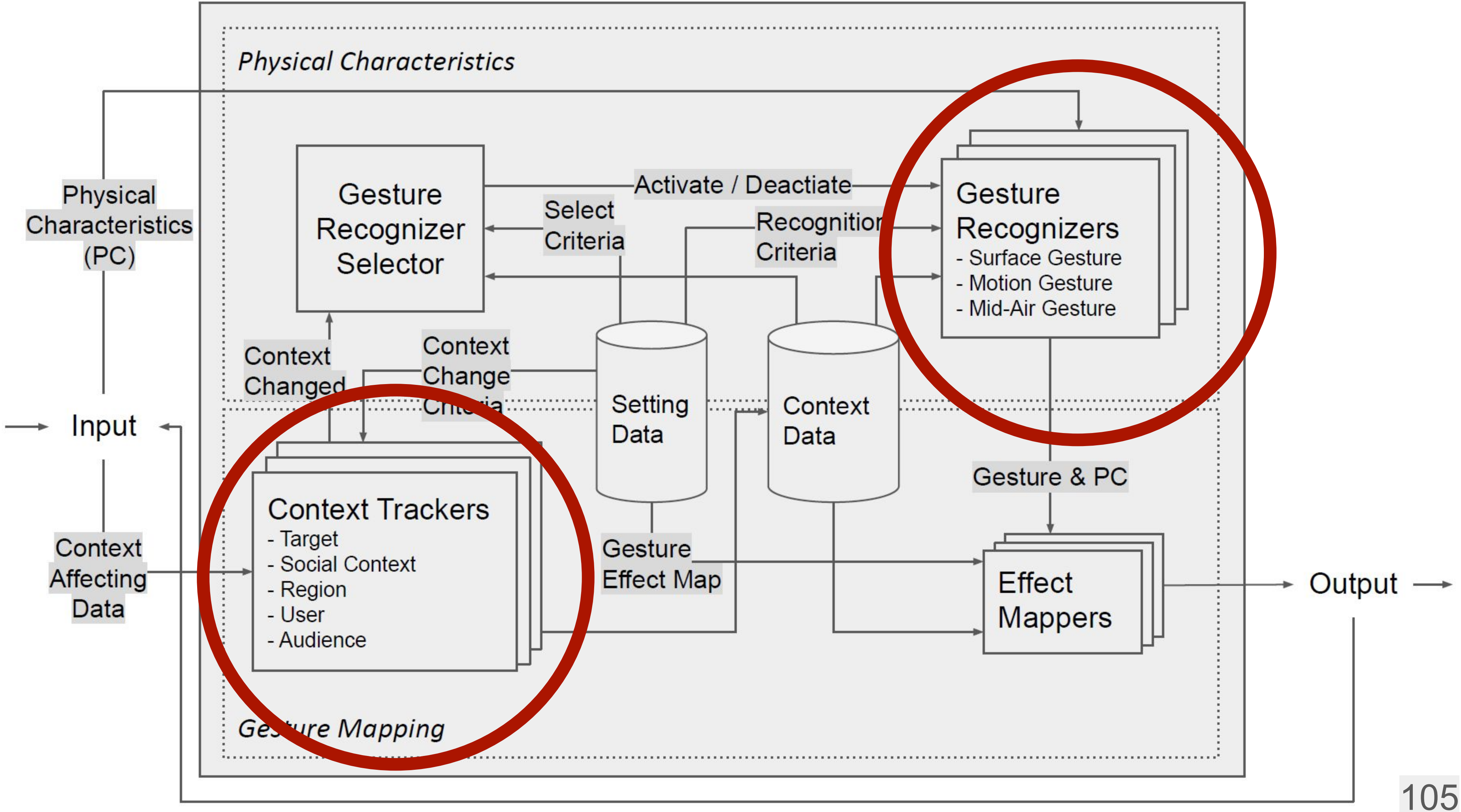
And many more..

Gesture Mapping - User Contexts

Social Context		*Personal*	My friends
		Social Groups	My teammates
		Public	Anyone else
User	***Proximity***	*Personal Space*	Gesture is performed in user's Personal Space
		Peripersonal Space	Gesture is performed in user's Peripersonal Space
		Extrapersonal Space	Gesture is performed in user's Extrapersonal Space
		Not Relevant	Gesture is performed in any space
	Posture	*Standing*	Gesture is based on User in the standing posture
		Sitting	Gesture is based on User in the sitting posture
		Lying Down	Gesture is based on User in the lying posture
		Other postures	Gesture is based on User in other postures not listed above
	Mobility	*Stationary*	Gesture is based on if the User is stationary
		Mobile	Gesture is based on if the User is travelling
		Mobile/Transportation Method	Gesture is based on the User's transportation method, e.g. bicycle, bus, car
Audience		*Human*	Gesture has human as the audience
		Rigid System	Gesture has a rule-based program as the audience
		Intelligent Agent	Gesture has an intelligent agent similar to human

Gesture System Architecture


Physical Characteristics
Gesture Recognizer Selector
Activate / Deactiate
Select Criteria
Recognition Criteria
Gesture Recognizers
- Surface Gesture
- Motion Gesture
- Mid-Air Gesture
Physical Characteristics (PC)
Context Changed
Context Change Criteria
Setting Data
Context Data
Input
Gesture & PC
Context Trackers
- Target
- Social Context
- Region
- User
- Audience
Context Affecting Data
Gesture Effect Map
Effect Mappers
Output
Gesture Mapping


Physical Characteristics
Physical Characteristics (PC)
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Select Criteria
Recognition Criteria
Gesture Recognizers
- Surface Gesture
- Motion Gesture
- Mid-Air Gesture
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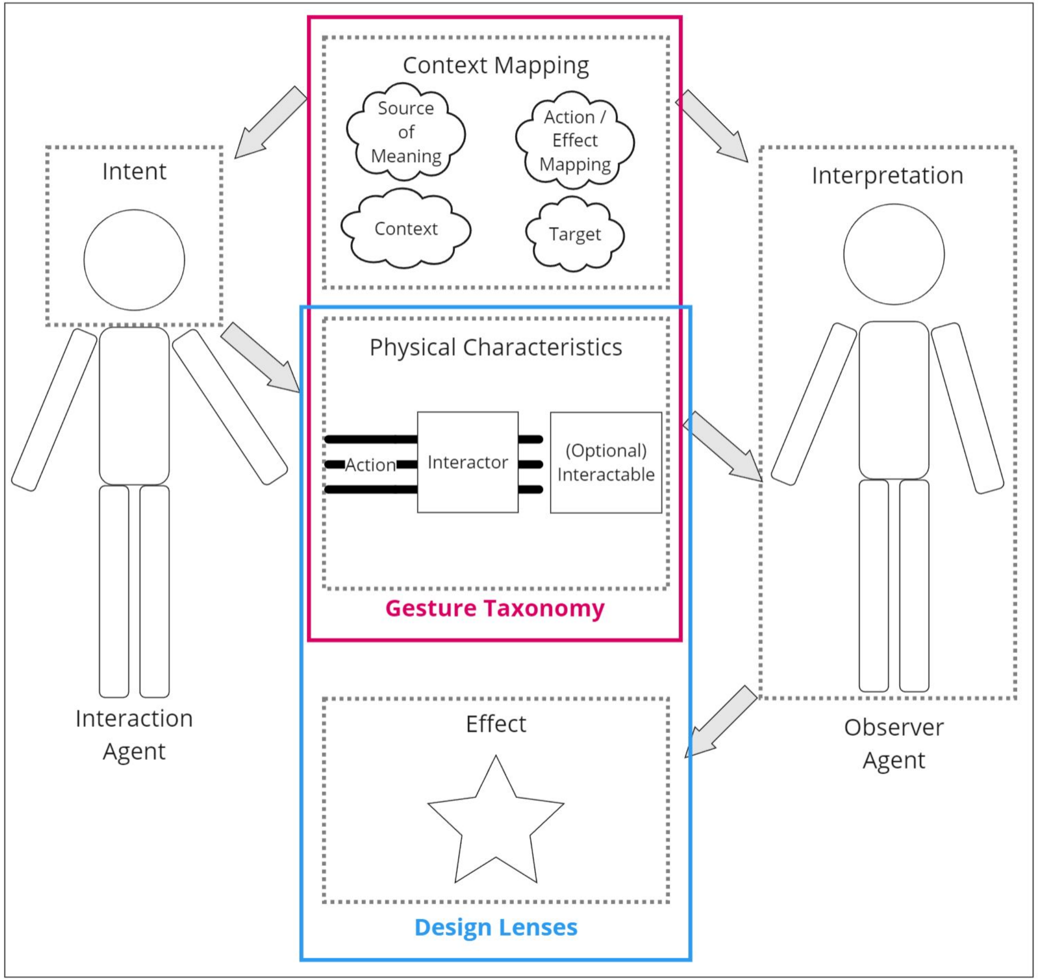
Context Trackers
- Target
- Social Context
- Region
- User
- Audience
Context Affecting Data
Gesture Effect Map
Effect Mappers
Output
Gesture Mapping

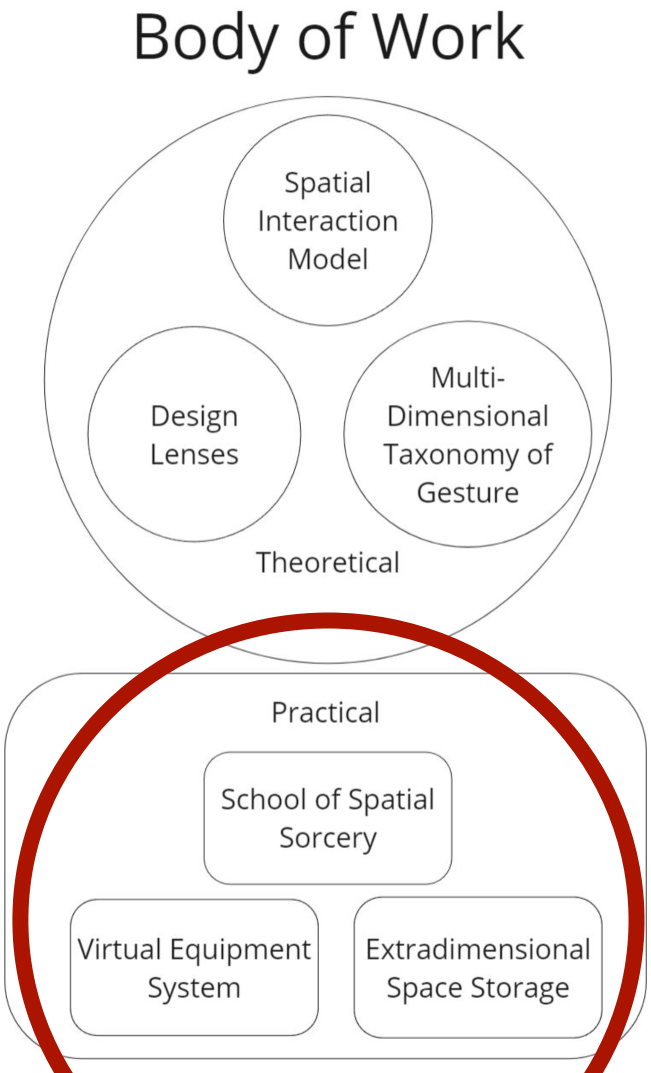
Putting It All Together

- **Spatial Interaction Model**
- **Design Lenses**
- **Gesture Taxonomy**

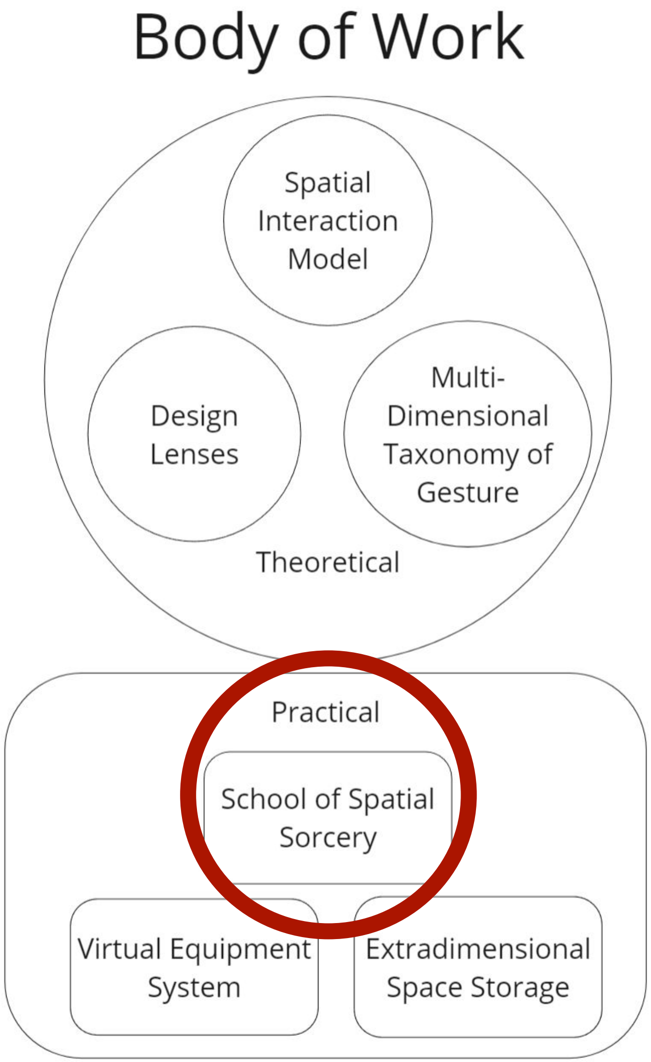
Spatial Interaction Model



Practical Components



School of Spatial Sorcery



Smart Home / Simulated Environment (Precursor to School of Spatial Sorcery)

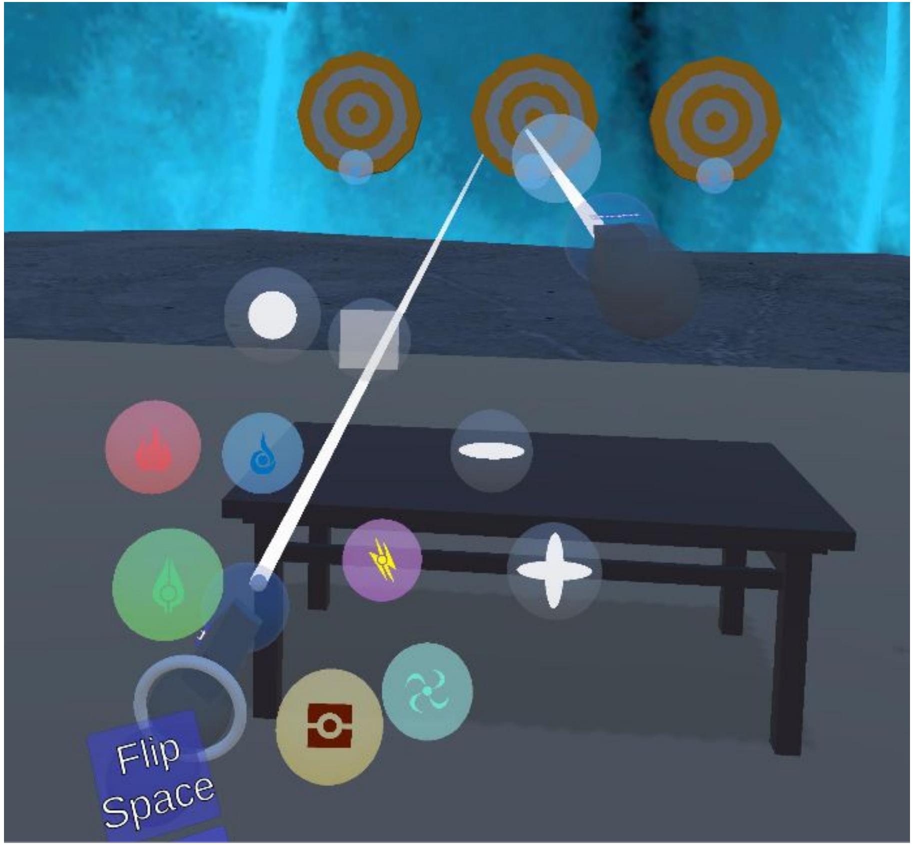
Zezhen Xu, **Powen Yao**, and Vangelis Lympouridis. "Virtual Control Interface: A System for Exploring AR and IoT Multimodal Interactions Within a Simulated Virtual Environment". HCII 2021

Powen Yao et al. "Toward Using Multi-Modal Machine Learning for User Behavior Prediction in Simulated Smart Home for Extended Reality". IEEE VR 2022

Powen Yao et al. "Using Multi-modal Machine Learning for User Behavior Prediction in Simulated Smart Home for Extended Reality". VAMR 2022 / HCII 2022

Introduction

The School of Spatial Sorcery is an exploration of spatial interactions using the creation of spells as a **substitute** for day-to-day interaction tasks.

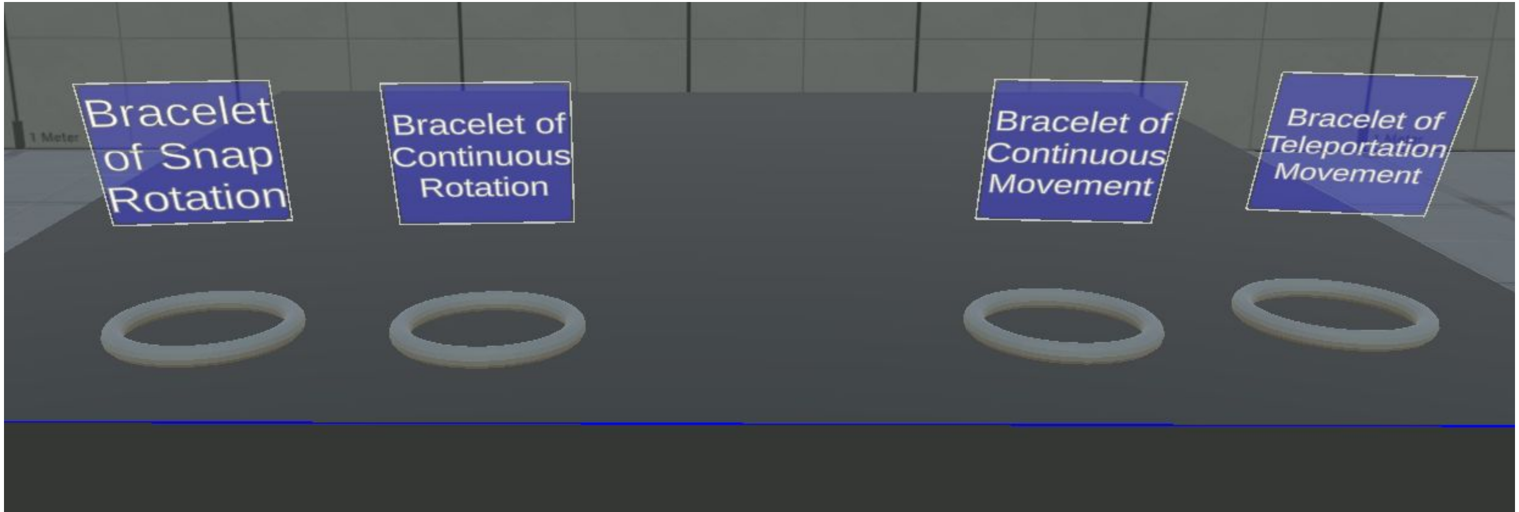


Arcane Symbols of Elements and of Shapes

Equipment as Metaphor for Having Abilities

Handheld Equipment

Wearable Equipment

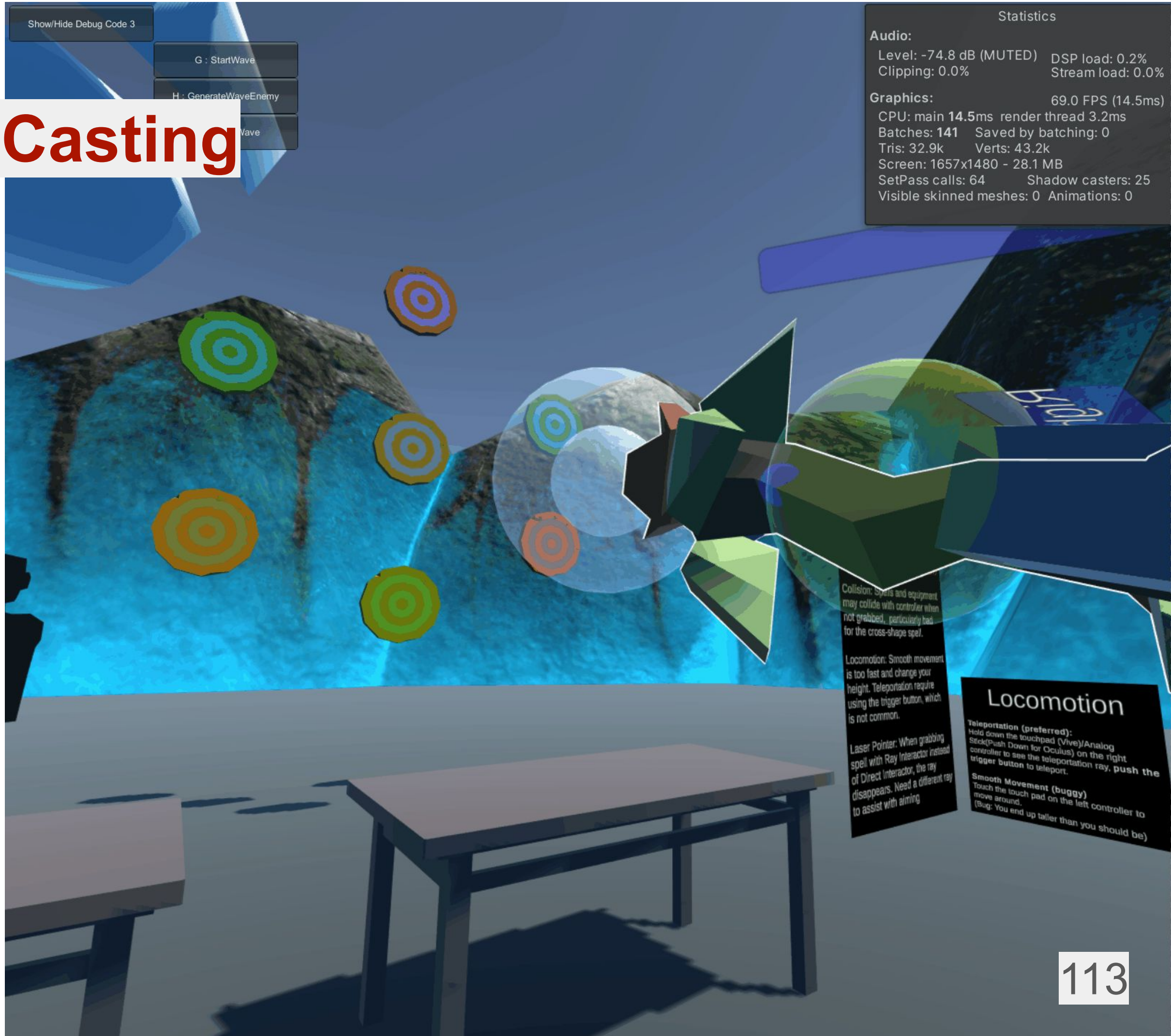


Handheld Equipment

Wand of Rotational Casting

Cast different elemental spells as you change the rotation of the Roll Axis.

Comes in Positional variety and the Angular Jerk variety.



Spellbooks

Spellbooks are storage for arcane symbols.

Spellbooks can also be stored in storages.

Wearable Equipment

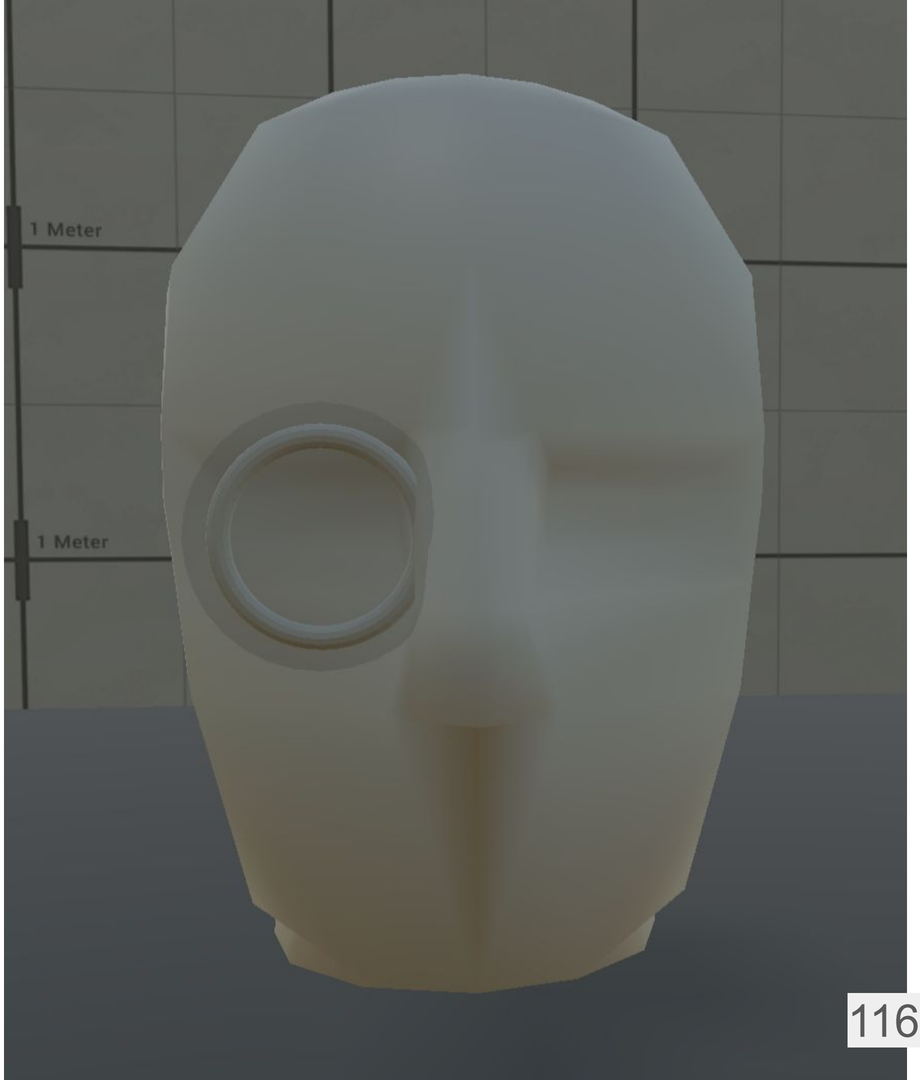
Extradimensional Sight

Extradimensional Sight allows the user to see information hidden away in another dimension.

This prevents the user from being overwhelmed by information.

User can access information based on their needs.

Managed through **Monocles**

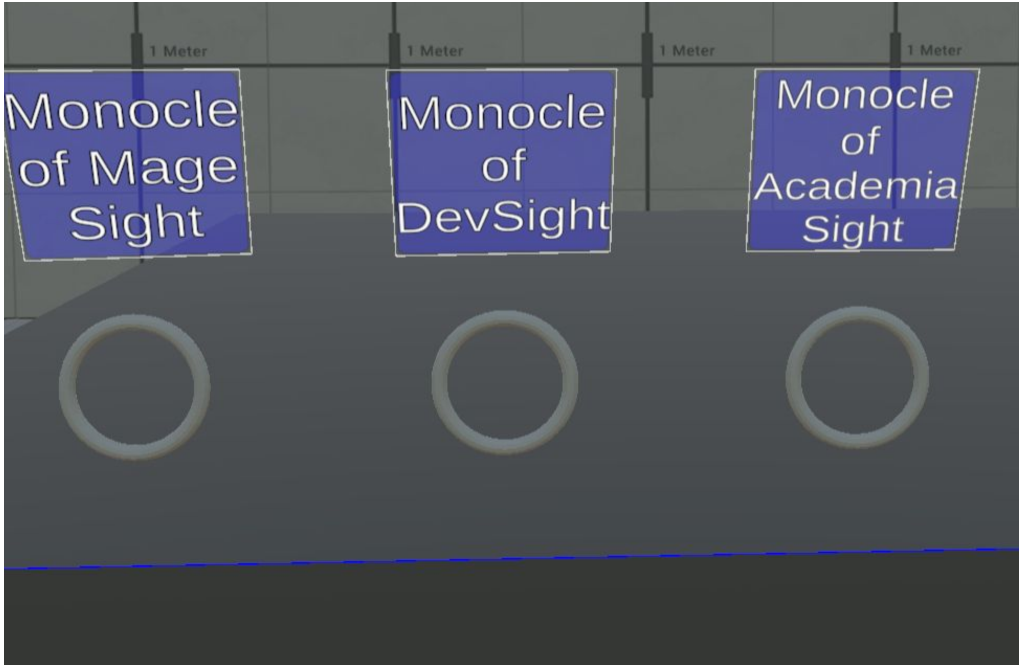


Monocle of Extradimensional Sight

Mage Sight: See ghosts, secret doors, or enemy elemental weaknesses.

Developer Sight: See and interact with user interfaces for debugging, such as a command console or level reset button.

Scholar Sight: See info about an item or a technique, such as relevant works, citations, or a summary of significance to academia.



Simple Extradimensional Storage

Type	Implementation	Description
Flipspace	Flipspace	Access by flipping an interactable upside-down
Reachspace	Sleevespace, Cloakspace	Access by passing the interactor through an Entry
Slidedoorspace	Lapel Space, Trunk Space	Access by first grabbing a handle to open the space, then by reaching in
Drawerspace	Chest Space	Access by first grabbing a handle to pull out the space, the spatial location of the content changes as the handle position changes

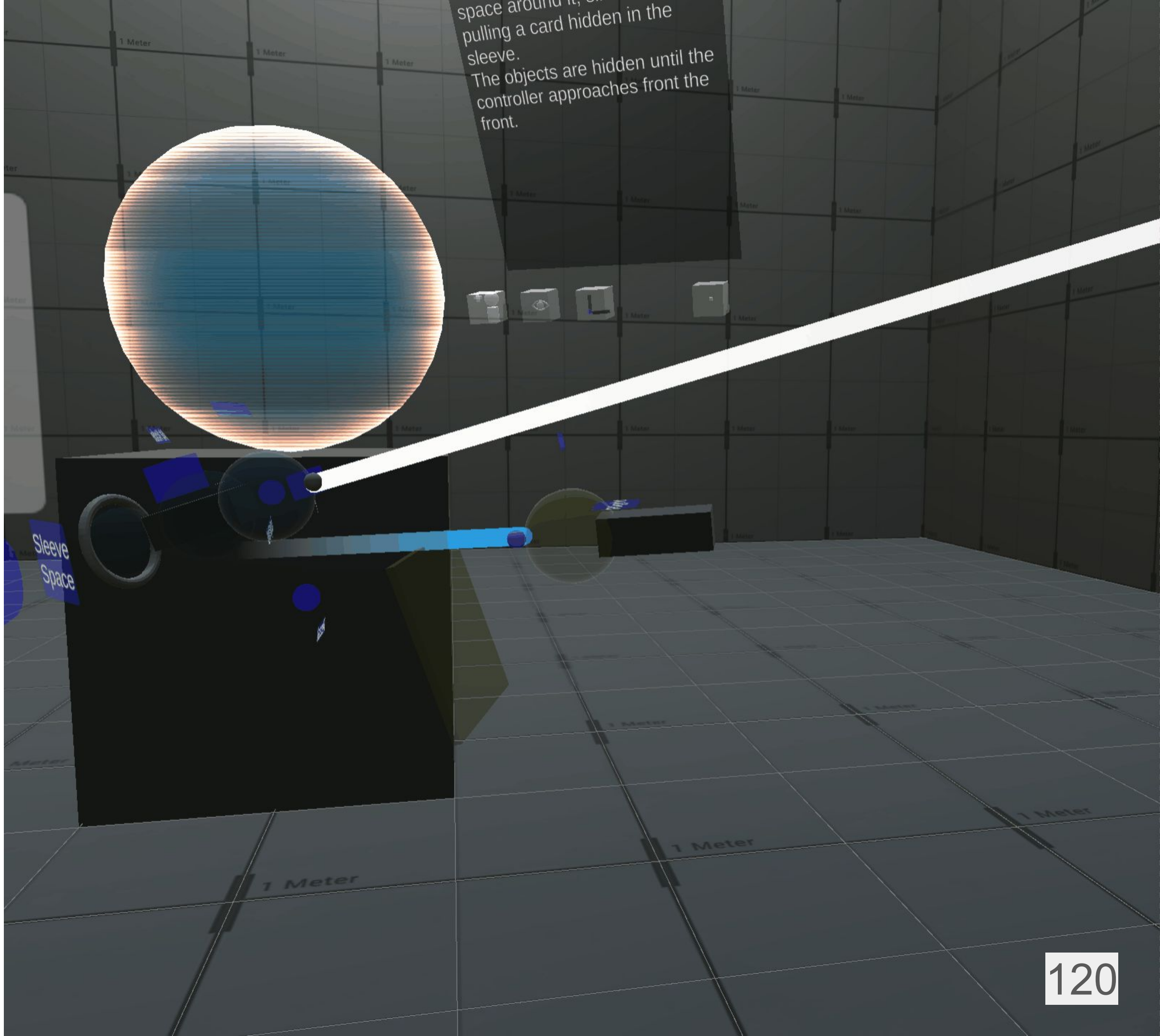
Flipspace

Access arcane symbols by flipping the controller upside down.

Sleevespace

Reachspace at user’s wrist

Access by simply **reaching** past the entry



Cloakspace

Reachspace at below user's forearm

Access by simply **reaching** past the entry

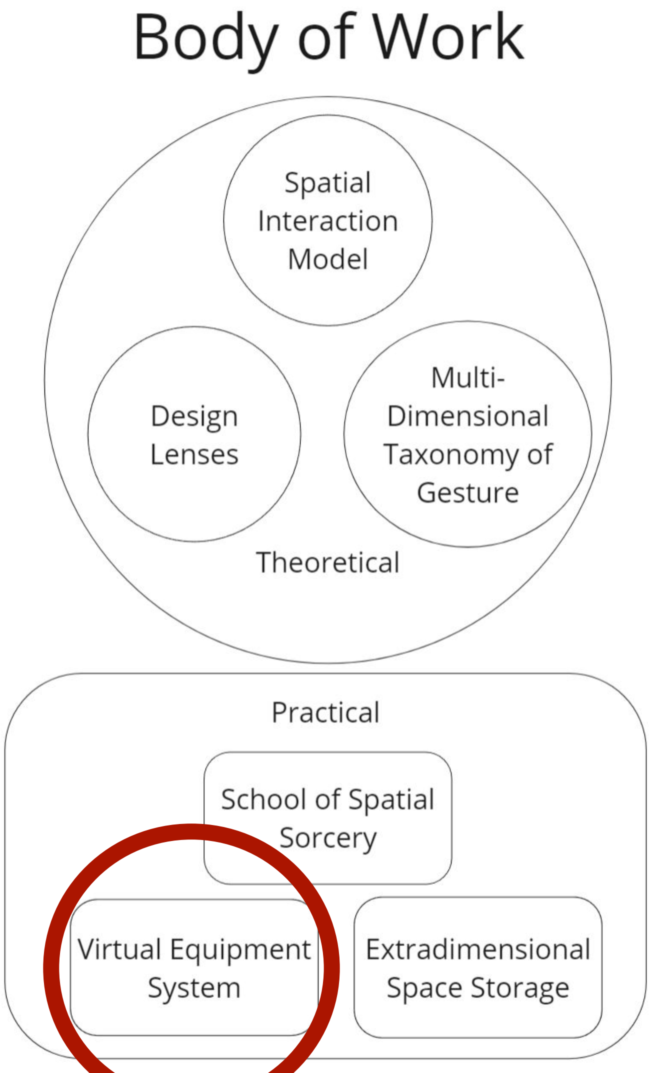
Simple Extradimensional Storage

Type	Implementation	Description
Flipspace	Flipspace	Access by flipping an interactable upside-down
Reachspace	Sleevespace, Cloakspace	Access by passing the interactor through an Entry
Slidedoorspace	Lapel Space, Trunk Space	Access by first grabbing a handle to open the space, then by reaching in
Drawerspace	Chest Space	Access by first grabbing a handle to pull out the space, the spatial location of the content changes as the handle position changes

Simple Extradimensional Storage

Type	Implementation	Description
Flipspace	Flipspace	Access by flipping an interactable upside-down
Reachspace	Sleevespace, Cloakspace	Access by passing the interactor through an Entry
Slidedoorspace	Lapel Space, Trunk Space	Access by first grabbing a handle to open the space, then by reaching in
Drawerspace	Chest Space	Access by first grabbing a handle to pull out the space, the spatial location of the content changes as the handle position changes

Virtual Equipment System



(Work listed on next slide)

VES Contribution

Powen Yao, Tian Zhu, and Michael Zyda. "Adjustable Pointer in Virtual Reality for Ergonomic Interaction". IEEE VR 2020

Powen Yao, Tian Zhu, and Michael Zyda. "Designing Virtual Equipment Systems for VR". HCII 2020

Powen Yao et al. "Interfacing with Sensory Options Using a Virtual Equipment System". SUI 2020

Powen Yao, Vangelis Lympouridis, and Michael Zyda. "Virtual Equipment System: Expansion to Address Alternate Contexts". HCII 2021

Powen Yao, Vangelis Lympouridis, and Michael Zyda. "Virtual Equipment System: Face Mask and Voodoo Doll for User Privacy and Self-Expression Options in Virtual Reality". IEEE VR 2021

Powen Yao, Shitong Shen, and Michael Zyda. "Virtual Equipment System: First Evaluation of Egocentric Virtual Equipment for Sensory Settings". VAMR 2022/HCII 2022

Introduction

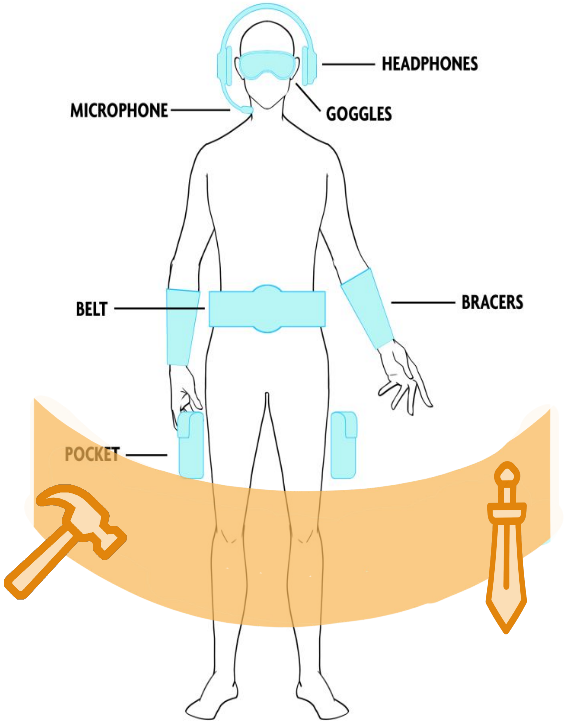
Virtual Equipment System makes use of visual **metaphors** to guide users on how to interact with their equipment and the associated functionalities based on the look and feel of the equipment.

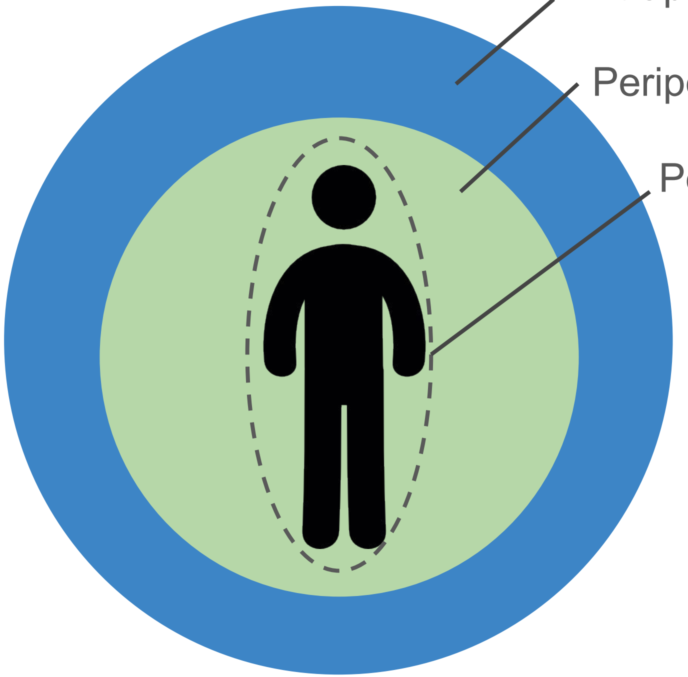
Virtual Equipment System can be integrated and implemented across different devices and systems to be part of a **universal user interface** for different extended realities.

Summary of VES

1. Manifestation
   a. **Egocentric Equipment can exist in peripersonal and extrapersonal space**
   b. **Egocentric Equipment can include traditional Exocentric Equipment and Workspace**
   c. Equipment in alternate space (list-space, tab-space, etc)
2. Action
   a. **Multiple Egocentric Equipment can be stored in the same Equipment Slot**
   b. **Egocentric Equipment in the same physical space, but in a different dimension**
   c. Accessing equipment not stored in physical space via multi-modal interaction
   d. Hybrid Interaction with other techniques
3. Effect
   a. **Alt Node Interaction**
   b. **Equipment Gestures (Motion, Surface, Tap, etc)**
   c. **Examples of different contexts**
      i. Sensory Set - Sensory Setting, Privacy Set - Privacy Options, Avatar Set - Avatar Presence

Manifestation: Equipment in Personal, Peripersonal, and Extrapersonal Space





Effect: Applying VES to Different Contexts

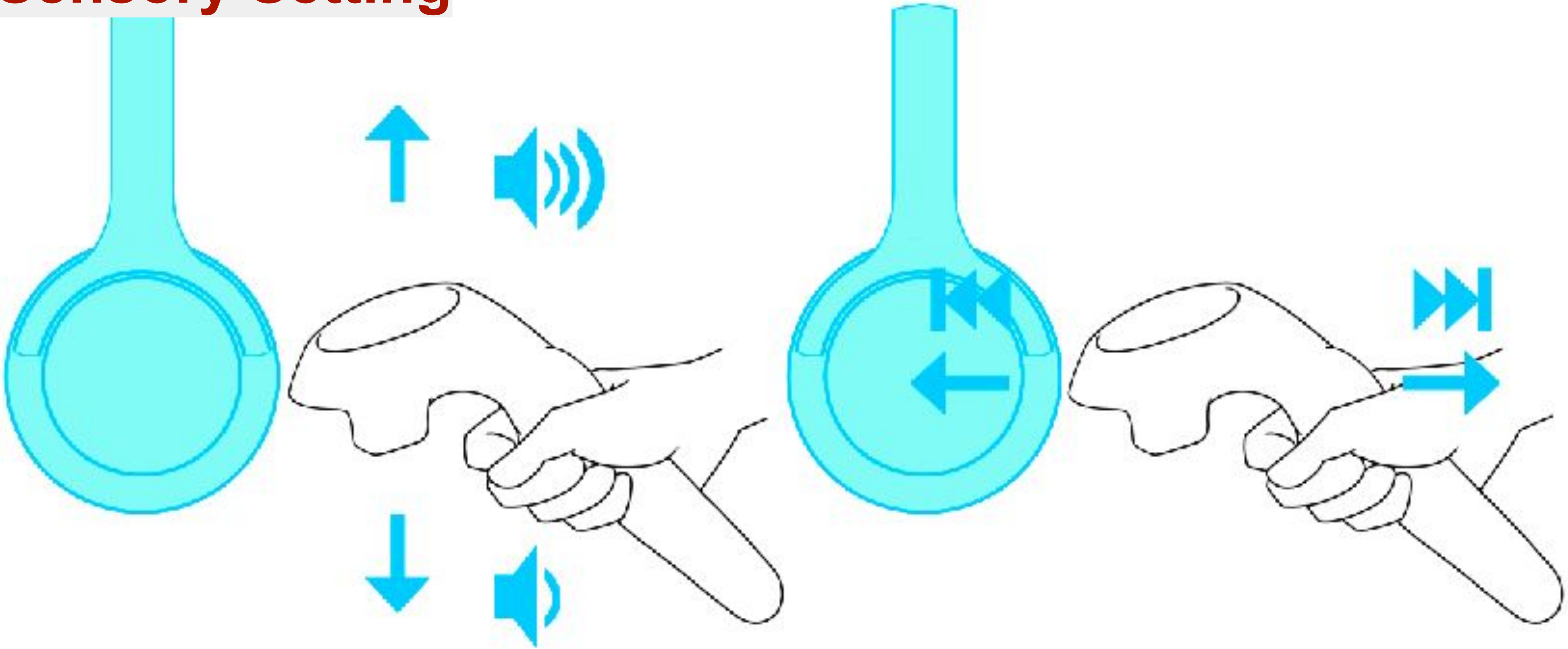
With the hyperphysical effects, we can apply VES to different contexts with different sets of Equipment.

Multiple Equipment Sets can be worn at a time.

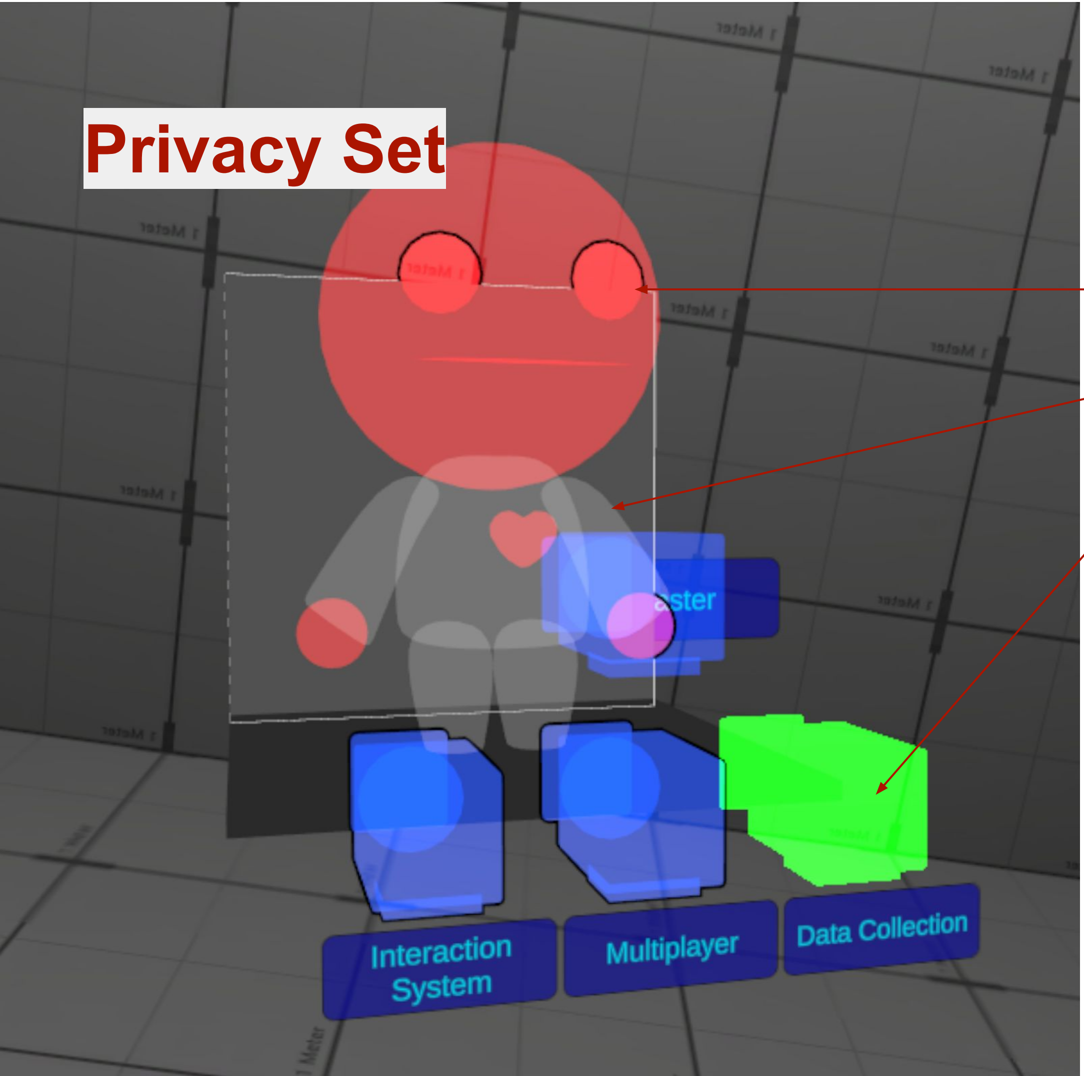
Equipment Sets

- **Sensory Set for Incoming Sensory Data**
- **Privacy Set for Outgoing User Data (Privacy)**
- Management Set for VES Management
- Cosmetic Set for Outgoing User Data (Cosmetic)
- **Avatar Set for Using Alternate Avatars**
- Dev Set for Development or Debug
- App/Game-Specific Set

Sensory Setting

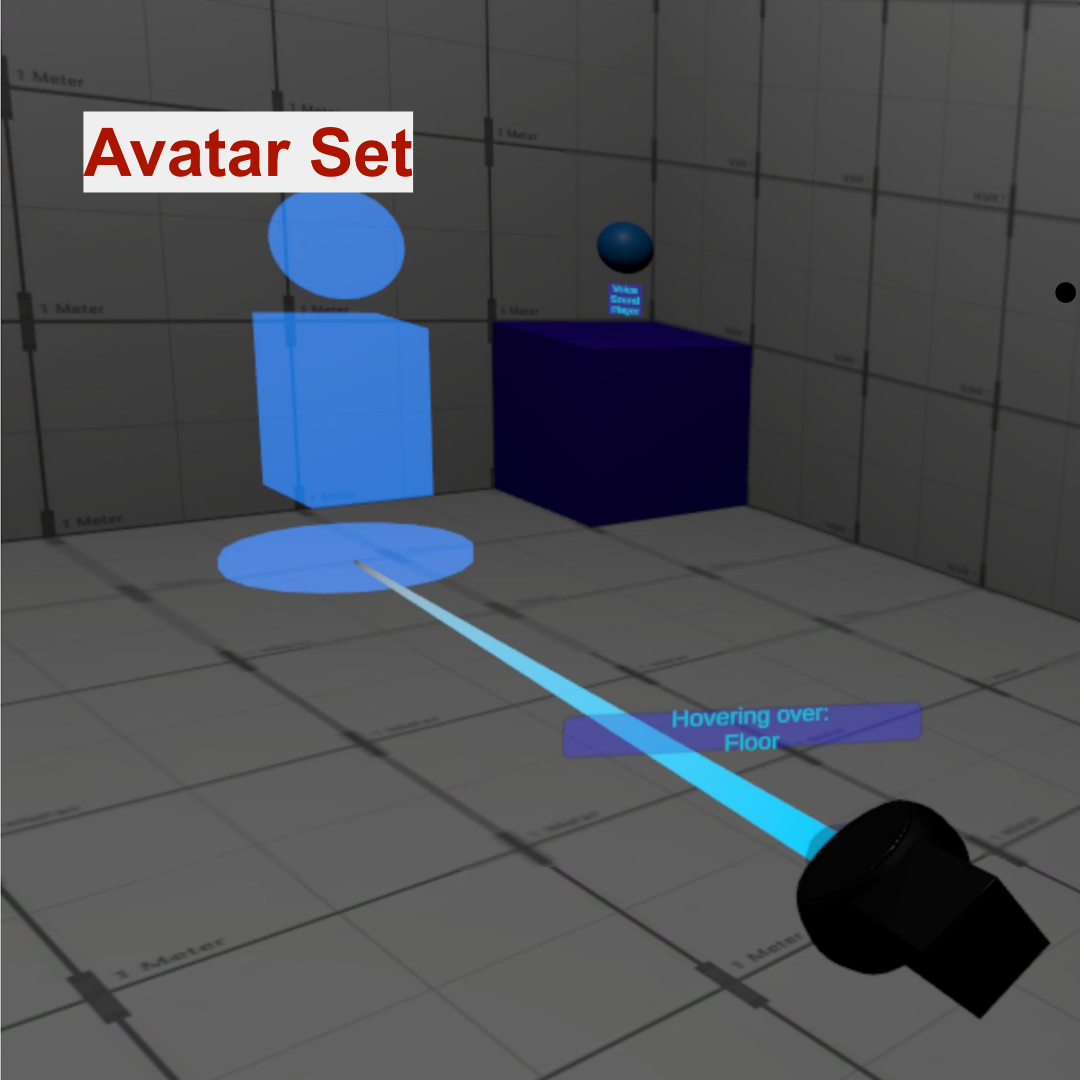


Privacy Set



- In red are body parts with tracking disabled.
- In gray are body parts that are not tracked.
- The green camera represents the perspective in which we are seeing the user's privacy data status.

Avatar Set



- User placing an **Alternate Avatar** in the virtual environment by interacting with the **Avatar Doll** at the back of the user's head

Action: Multiple Equipment Sets

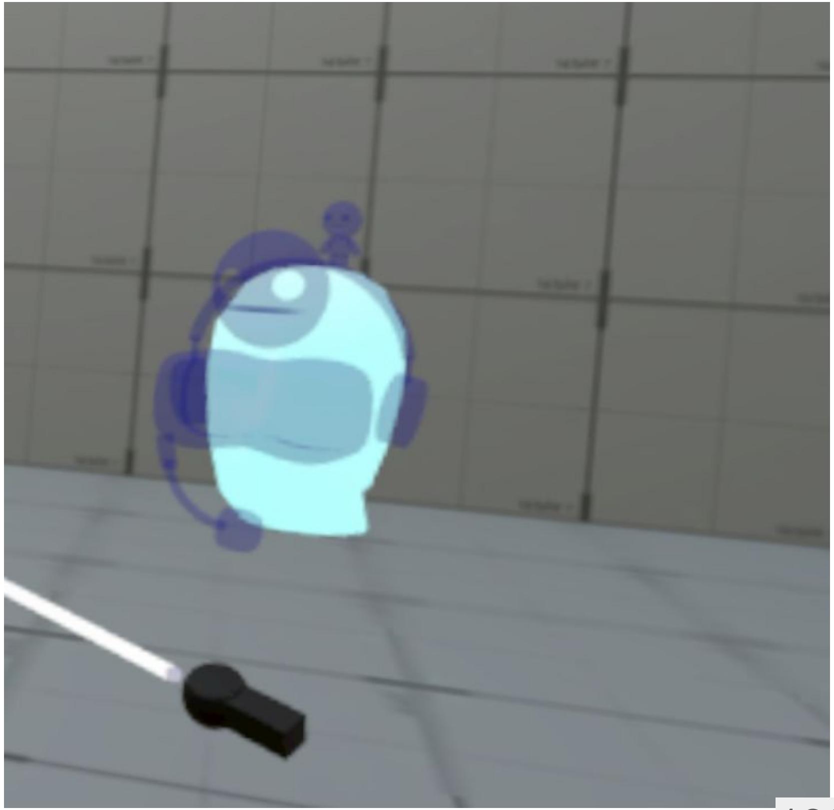
Equipment Set

- Sensory Set
- Privacy Set
- Avatar Set

Eye Location

- Sensory Set - Adjust Brightness
- Privacy Set - Turn on/off eye tracking
- Avatar Set - Create Eye Avatars

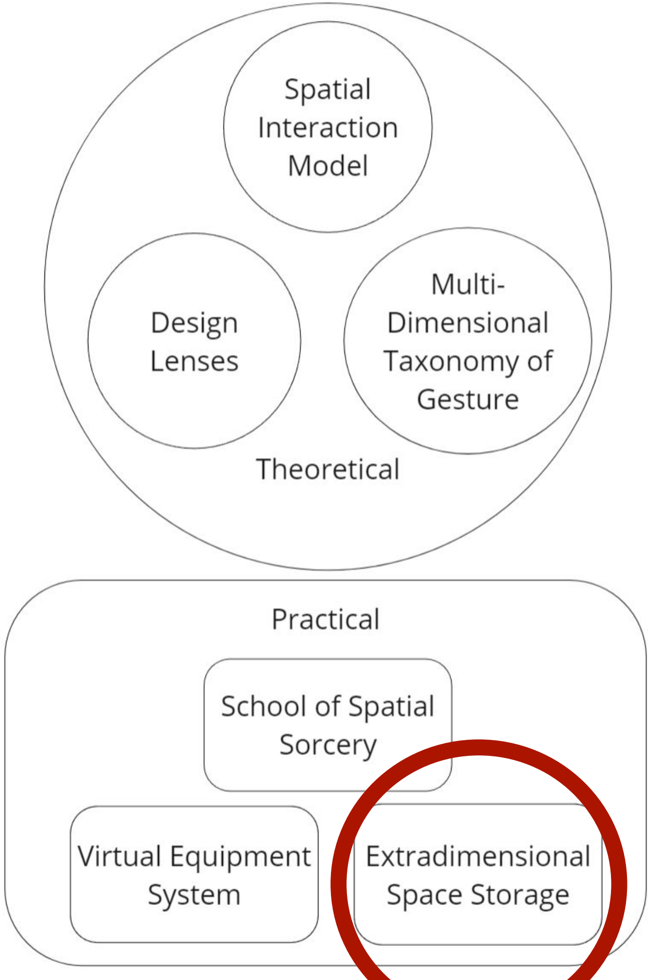
They utilize many of the same locations!
Need for **extradimensional space**!



Extradimensional Space Storage

Powen Yao, Zhankai Ye, and Michael Zyda. "Virtual Equipment System: Toward Bag of Holding and Other Extradimensional Storage in Extended Reality". VAMR 2022 / HCII 2022

Body of Work



EDS Storage in Pop Culture

4th dimension pocket from the anime Doraemon

From the Trading Card Game Magic the Gathering

5 Components of a Storage System

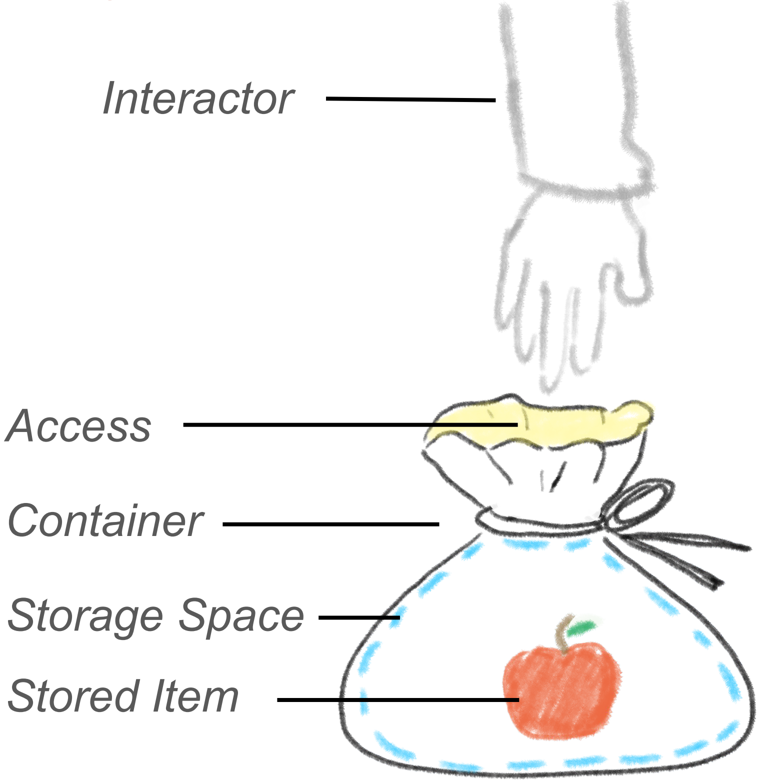
Access

Container

Storage space

Stored Item

Interactor



Extradimensional Space Storage

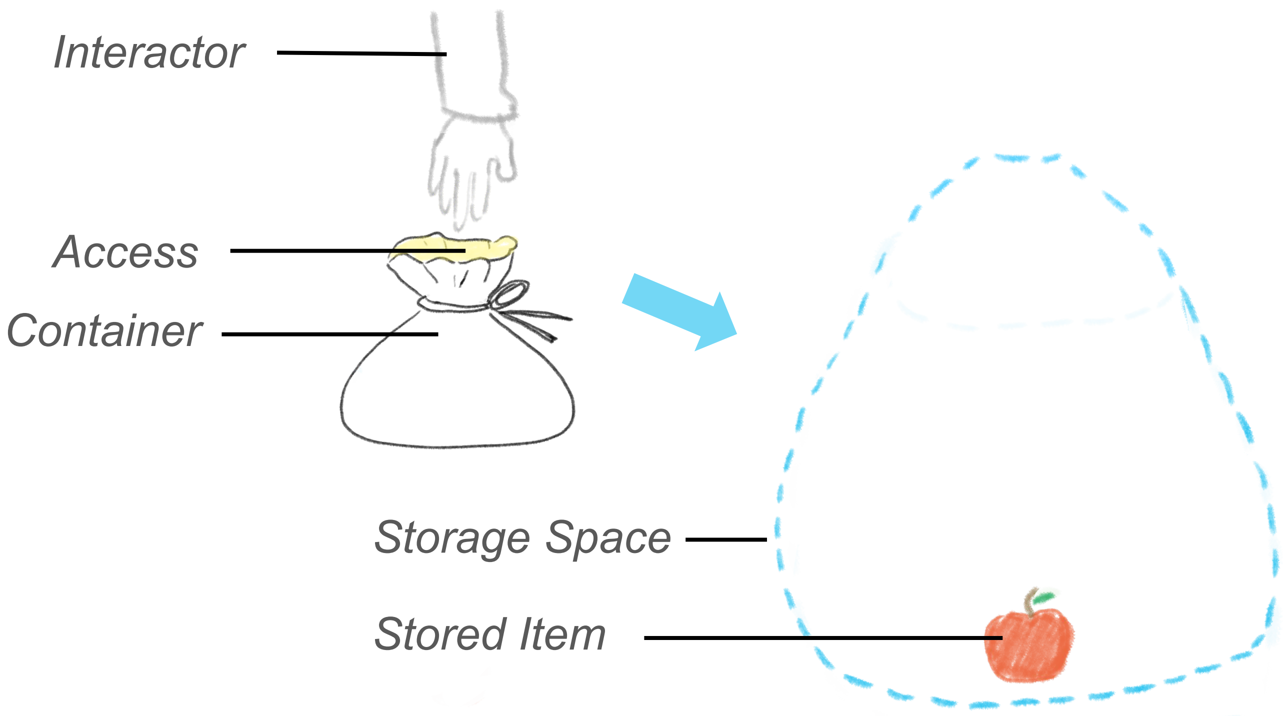
Access

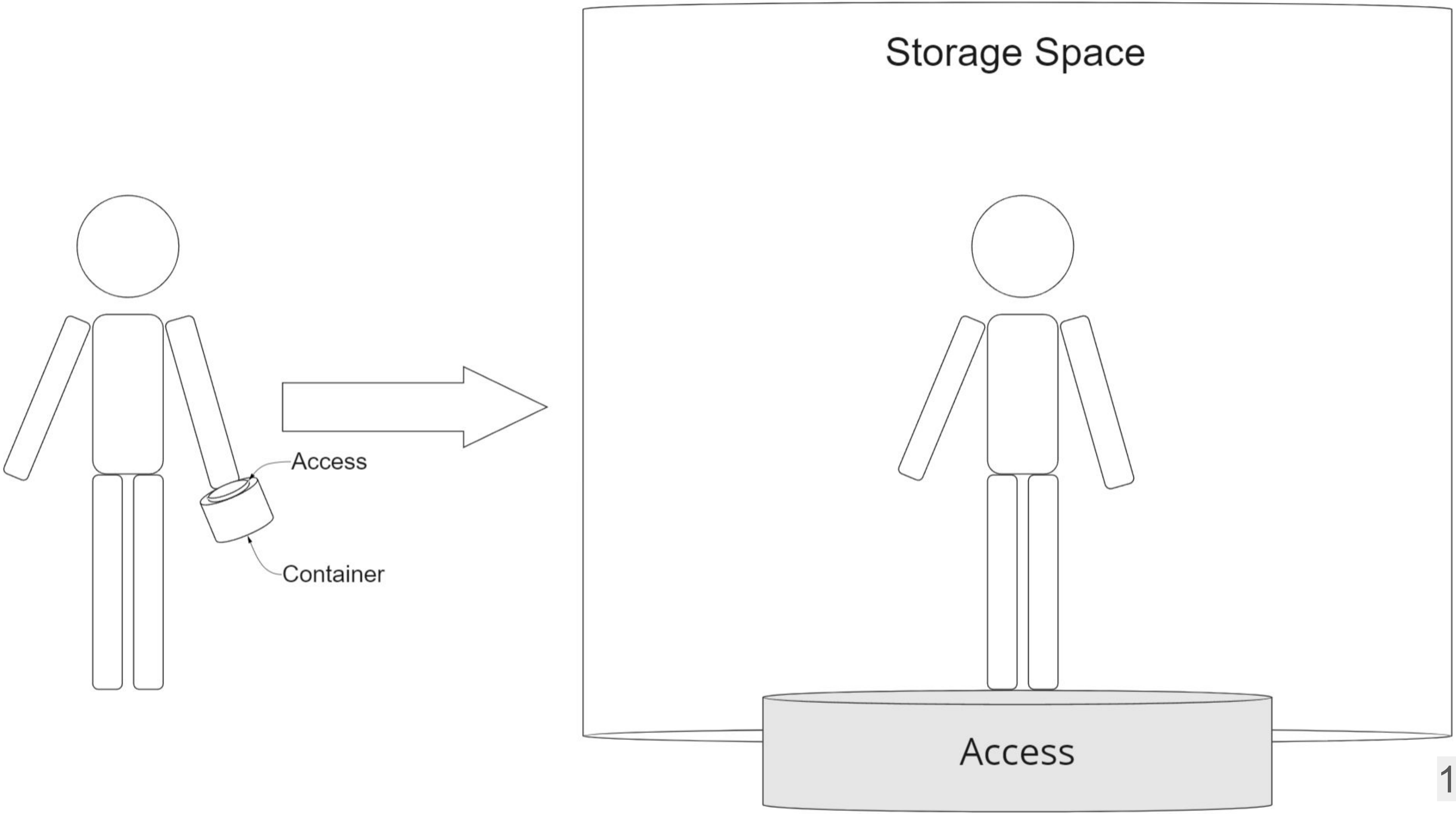
Container

Storage space

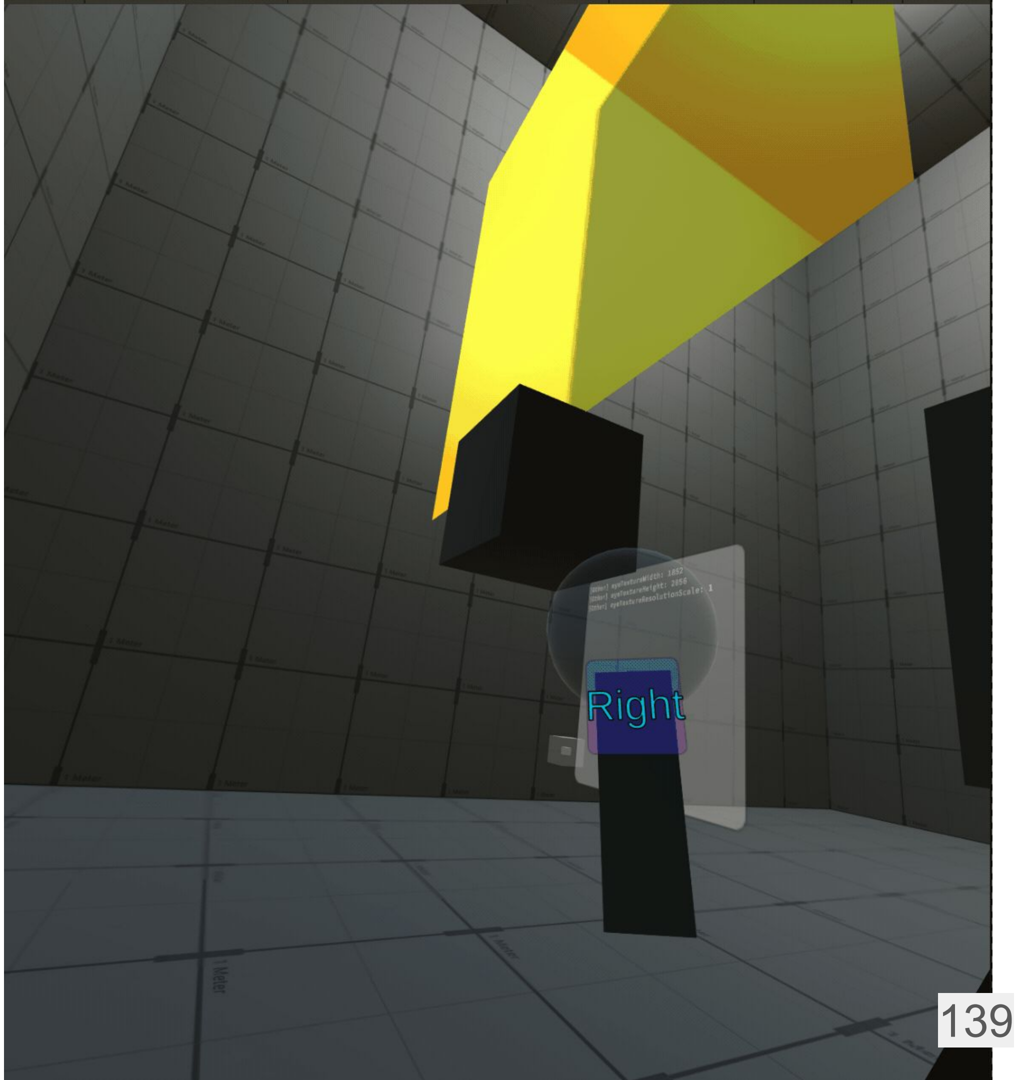
Stored Item

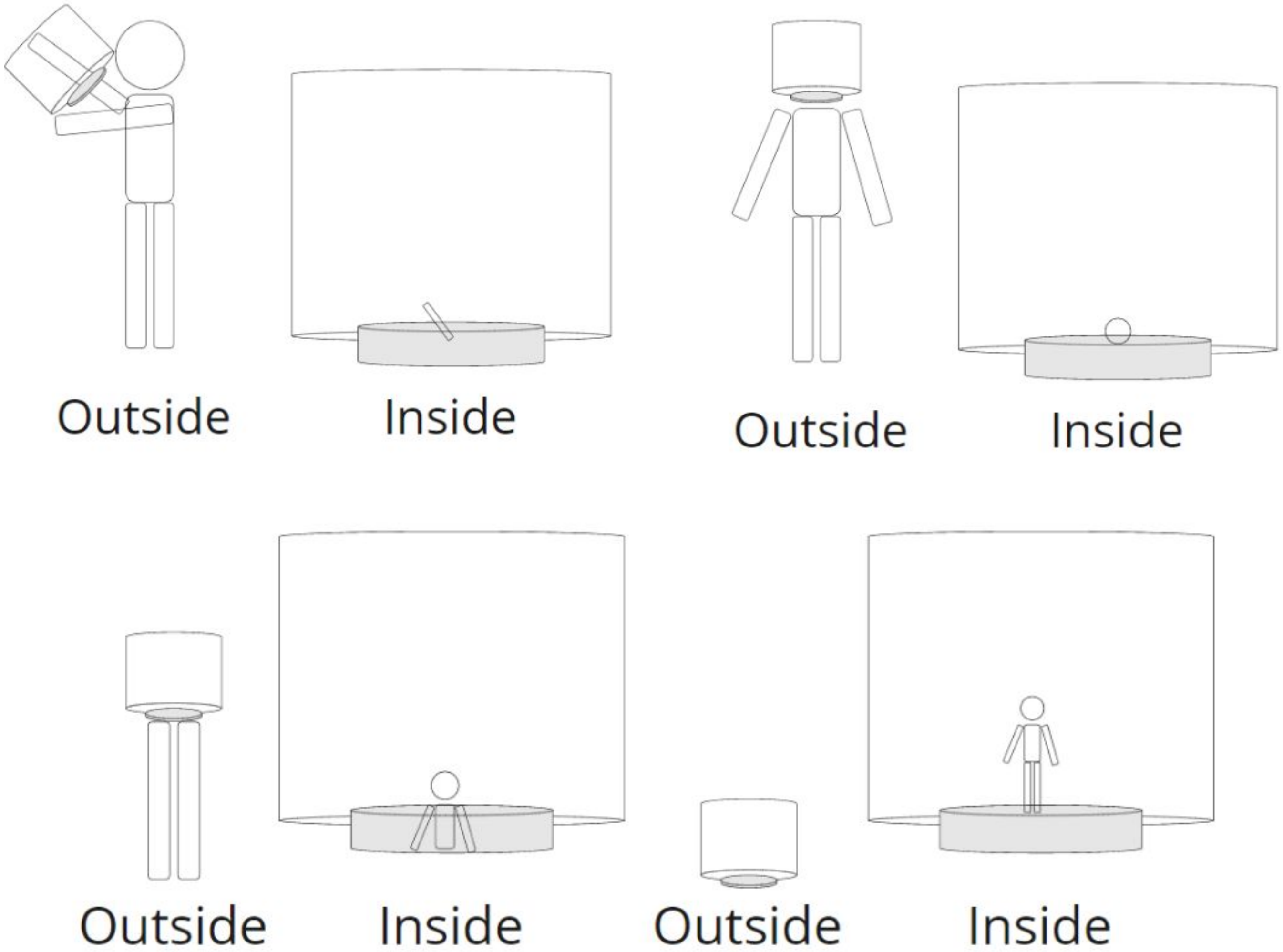
Interactor




Access
Container
Storage Space
Access

EDS Storage

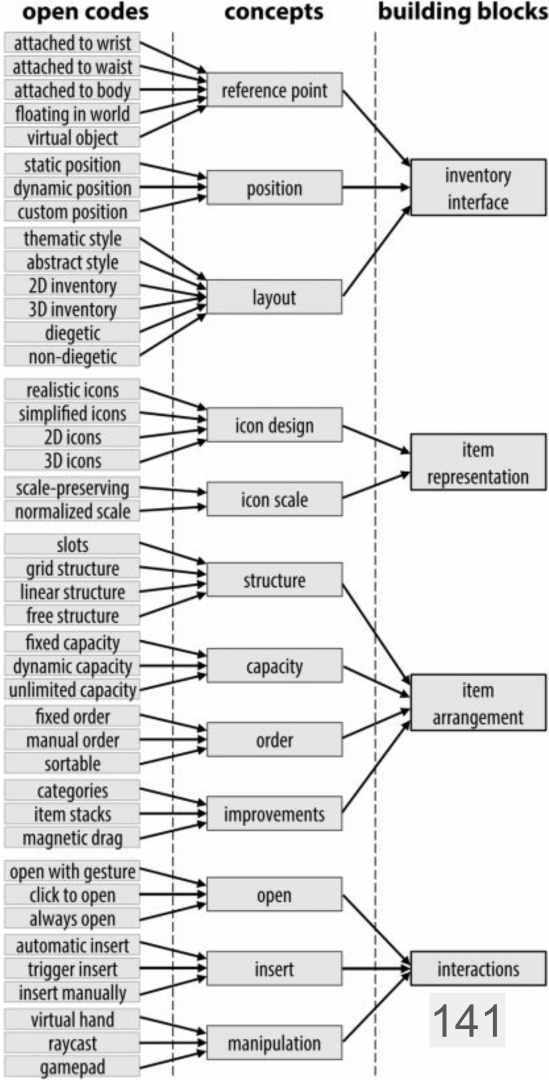



Outside
Inside
Outside
Inside
Outside
Inside
Outside
Inside

Taxonomy of Inventory Systems

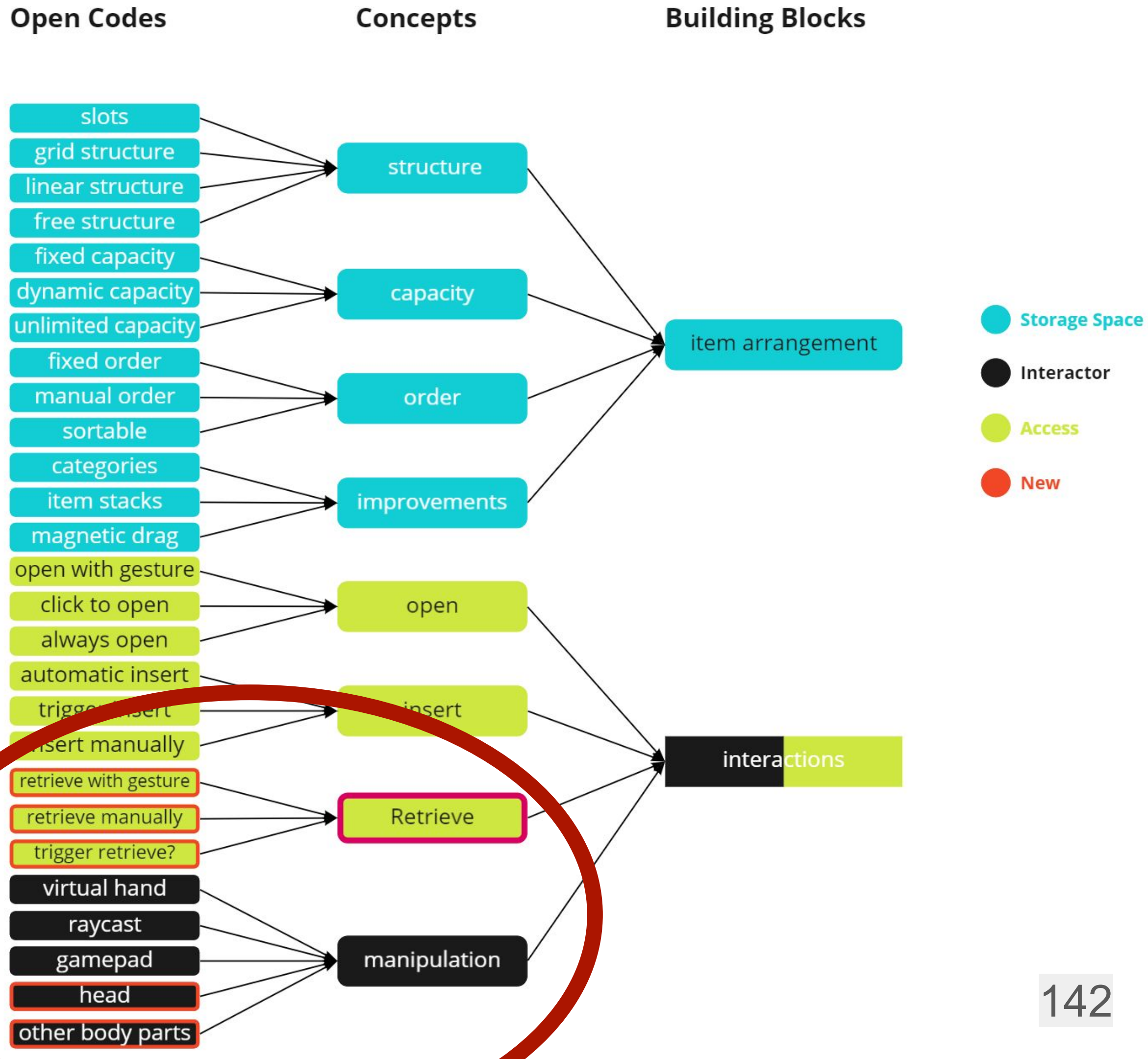
Cmentowski et al. performed Game Analysis using Grounded Theory Analysis

Cmentowski, Sebastian, Andrey Krekhov, and Jens Krüger. "” I Packed My Bag and in It I Put…”: A Taxonomy of Inventory Systems for Virtual Reality Games." 2021 IEEE COG



Modified Taxonomy

Based on our independent work of Extradimensional Space Storage, we introduce the components of interactor, interactable (access, container, stored Item), and storage space.



(Continued)

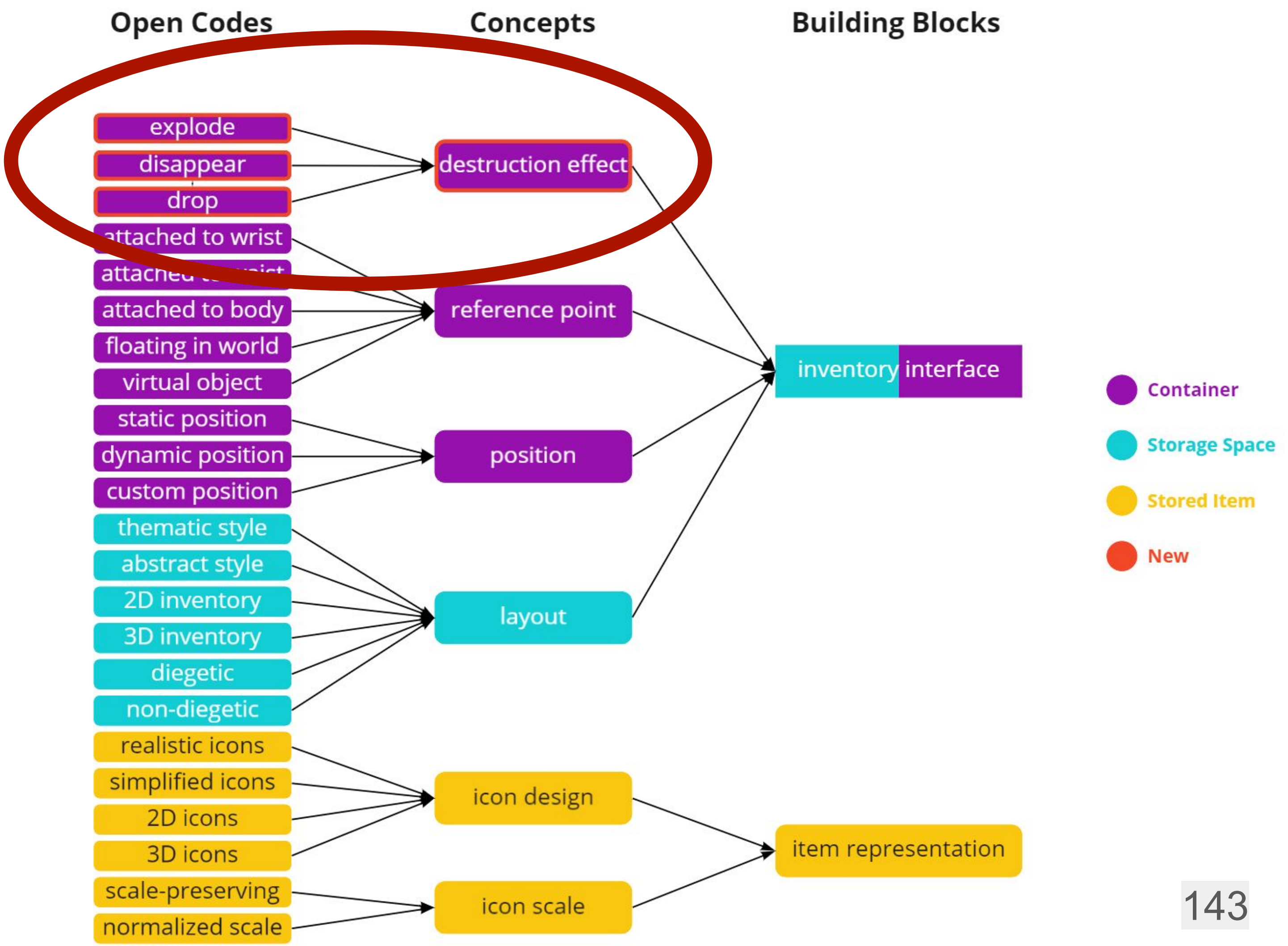
Interactor

Access

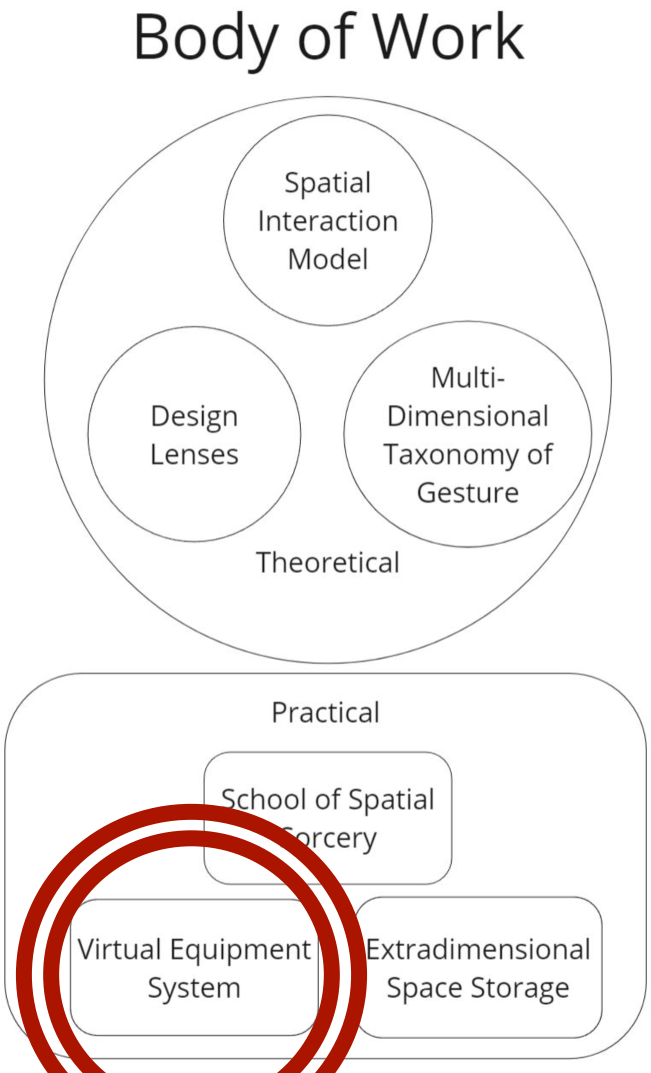
Container

Storable

Storage space



Evaluation
VES User Study



Introduction

We conducted a **within-subjects user study** followed by a questionnaire based on modified **NASA-TLX**.

In it, we compared **different interaction techniques** for adjusting audio volume. We also examined the effect of having Virtual Equipment in **different locations** within personal and peripersonal space.

We performed statistical analyses on the collected data, such as the Kruskal-Wallis H Test. Results suggests that there are definitive differences among the different classes of techniques.

Overall, some class of techniques are better in one aspect (duration required), while worse in another (motion required).

Research Questions

RQ1: How do the techniques compare in terms of efficiency?

RQ2: How do the techniques compare in the effort required for each interaction technique?

RQ3: What makes users prefer one technique over another?

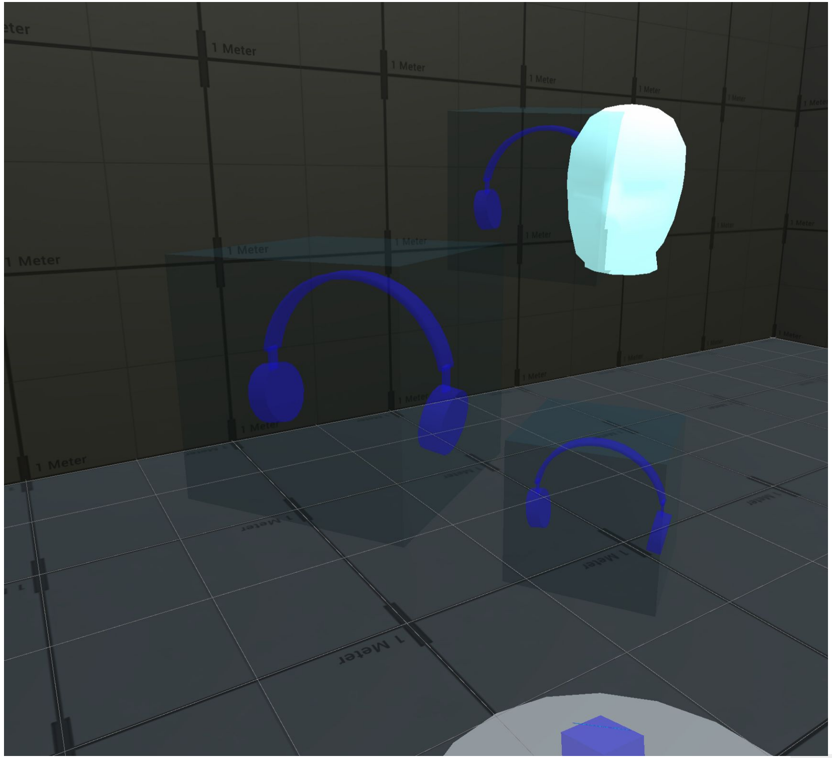
VES User Study
Interaction Techniques

Use of Virtual Equipment in Different Spaces

Virtual Headphones by the **user's ear** in Personal Space

Virtual Headphones by the **user's waist** in Personal Space

Virtual Headphones in **1 o'clock direction** in **Peripersonal Space**



Interaction Techniques

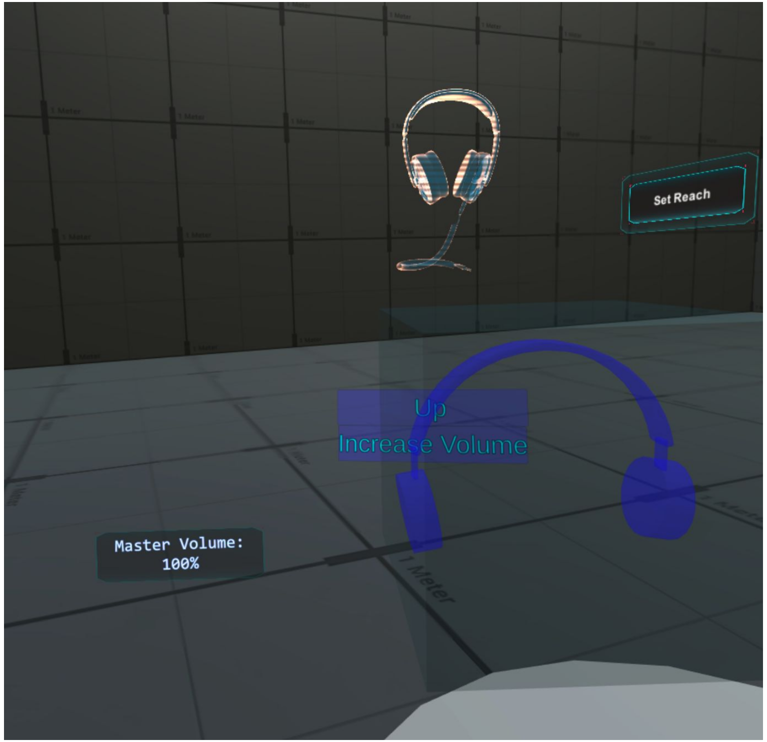
- Motion Gesture (as applied to 3 locations)
- Surface Gesture (as applied to 3 locations)
- Alt Node
- Menu

Task Type	Shorthand	Description
1	Headphones + Motion	Personal Equipment (Ear) Motion Gesture
2	Headphones + Surface	Personal Equipment (Ear) Surface Gesture
3	Waist + Motion	Personal Equipment (Waist) Motion Gesture
4	Waist + Surface	Personal Equipment (Waist) Surface Gesture
5	Peri + Motion	Peripersonal Equipment Motion Gesture
6	Peri + Surface	Peripersonal Equipment Surface Gesture
7	Alt Node + Slider	Moving a slider on a 2D Menu for Audio, through the use of Alt Node
8	Menu Button + Sliders	Moving a slider on a 2D Menu for Audio, through a menu button on the VR Controller

Motion Gesture

When the user grabs any of the Virtual Headphones and moves it up and down, this would trigger its Equipment Motion Gesture.

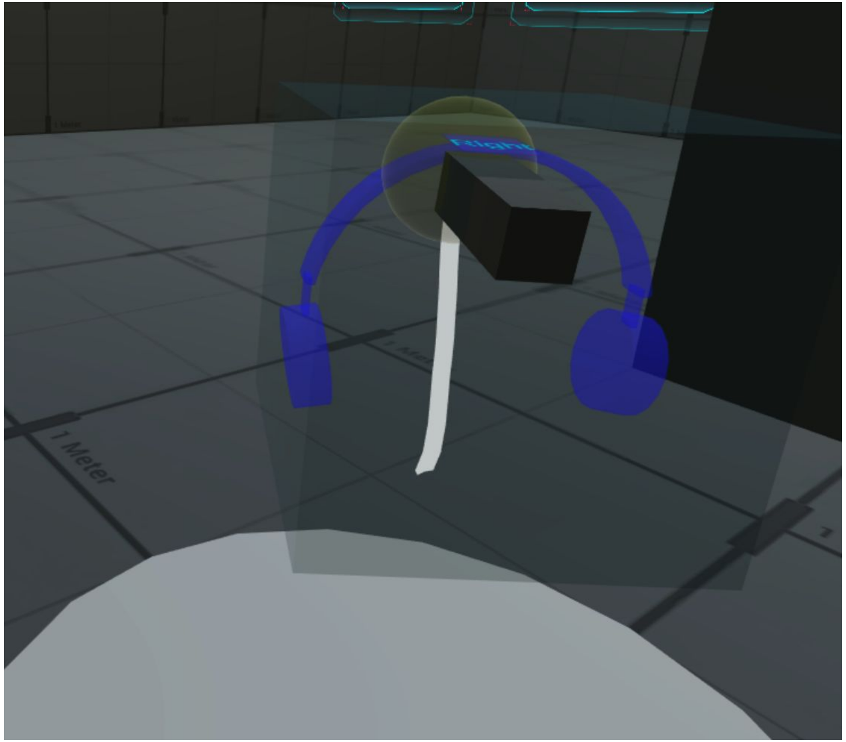
The up and down gestures correspond to the increase or decrease of the system's audio volume, respectively.



Surface Gesture

When the user pushes the trigger button and moves the controller, this draws a white line where the motion controller's tip is. As the user lets go, the white line is interpreted to determine which Equipment Surface Gesture it was.

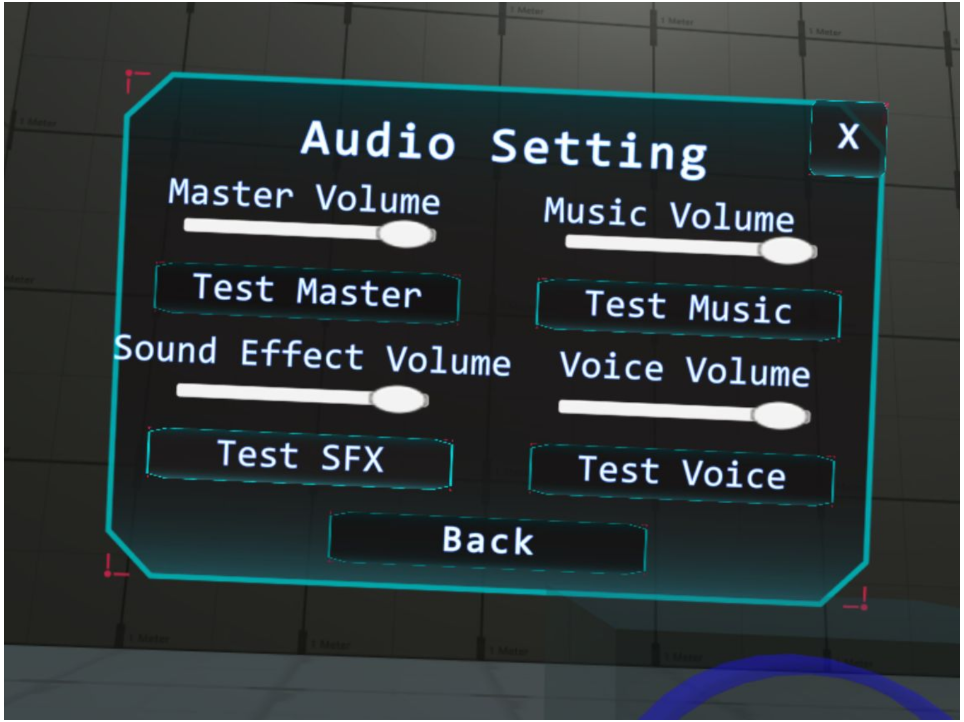
The up and down gestures correspond to the increase or decrease of the system's audio volume.



2D Menu (Traditional)

2D Menu is the most common way to adjust audio settings other than having physical buttons on the VR headset.

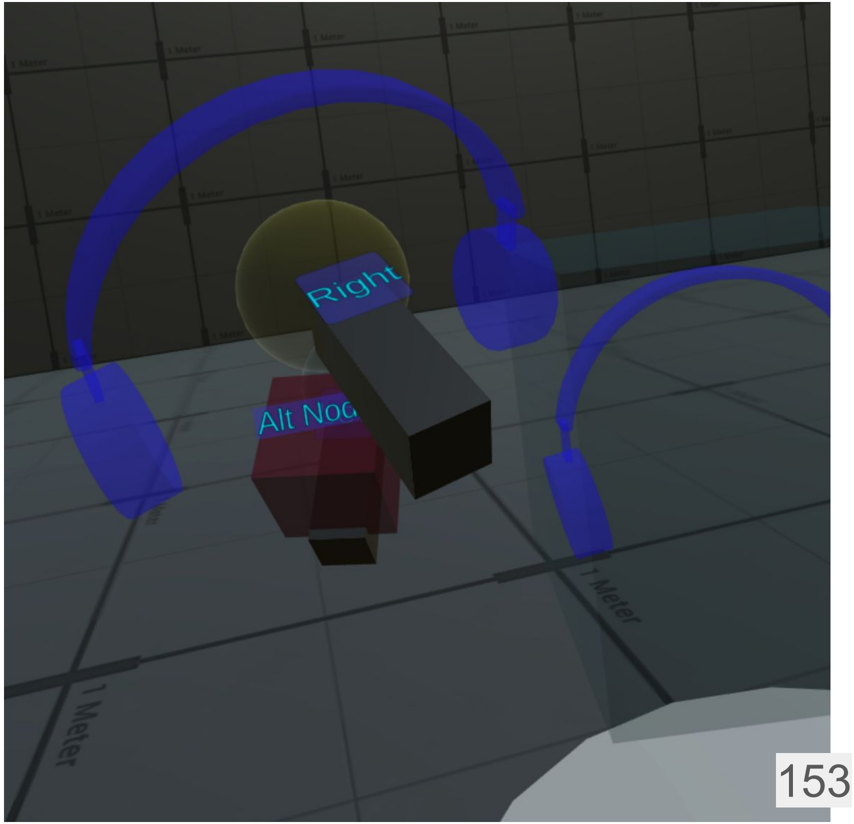
The user would push the menu button on the controller. Then use the ray interactor to navigate through the General Menu, Settings Menu, then Audio Settings Menu to adjust the Master volume.



Alt Node

User can grab the Virtual Headphones and dropping it in the Alt Node (think Alt Key). This summons the detailed setting menu associated with that Virtual

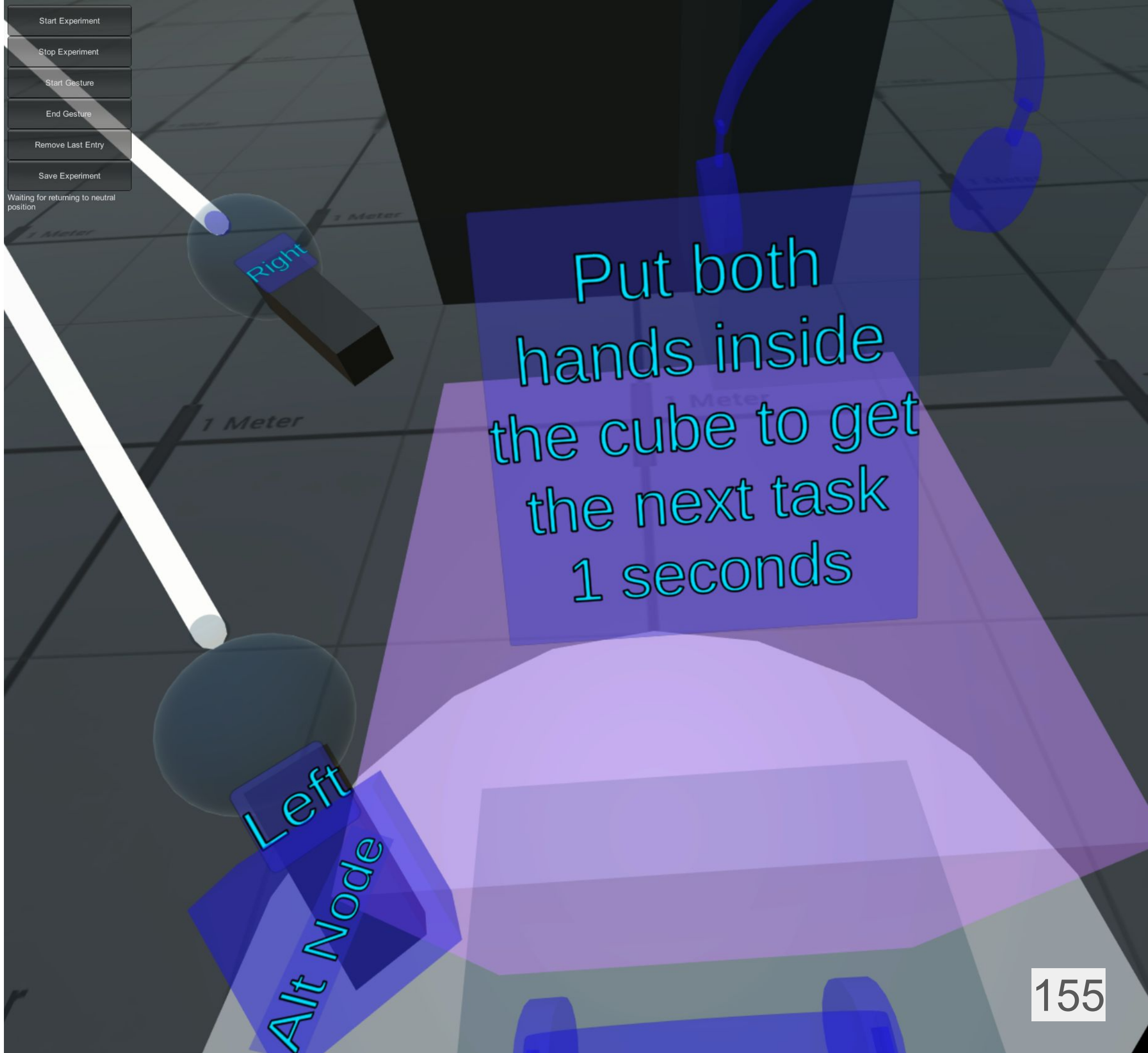
In the case of a Virtual Headphone, it is an detailed Audio Settings Menu. The user can then adjust the master volume



VES User Study Methods

Pink Cube

The user needs to place both controllers inside the pink cube to initiate a task.

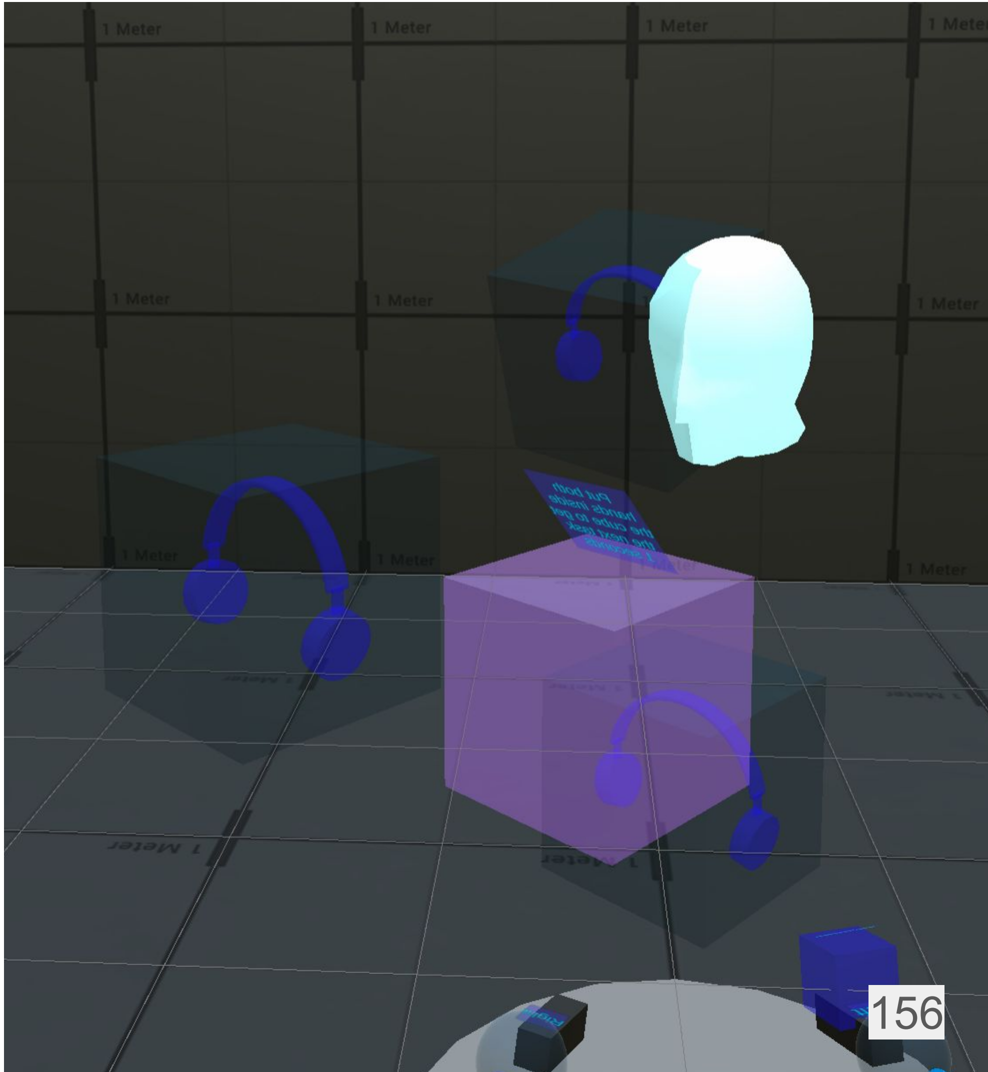


Pink Cube

To avoid giving any location too much advantage, the pink cube is placed in the center of the equipment.

This roughly places the pink cube 49.5 cm away from the ear, 28 cm away from the waist, and 48.9cm away from the peripersonal location.

Location	x	y	z
Personal Equipment (Ear)	0.15	0	-0.07
Personal Equipment (Waist)	0	-0.6	0
Peripersonal Equipment	0.2	0.2	0.6



Eight Tasks

The user is given one of the eight tasks at random. After the user has performed each of the eight tasks once, the user will be asked to do a 9th task with any method they like.

Task Type	Shorthand	Description
1	Headphones + Motion	Personal Equipment (Ear) Motion Gesture
2	Headphones + Surface	Personal Equipment (Ear) Surface Gesture
3	Waist + Motion	Personal Equipment (Waist) Motion Gesture
4	Waist + Surface	Personal Equipment (Waist) Surface Gesture
5	Peri + Motion	Peripersonal Equipment Motion Gesture
6	Peri + Surface	Peripersonal Equipment Surface Gesture
7	Alt Node + Slider	Moving a slider on a 2D Menu for Audio, through the use of Alt Node
8	Menu Button + Sliders	Moving a slider on a 2D Menu for Audio, through a menu button on the VR Controller

VES User Study Evaluation

Demographic

Eleven participants (N=11, mean age: 27.1, SD: 4.43, male/female 9/2) volunteered for the experiment.

Due to the COVID-19 pandemic, the experiment instructions were sent to the participants. It was conducted remotely at their homes with the participant's own VR equipment.

The VR devices include HTC Vive,

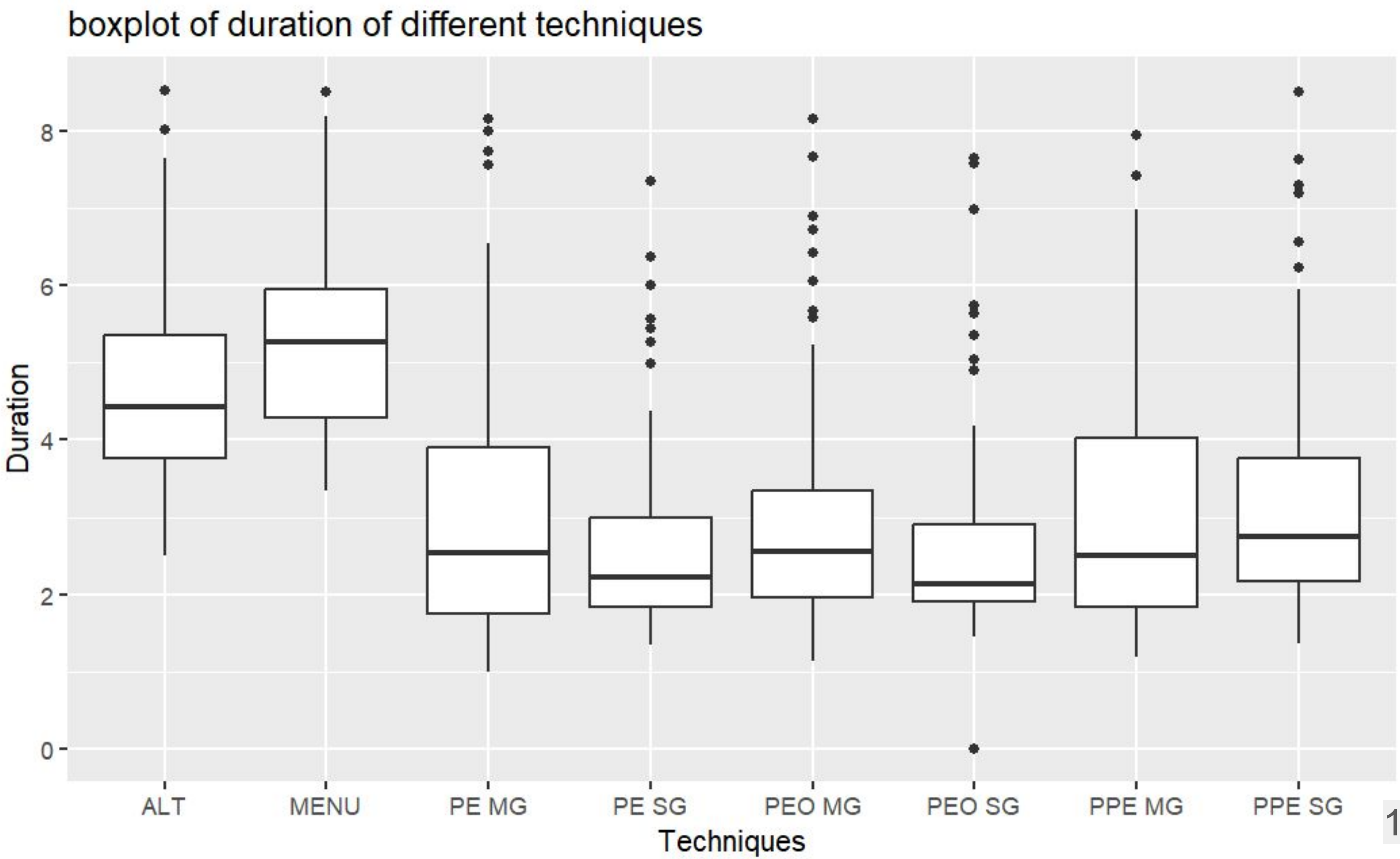
HTC Vive Cosmos, Valve Index, Oculus Rift S, and Oculus (now Meta) Quest 1 and 2.

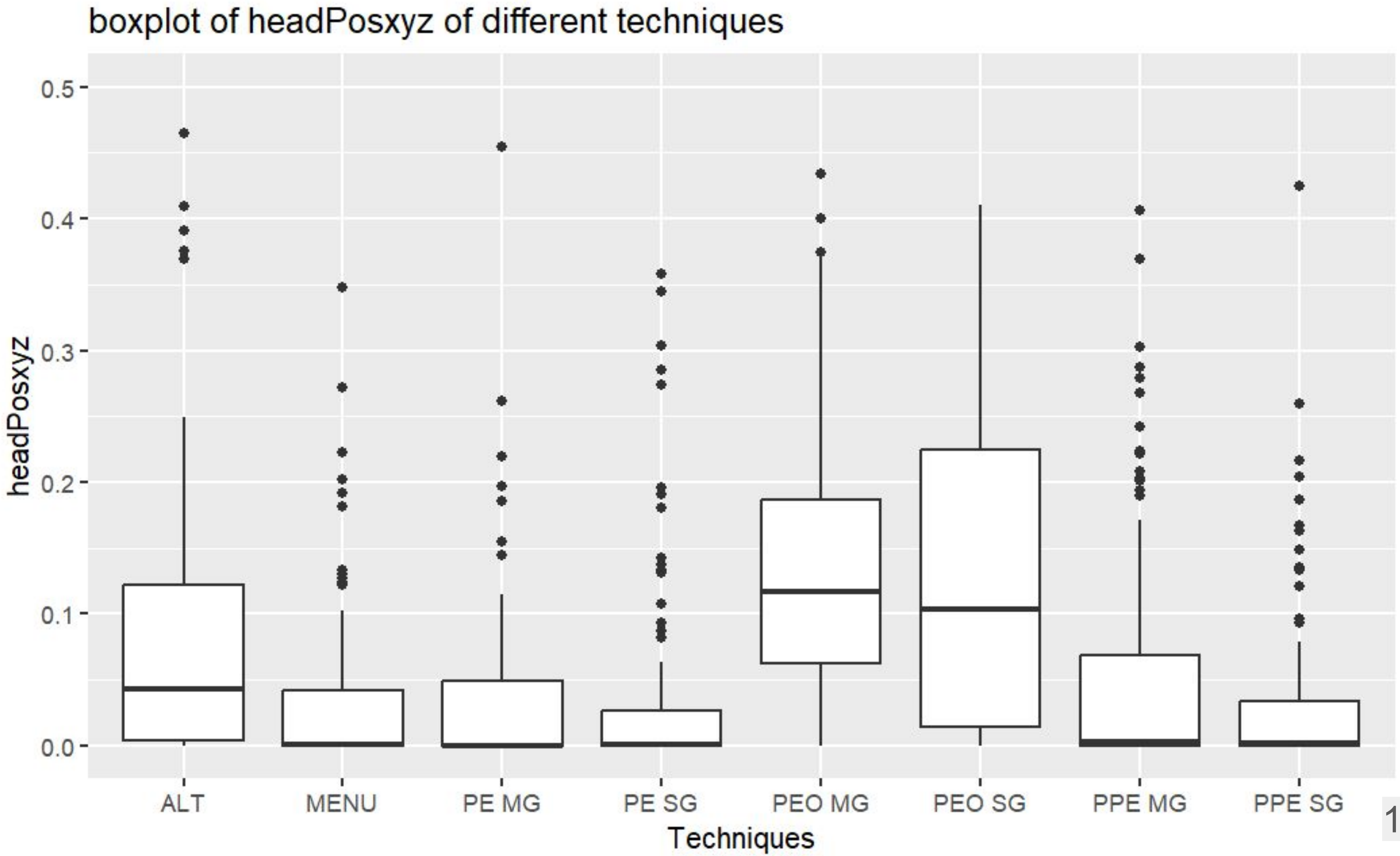
Statistical Analysis

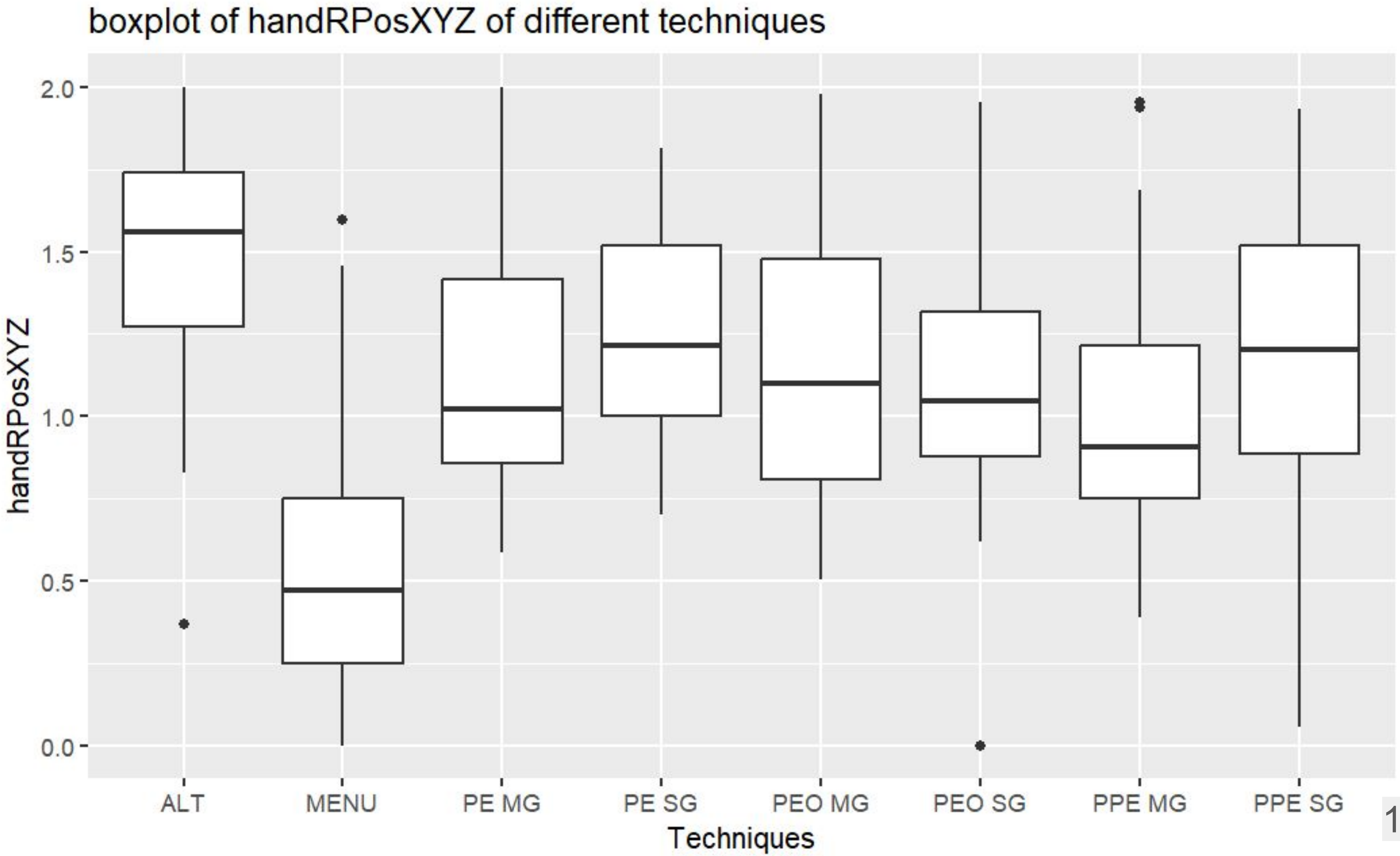
The data did not follow a normal distribution as shown by plotting Normal Quantile-Quantile Plots and using the Sharpiro-Wilk Test..

We used the Kruskal-Wallis test to compare the different techniques. We found that we had a p-value of 0.1481. **However**, if we remove the first block of the data (out of the 10 blocks), the p-value changes to 0.0001244.

This suggests that 1) despite the tutorials, participants were still learning in the first block, and 2) there is a significant difference between these techniques once we account for the learning that occurred in the first block

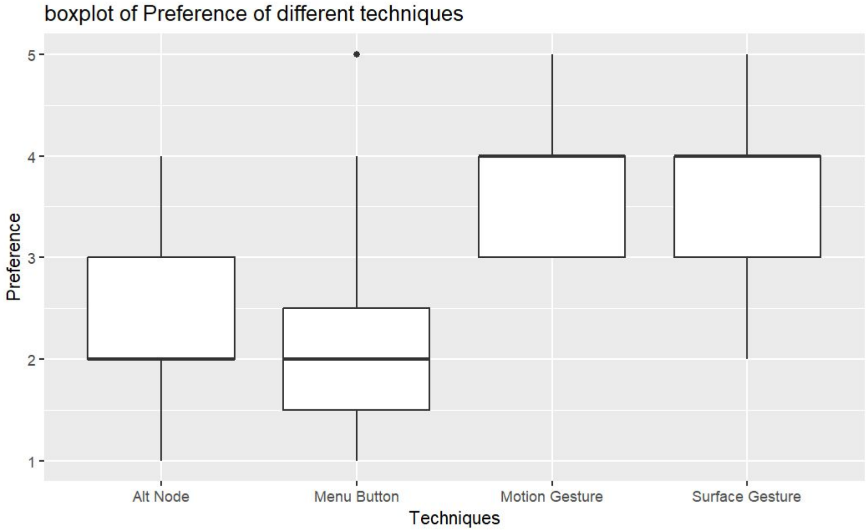

boxplot of duration of different techniques
Duration
0
2
4
6
8
ALT
MENU
PE MG
PE SG
PEO MG
PEO SG
PPE MG
PPE SG
Techniques


boxplot of headPosxyz of different techniques
headPosxyz
0.0
0.1
0.2
0.3
0.4
0.5
ALT
MENU
PE MG
PE SG
PEO MG
PEO SG
PPE MG
PPE SG
Techniques


boxplot of handRPosXYZ of different techniques
handRPosXYZ
2.0
1.5
1.0
0.5
0.0
ALT
MENU
PE MG
PE SG
PEO MG
PEO SG
PPE MG
PPE SG
Techniques

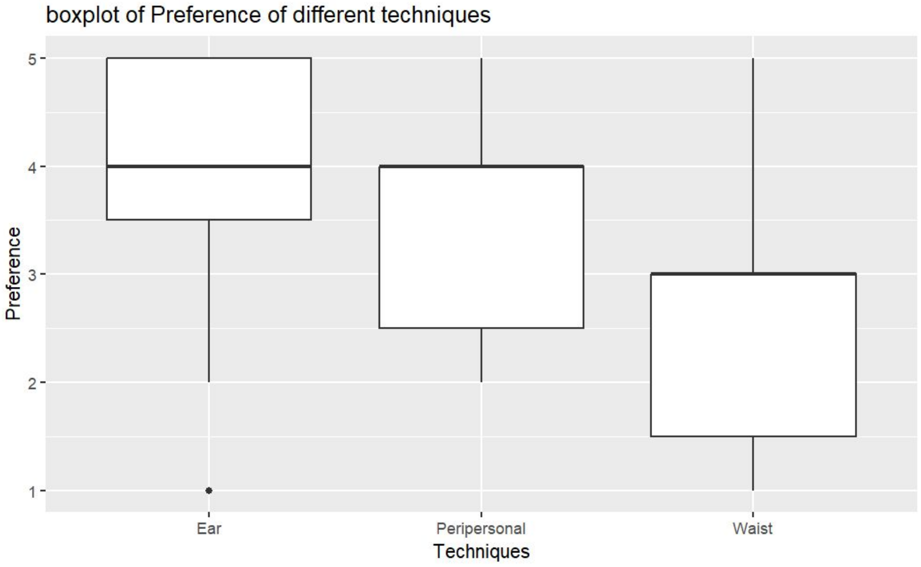
Post-Experiment Question - Techniques

Technique	Mental Demand	Physical Demand	Preference
Motion Gesture	1.55	1.82	3.82
Surface Gesture	1.73	1.55	3.55
Alt Node + Slider	2.27	2.45	2.45
Menu Button + Slider	2.09	2.00	2.27



Post-Experiment Question - Location

Location	Mental Demand	Physical Demand	Preference
Ear	1.82	1.82	3.91
Waist	2.36	2.27	2.45
Peripersonal	1.55	1.82	3.55



VES User Study Conclusion

Discussion

Techniques that are the most efficient (RQ1) are not those that require the least effort (RQ2). Interestingly, the techniques requiring the least movement are not perceived as least physically demanding.

Surface Gesture and Motion Gestures are not significantly different.

RQ1: How do the techniques compare in terms of efficiency?

RQ2: How do the techniques compare in the effort required for each interaction technique?

RQ3: What makes users prefer one technique over another?

Limitation

Due to the risk of COVID-19, user experiments were conducted with participants' own devices and at their respective homes. Combined with small sample size, these limitations reduce the generalizability of the study.

Even with the unorthodox data collection, the study has shown virtual equipment does not need to be restricted to personal space, demonstrated that different classes of techniques are useful for different contexts, and provided insights on how future user studies should be conducted.

Future Explorations for VES

1. Focus not on speed, but precision.
2. Combination of Virtual Equipment with different purposes (audio, visual, privacy)
3. In-Person Study

Other Work

Other related work

Text Entry

Powen Yao et al. “Punch Typing: Alternative Method for Text Entry in Virtual Reality” SUI 2020
Tian Yang, **Powen Yao**, and Mike Zyda. “Flick Typing: Toward A New XR Text Input System Based on 3D Gestures and Machine Learning”. IEEE VR 2022
Tian Yang, **Powen Yao**, and Michael Zyda. “Flick Typing: A New VR Text Input System Based on Space Gestures”. VAMR 2022 / HCII 2022

Machine Learning Explorations
(in collaboration with students in the class Machine Learning in Games)

Sloan Swieso et al. “Toward Using Machine Learning-Based Motion Gesture for 3D Text Input”. SUI 2021

Adityan Jothi et al. “Toward Predicting User Waist Location From VR Headset and Controllers Through Machine Learning”. SUI 2021

Mark Miller et al. “Virtual Equipment System: Toward Peripersonal Equipment Slots with Machine Learning”. SUI 2021

Pranavi Jalapati et al. “Integrating Sensor Fusion with Pose Estimation for Simulating Human Interactions in Virtual Reality”. HCII 2022

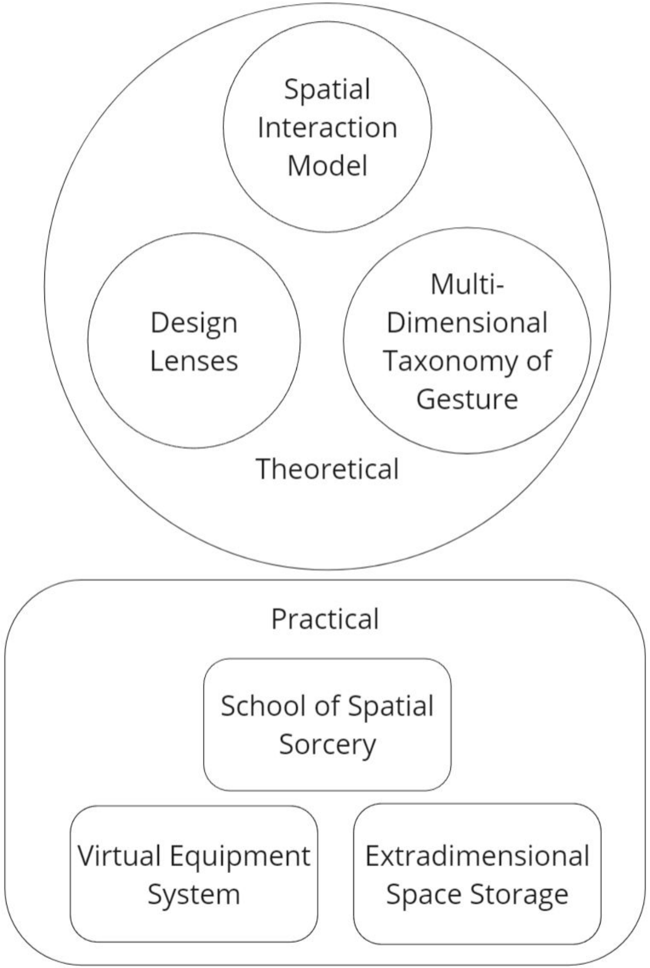
Summary And Conclusion

Summary

The main objective of this thesis is to explore design principles of 3D interaction techniques in the domain of Extended Reality that advances in body tracking technology will enable.

This thesis solves this problem by providing a framework that developers can use to understand existing hyperphysical techniques and to develop their own.

Body of Work

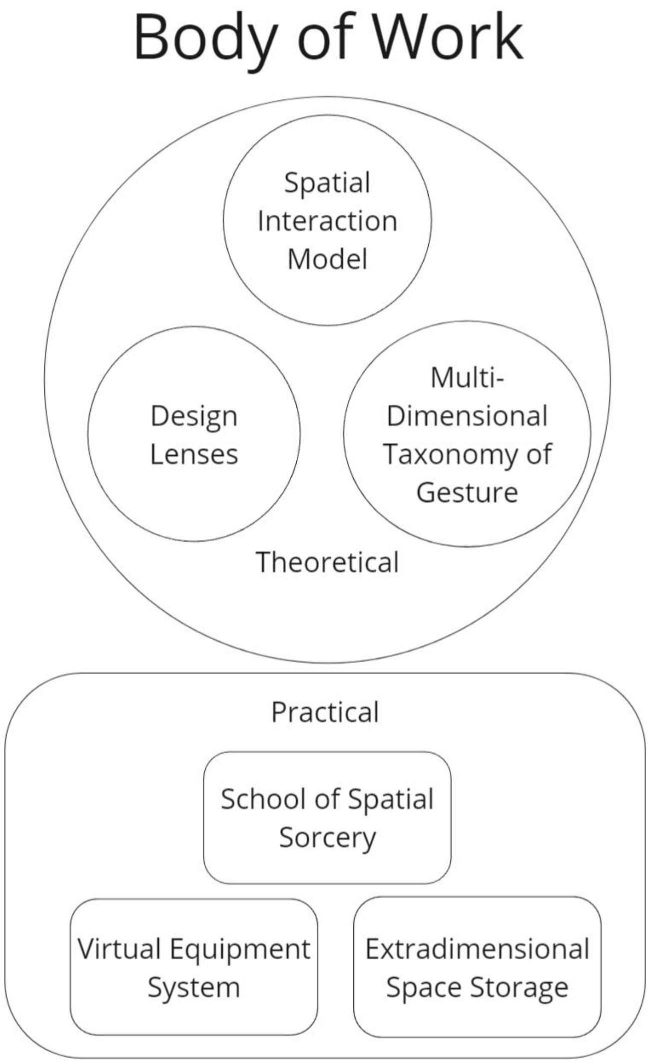


Summary

There will be a dominant interaction technique.

Many use cases will still require use of non-dominant interaction techniques.

Continue to develop specialized solution for different needs



Future Works

Future Works

- Short Term
  - Extradimensional Space Storage User Study
  - Gesture Taxonomy Submission now with Spatial Interaction Model
- Long Term
  - Neuropsychological Impact of Equipment and Interaction in Peripersonal and Extrapersonal Space
  - “Walking through doorways causes forgetting” with Extradimensional Space and other Hyperphysical Transitions

Final Thoughts

With **hyperphysicality**, the sky is the limit to what our interactions can do. Meanwhile, **whole-body interaction** can ground us to what is desirable out of the infinite possibilities.

Extradimensional Space makes it easy to access the most relevant technique to solve problems we face in daily life.

Together, these design lenses will create a future, described by Arthur C. Clarke's Third Law, with advanced interactions that will be truly indistinguishable from magic.

Design Lenses for 3D User Interface in Extended Reality

Powen Yao
powenyao@usc.edu, powenyao@gmail.com
LinkedIn/Facebook/Google/Wechat: powenyao

Backup Slides

Qualification Scope

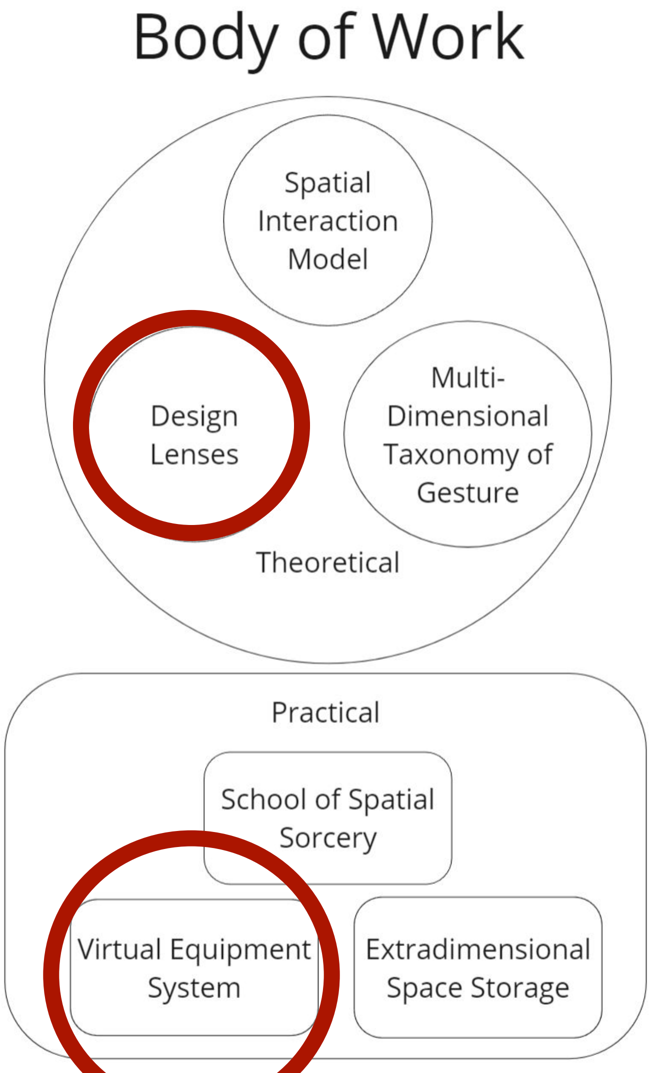
Design Lens

1. Hyperphysical User Interface
2. Whole-Body Interaction
3. Extradimensional Space

Virtual Equipment System

To do for Defense:

Evaluation of Virtual Equipment System



Extradimensional Space Storage User Study

Interaction Techniques

Name	Shorthand	Description
2D Grid Inventory	2DUI	Grabbing item laid out on a 2D User Interface grid
Bag of Holding	Nonlinear	Grabbing items in a 3D volume where the item positions are a non-linear mapping from their actual positions in the Extradimensional Space storage.
Extradimensional Space Storage	EDS Storage	Entering an Extradimensional Space Storage and grabbing objects stored within as if one would in a storage room
Flick Storage	Flick	Accessing items stored on the surface of a sphere by rotating the user's controller

Research Question

1. How do the techniques compare in terms of efficiency?
(a) How do the different techniques compare regarding task completion time?
(b) How do the different techniques compare regarding accumulated head movement required for task completion?
(c) How do the different techniques compare regarding accumulated hand movement required for task completion?
2. How do the techniques compare in the effort required for each interaction technique?
(a) How do the techniques compare in terms of mental demand?
(b) How do the techniques compare in terms of physical demand?
(c) How do the techniques compare in terms of temporal demand?
(d) How do the techniques compare in terms of effort?
3. What makes users prefer one technique over another?
(a) In what scenario does the user prefer one technique over another?
(b) Why does the user prefer one technique over another?

Study Flow

11 min Informed Consent Form

11 min Warm-Up (Wearing VR, VR Equipment Introduction, Safety)

40 min, 10 each Treatments, repeated 4 times total, 1 for each treatment

2 min Walkthrough & Tutorial

6 min Tasks

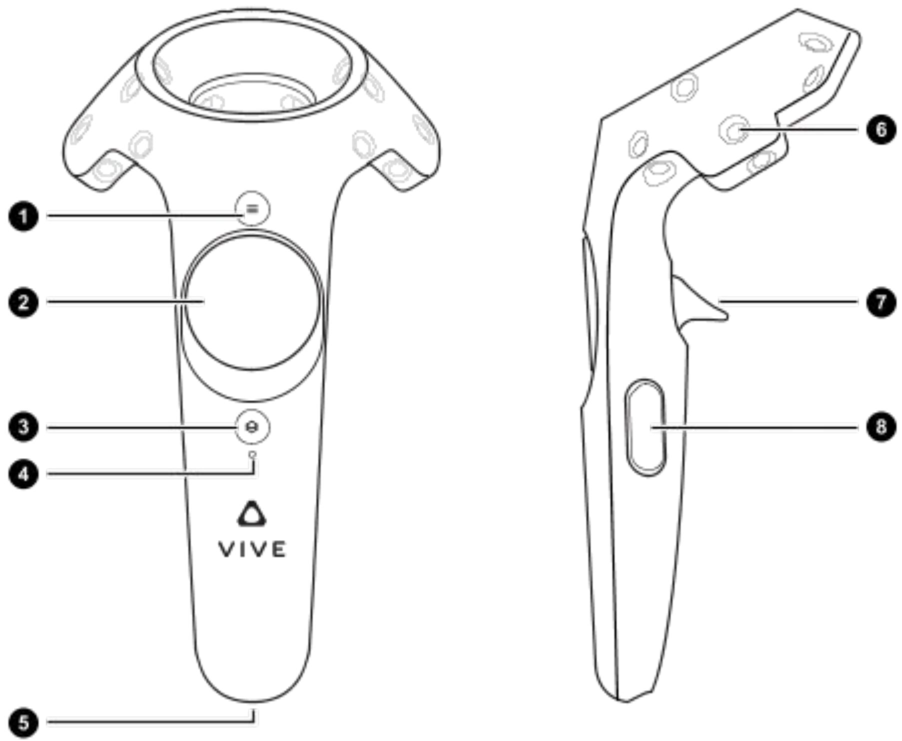
2 min Break & Questionnaire

20 min Semi-Structured Interview

5 min Debrief

“Not enough buttons”

“Not enough buttons”



Plan after Defense

Immediate

- **Donate Platelet at American Red Cross**
- **See a therapist**
- **Grab dinner with friends**

After

- **Get a job**
- **Taxonomy paper again.. But now with SIM**
- **Global Game Jam**
- **Publish Innovation in Games paper from my second PhD of Game Design**

XROS UI Project

Project Codebase:

https://github.com/powenyao/XR-Interaction-Toolkit-Examples

Project Website:

https://powenyao.github.io/XR-Interaction-Toolkit-Examples/website/index.html

Relevant Youtube Videos

https://www.youtube.com/playlist?list=PLQkQPxKAn5cRffVUPzxOg6kWXBP46UCV_

@Shitong Sketches needed?

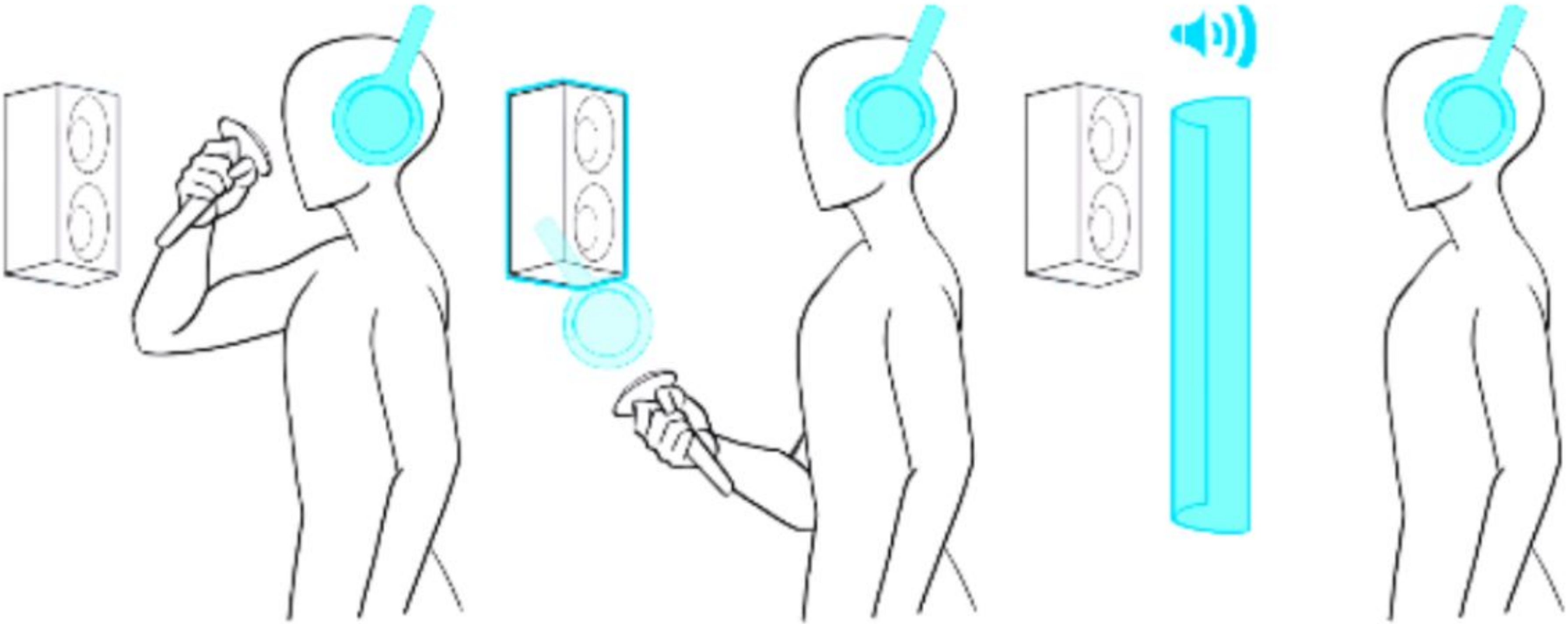
F2. Personal, Peripersonal, Extrapersonal Space the othe after
H. Definition of Extradimensional Space
I think the example we have look decent, though its from wikipedia on connectivity (graph theory). Anything better would require a lot more work?

O. Extradimensional Space Storage sketches are... well they could be better lo
P. **(Higher Priority)** 5 Components of a Storage System

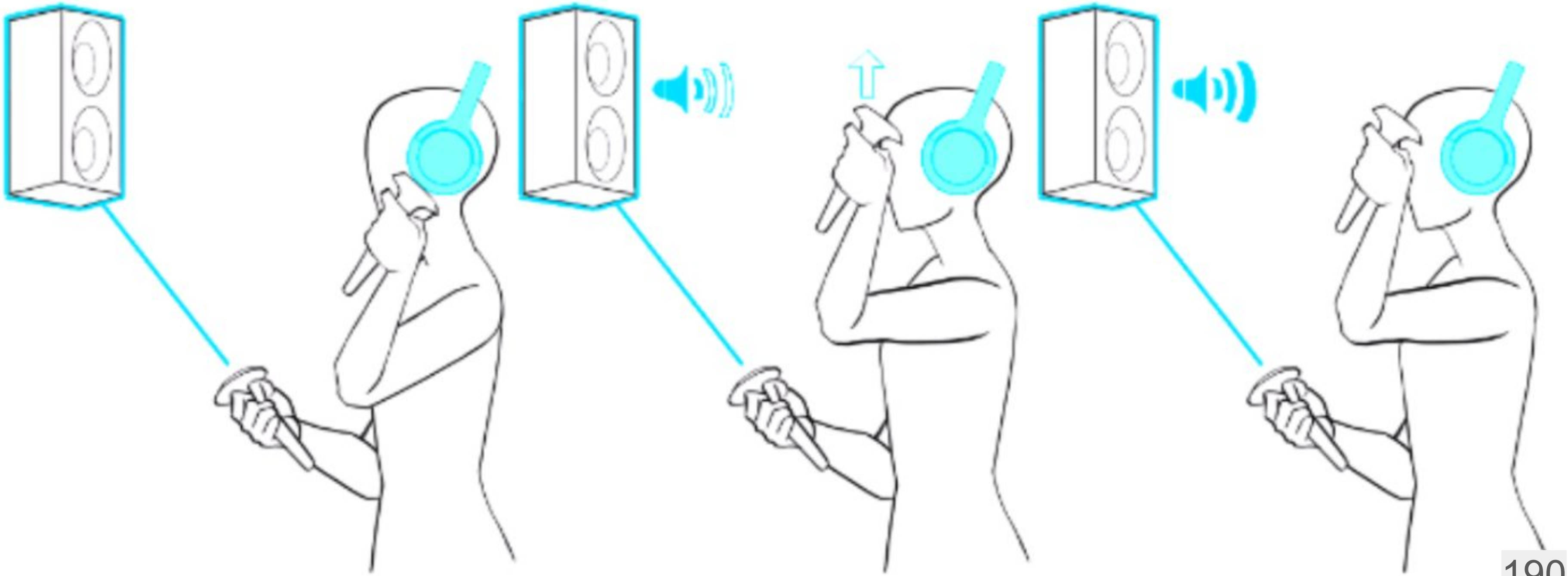
Q. Assumptions Slide “this "position and rotation" comment sounds like a good place for some hand gestures with a held object for clarity.”

A. (Low priority?) sketch that help explains AR/VR/MR is represented by XR
B. (Low priority?) Sketch to show different posture of a person, standing, sitting, lying down, prone (?), moving (room scale)
C. (Low Priority) Mobile Augmented Reality
Walking, Bicycling, Driving Vehicle, Riding as Passenger
K. (Low priority?) Should we replace the coordinate system image in context mapping...? 93
L. (Low priority?)Spatial Interaction Model (being shown everything, made in Miro. Do you

Affecting Remote Target



Affecting Remote Target



Reference Links

Where some figures are created

https://miro.com/app/board/o9J_lAa4mjU=/

Qualification Slides

https://docs.google.com/presentation/d/1GuzySbaRNpcD5JWaW6wE2jLJ5QrtebpKtc6LvTAuLuQ/edit

PhD Thesis

https://www.overleaf.com/read/ncptfcvcczwx#3b1888

TODO

~~1) better introduction stating the challenges~~
~~2) Nature breakdown slides quotes added for the six examples~~
~~3) Context Mapping - User~~
~~4) SSS~~
- ~~a) talk more about what the symbols do quotes added~~
- ~~b) Dimensional Sight example quotes added~~
- ~~c) equipment as metaphor for having abilities~~
- ~~d) Simple extradimensional storage~~

5) VES
- a) 1 slide to talk about sets
- ~~b) 1 slide for each set~~
- ~~c) talk about surrogate object, actor, effect, voodoo doll, etc?~~ No time..

6) explanation of the EDS quotes added for the four diagrams
7) VES user study details
- ~~a) description of technique~~
- ~~b) questionaire, user study, questionaire~~
- c) findings and interpretations

8) summary and conclusion from thesis