Human-Centered VR Design

MIT VR Hackathon
Oct 6, 2017

Jason Jerald, PhD

NextGen Interactions
Consulting & Contracting Services

NEXTGEN Interactions

Presents:

The VR Workshops

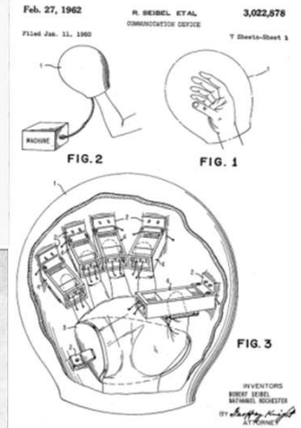
Are you ready to propel your VR Projects to the next level?

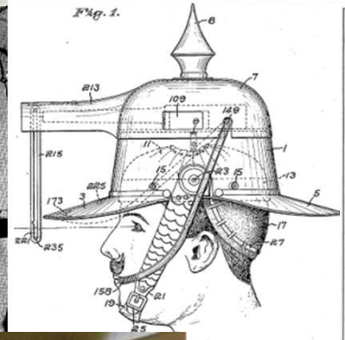
Human-Centered Design Workshop

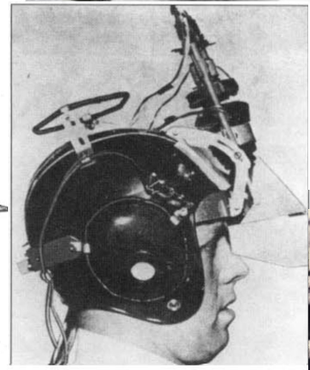
Creators of the VR Book

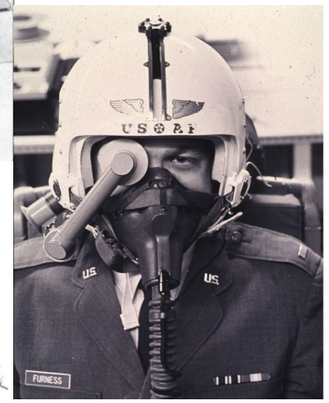
VR is not New!

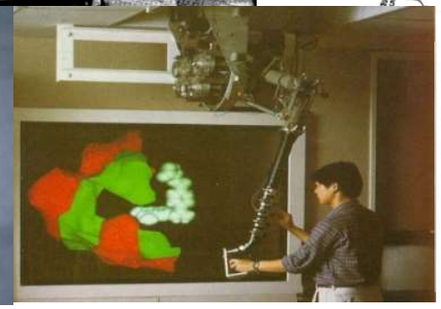
1830s to 1990s

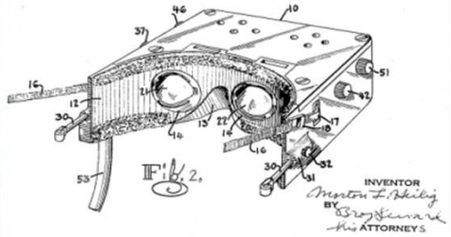






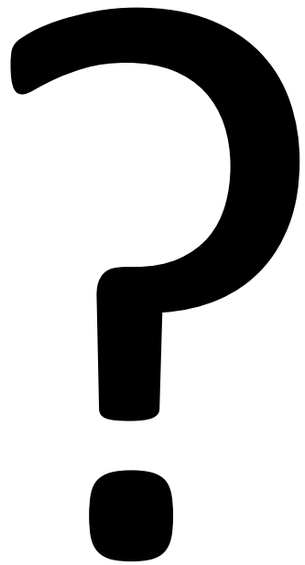






Images Courtesy of The VR Book (with permissions from original sources)

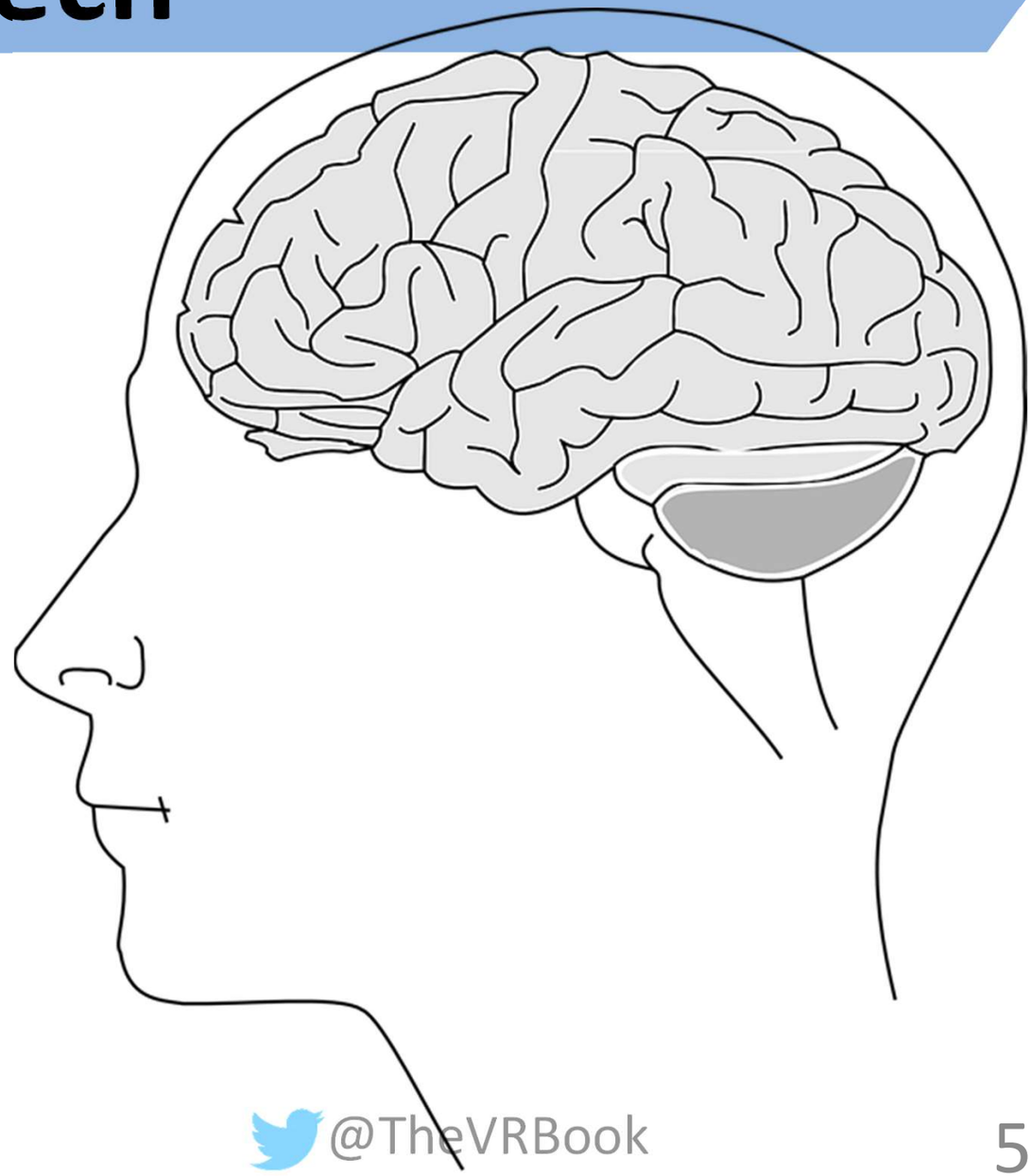
The Most Exciting VR Tech



The Most Exciting VR Tech

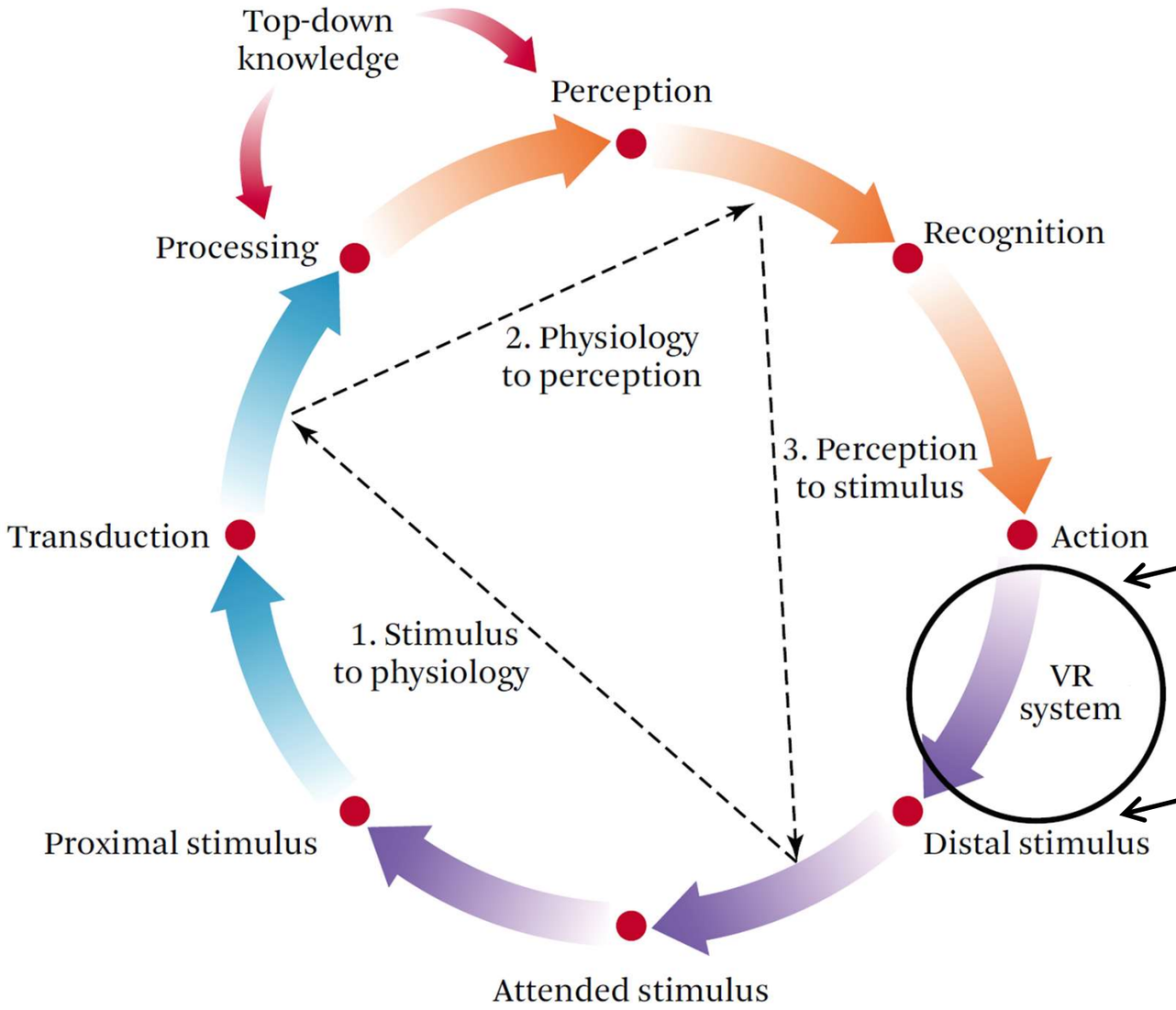
The Human Brain!

- ✓ ~100B Neurons
- ✓ Thousands synapses/neuron
- ✓ ~1B Synapses/mm^3
- ✓ 150,000 km of nerve fibers
- ✓ Six degrees of separation



Marois & Ivanoff 2005
Alonso-Nanclares et al. 2008

The Iterative Perceptual Process



With VR, we hijack the human perception-action system

Human action = VR input/tracking

VR Output = Distal stimuli

Image Courtesy of The VR Book (adapted from Goldstein [2007])

What is needed for Successful VR?

An open mind!

- ✓ New insight comes from diverse perspectives
- ✓ Save your judgments of what others are doing
  - There are likely good reasons for their design
- ✓ Understand there are few universal truths to VR design
  - The answer is most often “It depends” or “I don’t know lets find out!”
- ✓ Consider that what you know may be wrong
  - Or at least not apply in different situations
- ✓ The most value may come from what you don’t know you don’t know

You the Hackers

Project Ideas?

Teams?

Systems?

Most useful workshop topics?

Potential Topics

Humans
- ✓ Perception & Action
- ✓ Immersion & Presence
- ✓ Communication
- ✓ Fidelities

Interaction
- ✓ Multimodal Input
- ✓ Norman's Principles of Interaction
- ✓ Classes of Input Devices
- ✓ #1 The Hands
- ✓ Reference Frames
- ✓ #1 Interaction Patterns & Techniques

Comfort
- ✓ Adverse Health Effects
- ✓ Factors & Theories
- ✓ Improving Comfort
- ✓ Measuring Sickness

Virtual Worlds
- ✓ Scene Space & Depth
- ✓ Environmental structure
- ✓ Audio
- ✓ Collaboration
- ✓ Art
- ✓ #2Story
- ✓ #2In-App Tutorials

Iteration
- ✓ Define
- ✓ Make
- ✓ Learn

- ✓ Eye tracking
- ✓ Weight/physics and perceptual illusions
- ✓ #3 Haptics
- ✓ Information overload
- ✓ Live 360 video

Workshop Schedule (tentative)

Humans

Interaction

Comfort

Virtual Worlds

Iteration

Workshop Schedule (tentative)

Humans

Interaction

Comfort

Virtual Worlds

Iteration

Humans

Humans

Perception

Immersion and Presence

Communication

Fidelity

What We Perceive is not Reality

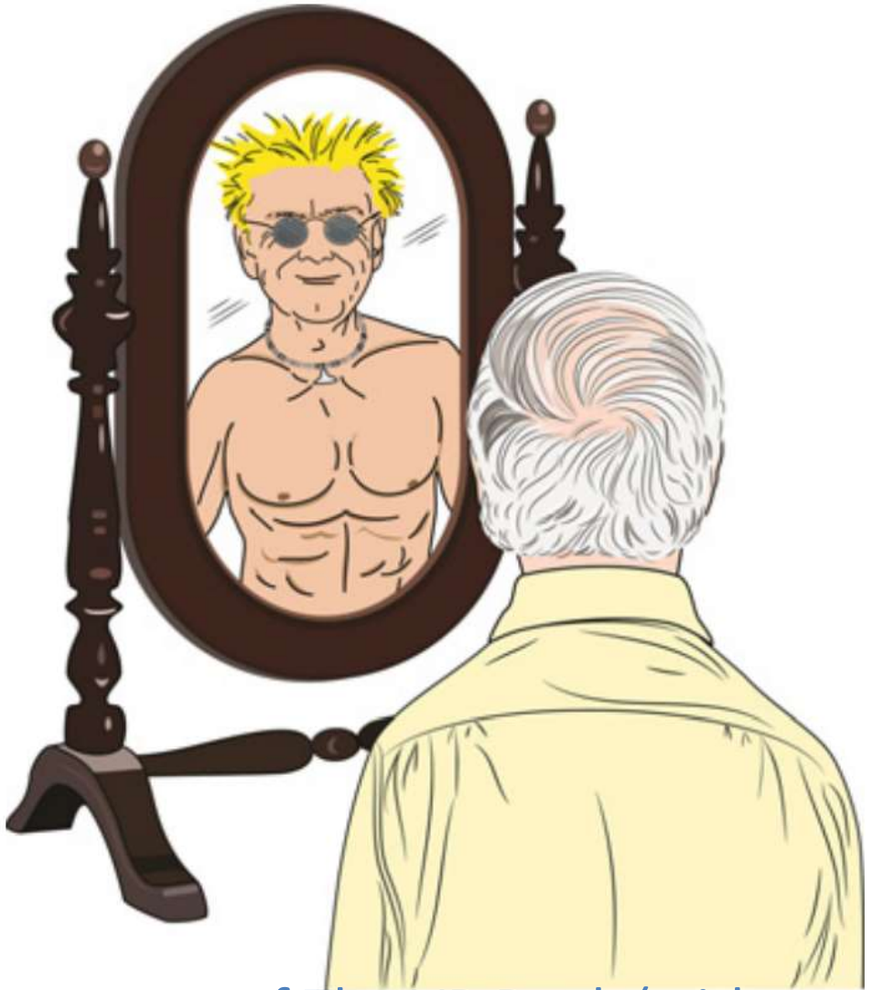


Image courtesy of The VR Book (with permission from original source)

Perception

The Human Senses

- ✓ Sight
- ✓ Hearing
- ✓ Touch
- ✓ Proprioception
- ✓ Balance and physical motion
- ✓ Smell and Taste
- ✓ Multimodal

Immersion and Presence

Why two terms?

Is there a difference?

Immersion and Presence

Immersion

*The **objective degree** to which the real world or a VR system and application **projects stimuli onto the sensory receptors of users**.*

Immersion

Matching is the congruence between sensory modalities (e.g., appropriate visual presentation corresponding to head motion and a virtual representation of one's own body).

Surroundness is the extent to which cues are panoramic (e.g., wide field of view, spatialized audio, 360◦ tracking).

Vividness is the quality of energy simulated (e.g., resolution, lighting, frame rate, audio bitrate).

Interactability is the capability for the user to make changes to the world, the response of virtual entities to the user's actions, and the user's ability to influence future events.

Plot is the story—the consistent portrayal of a message or experience, the dynamic unfolding sequence of events, and the behavior of the world and its entities.

Immersion and Presence

Presence

*A **psychological state** or **subjective perception** in which even though part or all of an individual's current experience is generated by and/or filtered through human-made technology, part or all of the individual's **perception fails to accurately acknowledge the role of the technology** in the experience.*

-International Society for Presence Research, 2000

Presence

The illusion of being in **a stable spatial place**

The illusion of **physical interaction**

The illusion of **self-embodiment**

The illusion of **social communication**

The illusion of **plausibility**

Questions: Immersion & Presence

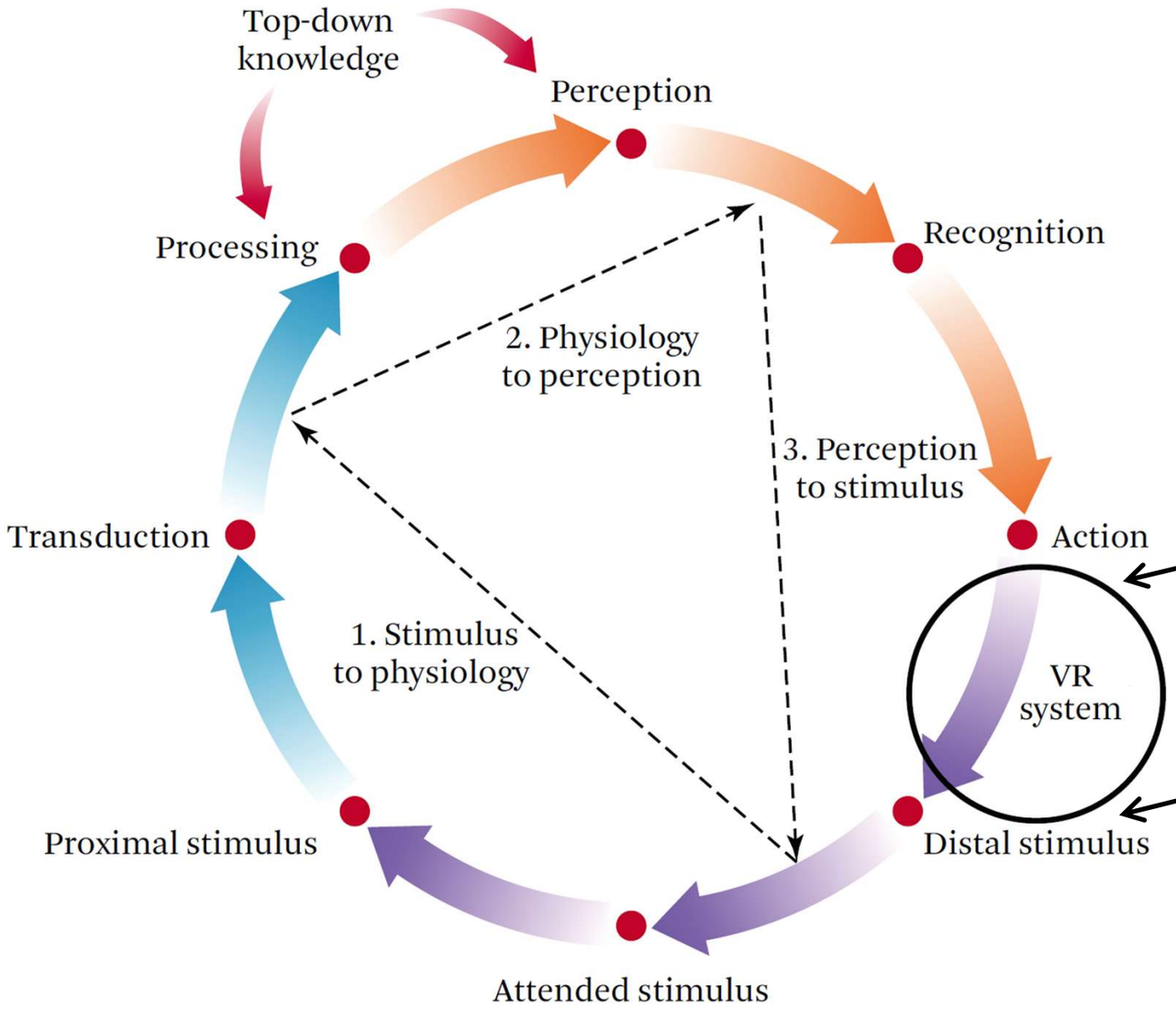
What type(s) of immersion & presence are you using in your VR project(s)?

What other types of immersion & presence might you utilize?

Perceptual Psychology

- Objective vs subjective reality
- Distal and proximal stimuli
- Sensation vs perception
- Bottom-up and top-down processing
- Afference and efference
- Iterative perceptual processing
- The subconscious and conscious
- Mental models
- Visceral, behavioral, reflective, and emotional processes
- Neuro-linguistic programming
- Space, time, & motion
- Perceptual constancies
- Adaptation
- Attention
- Action

The Iterative Perceptual Process



With VR, we hijack the human perception-action system

Human action = VR input/tracking

VR Output = Distal stimuli

Image Courtesy of The VR Book (adapted from Goldstein [2007])

The NLP Communication Model

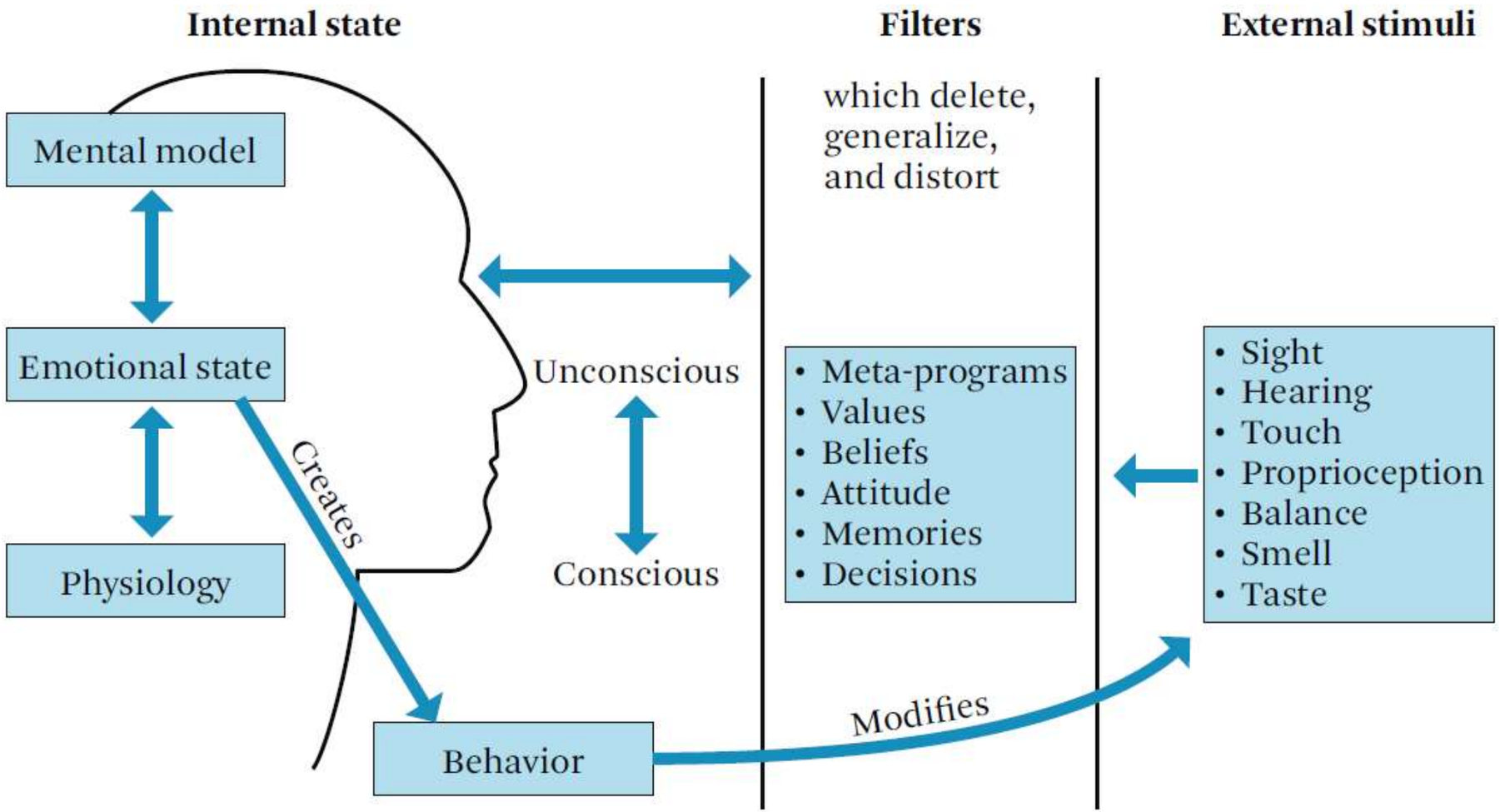


Image Courtesy of The VR Book (adapted from James & Woodsmall [1988])

VR is all About Communication

Communication

- ✓ The **transfer of energy** between two entities
- ✓ Even if just the cause and effect of one object colliding with another object

A **basis for interaction**

Can broken down into

- ✓ **Direct communication**
- ✓ **Indirect communication**

Types of Communication

Direct Communication

- ✓ Real World
  - **Transfer of energy** between two or more entities
    - **No intermediary**
    - **No interpretation attached**
- ✓ VR
  - Creators utilize an **artificial intermediary** (the VR system) between the user and carefully controlled stimuli
    - If designed well and system is **transparent**, users f**eel like they have direct access** to virtual entities
- ✓ Can be further broken down
  - **Structural communication**
  - **Visceral communication**

Types of Communication

Structural communication

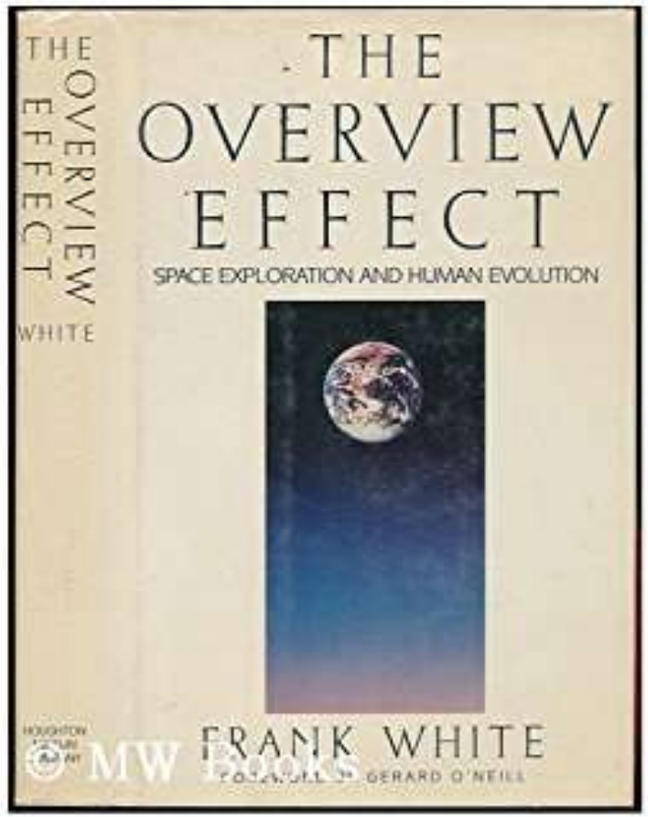
- ✓ The **physics of the world**, the **thing-in-itself**
- ✓ **NOT the description** or the mathematical description
- ✓ The **starting point** for perception, interpretation, and feeling
- ✓ The **signifiers and constraints** of the world
- ✓ VR structural stimuli include
  - pixels on a display
  - sound through headphones
  - rumble/vibration of a controller

Types of Communication

Visceral communication

- ✓ The language of **automatic emotion and primal behavior**
- ✓ **Always present** for humans
- ✓ **NOT the rational representation** of the emotions and behavior
- ✓ The in between of structural and indirect communication
- ✓ **Presence is the act of being fully engaged via visceral communication**
- ✓ Examples
  - The feeling of awe while sitting on a mountaintop
  - Solid eye contact
  - Experiencing VR

Example: Visceral Communication



Types of Communication

Indirect Communication

- ✓ The **connection of two or more things through some intermediary**
  - E.g., our minds interpretation that sits between world and behavior/action
- ✓ Examples
  - **Languages**—spoken, written, & sign
  - **Internal thoughts and giving meaning** (communicating with oneself)
    - understanding, creating stories/histories, giving meaning, comparing, negating, fantasizing, lying, romancing
  - **Internal mental model**—how we "think" about interacting
  - **Speech recognition systems**
  - **Indirect gestures**
  - **Indirect interactions** (e.g., moving a slider to change an object property)

Questions: Communication

What type of communication does your VR experience utilize?

What type of communication might your VR emphasize that it currently is not?

Fidelity

"The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal."

–Ivan Sutherland, 1965

Fidelity Continua

Experiential fidelity [Lindeman and Bechhaus, 2009]

Representational fidelity [Jerald 2015]

Interaction fidelity [Bowman et al., 2012]

Experiential Fidelity

The **degree to which the user's personal experience matches the creators intent.**

Immersive film has high experiential fidelity.

Free-roaming social virtual worlds have low experiential fidelity.

Representational Fidelity

The **degree to which the VR experience conveys a place that is, or could be, on Earth.**

The content

✓ Not the technical quality (e.g., not immersion).

Not necessarily the goal

✓ abstract relaxing worlds of color blobs has low representational fidelity.

A cartoon world is somewhere in the middle.

Interaction Fidelity

The **degree to which physical reality for a virtual task matches the equivalent real world task.**

Training vs efficiency

Interaction Fidelity

Realistic

✓ Reaching out to grab something

Magic

✓ Superhuman powers

✓ Shooting fireballs from the hand

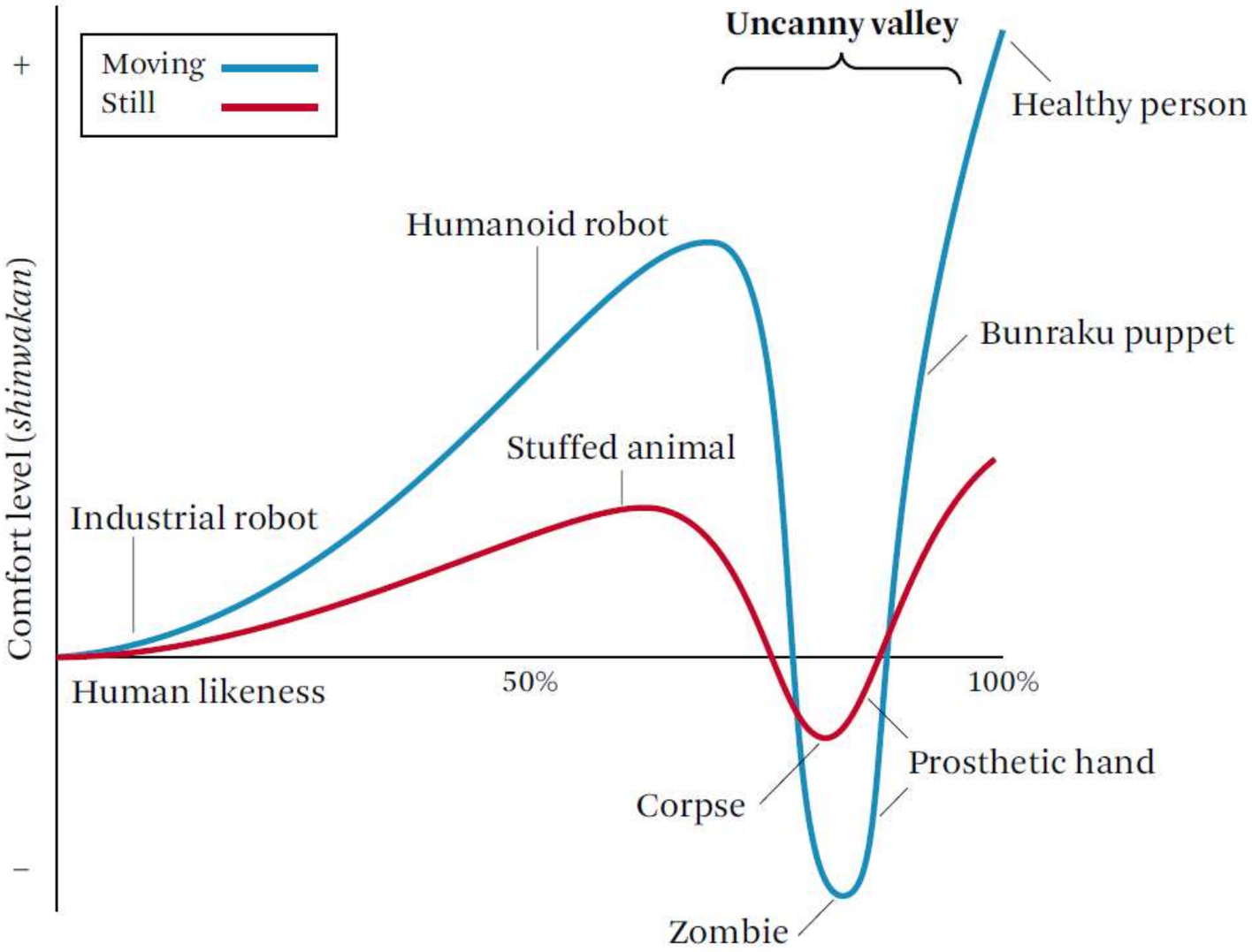
✓ Selection at a distance

Non realistic

✓ Buttons

✓ Speech recognition

Fidelity: The Uncanny Valley



Hand/Arm Fidelity



Questions: Fidelity

Is perfect fidelity required for your project?

Where does your project fall upon the fidelity continua?

- ✓ Experiential fidelity
- ✓ Representational fidelity
- ✓ Interaction fidelity
- ✓ Other fidelity?

What if you chose different fidelities?

Interactions and Interfaces

Interaction

The **communication that occurs between a user and the VR application** that is mediated through the use of **input and output devices**

Interface

The **VR system side of the interaction** that exists whether a user is interacting or not

Human-Centered Interaction Design

✓ Designing interactions and interfaces from the **user's perspective**

Course Outline

Humans

Interaction

Comfort

Virtual Worlds

Iteration

Interaction

Interactions

Overview

Norman's Principles of Interaction

Classes of Input Devices

The Hands

Reference Frames

Interaction Patterns

Interactions and Interfaces

Interaction

- ✓ The **communication that occurs between a user and the VR application** that is mediated through the use of **input and output devices**

Interface

- ✓ The **VR system side of the interaction** that exists whether a user is interacting or not

Human-Centered Interaction Design

- ✓ Designing interactions and interfaces from the **user's perspective**

Action

Some researchers believe the **purpose of perception is not to create a representation** of what is out there but **to guide actions**

Taking action on information from our senses helps us to **survive** so we can **perceive another day**

Perception and **actions** are **closely intertwined**

- ✓ Intended action affects distance perception

Action

Some example VR actions

- ✓ Pressing button
- ✓ Making gestures
- ✓ Directional gazing
- ✓ Speaking
- ✓ Walking

Modal Actions

Based on Laviola [1999] & Martin [1998]

Single Input

Specialized

- ✓ Single modality where that modality is clearly ideal and sufficient
- ✓ Selection via physical intersection when input is reliable

Equivalent

- ✓ User chooses the modality
- ✓ Identical results
- ✓ System indifferent to user preferences
- ✓ Select a menu option by voice or through a panel

Simultaneous Input

Redundant

- Modalities contain same optional info to perform a single command
- Reduces ambiguity
- Grab gesture on cube while saying “select cube”

Complementarity

- Merge different required info from each modality
- Place object behind back while saying “delete”

Concurrent

- Issue different commands simultaneously
- Point to fly while verbally requesting info

Sequential Input

Transfer

- Transfer info from one modality to another
- Push-to-talk / Push-to-gesture

Questions: Multimodal Input

What Input modalities are you using for your project(s)?

What additional modalities could help increase presence and help your users more easily reach their goals?

Where might combining modalities be more effective?

Norman's Principles of Interaction

Affordances

Signifiers

Constraints

Feedback

Mappings

Affordances are **NOT** Signifiers

Affordances

The **possible actions** of how something can be interacted with **by a user**

Not a property!

The **relationship** between the capabilities of a user and the properties of a thing

Interface elements afford interaction

Different users might have **different affordances**

Signifiers

A **perceivable indicator** (a signal) that communicates appropriate purpose, structure, operation, and behavior of an object to a user

A good signifier **informs what is possible** before interaction occurs with its corresponding affordance

Questions: Affordances vs Signifiers

What are some affordances in your project?

How are those differentiated from your signifiers?

How could differentiating between affordances and signifiers help you think about your project differently?

Constraints

Limitations to guide actions/behaviors and **ease interpretation**

- ✓ Logical
- ✓ Semantic
- ✓ Cultural
- ✓ **Physical**
- ✓ **Mathematical**

Questions: Constraints

What are some constraints in your project?

What are some other constraints to consider?

Feedback

Communication to the user that provides results of an action or status of a task

Helps to **aid understanding** of the state of the thing being interacted with, and **helps to drive future action**

Feedback

Sensory substitution

- ✓ **Replace** one sensory modality with another
- ✓ Examples
  - Highlights
  - Vibrations
  - Audio

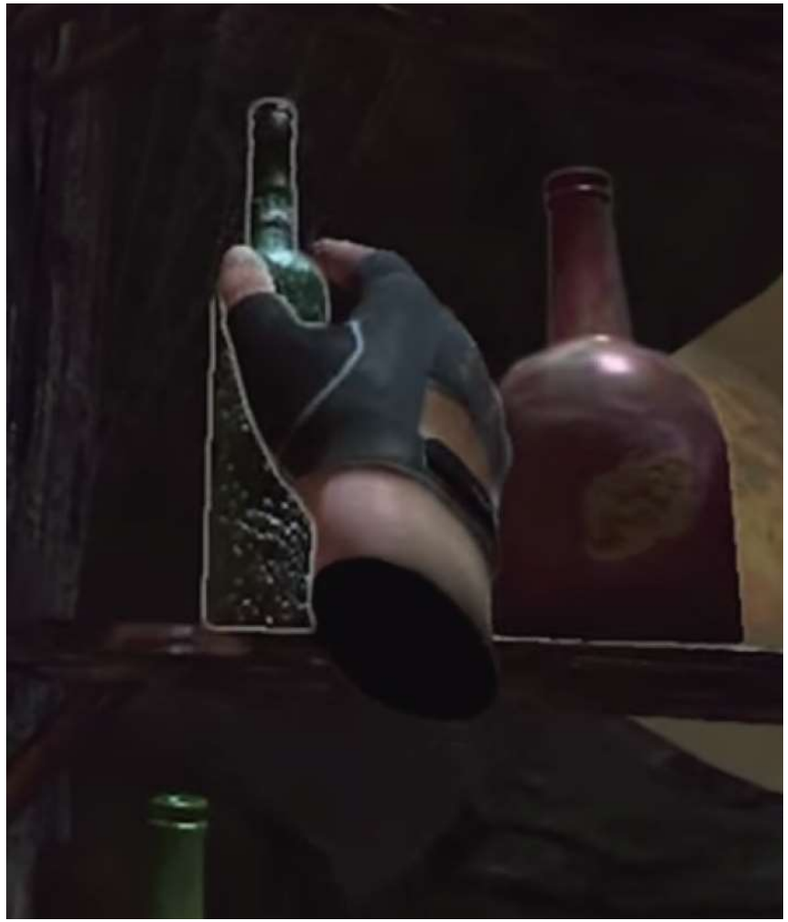


Image courtesy of The VR Book (with permissions from Cloudhead Games)

@TheVRBook

Questions: Feedback

What type of feedback do/could you use?

What type of feedback can you not possibly provide given the hardware you are using?

How could you use sensory substitution?

Mappings

A **relationship** between two or more things

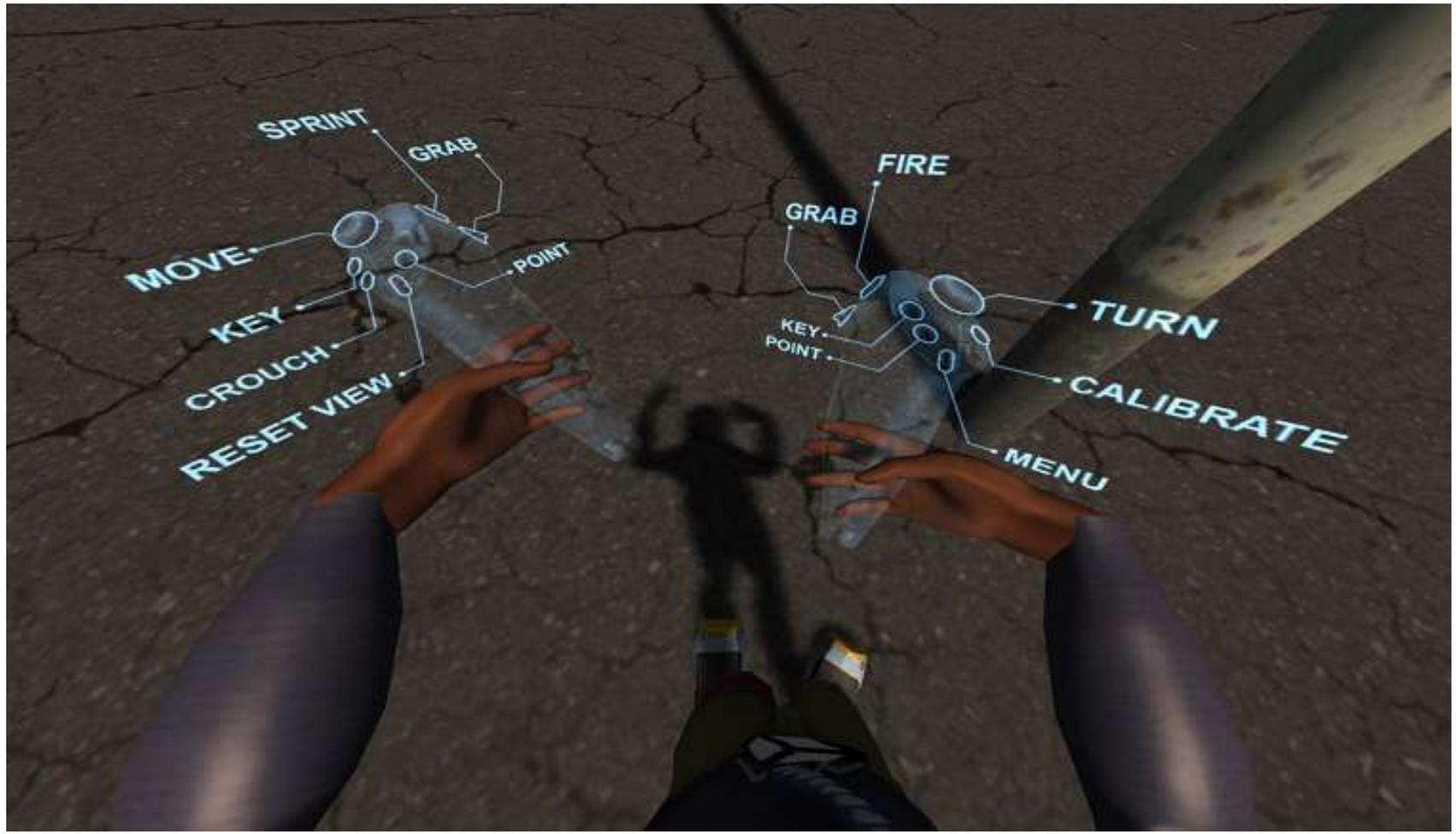
Interactions are easiest to learn where there is an **obvious understandable mapping** between controls, action, and the intended result

Useful even when the person is not directly holding the thing being manipulated

Mappings from **hardware to interaction techniques** defined by software are especially important for VR

Often an input device will have a natural mapping to one technique but poor mapping to another technique

Mapping Signifiers in the Hands



Trainexus NextGen Interactions

@TheVRBook

Compliance

The **matching of sensory feedback** with input devices across time and space

Improves user **performance and satisfaction**

Results in **perceptual binding**

- ✓ Interaction feels as if interacting with a single coherent object

Visual-vestibular compliance is especially important for reducing motion sickness

Compliance

Temporal

Spatial

- ✓ **-Directional**

  -Sensory feedback that matches the **rotation and directional movement** of an input device

- ✓ **-Positional**

  -Co-location of sensory feedback with the input device position.

- ✓ **-Nulling**

  -The matching of the initial placement of a virtual object when the corresponding input device **returns to its initial placement**

  -Achievable with **absolute input devices but not relative input devices**

Questions: Mappings & Compliance

Are your mappings direct or indirect? Or somewhere in between?

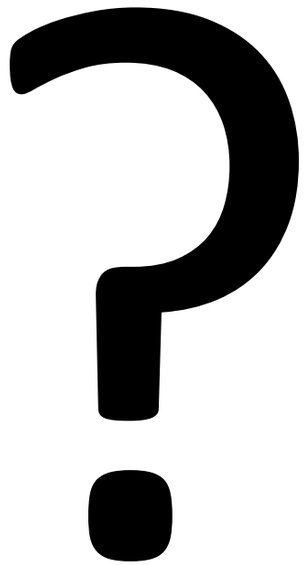
What type of compliance are you utilizing?

What type of compliance is important for your project?

Input Device Classes

	Proprioception	Consistent	Useable in lap or the side	Haptics capable	Unencumbered	Physical buttons	Hands free to interact with real world	General Purpose
Hand								
World-Grounded Devices	✓	✓		✓	✓	✓	✓	
Non-Tracked Hand-Held Controllers		✓	✓	✓		✓		
Bare Hands	✓				✓		✓	✓
Tracked Hand-Held Controllers	✓	✓	✓	✓		✓		✓
Hand Worn	✓	✓	✓	✓		✓	✓	✓
Non Hand								
Head Tracking	✓	✓					✓	✓
Eye Tracking							✓	
Microphone			✓		✓		✓	✓
Full-Body Tracking	✓	✓	✓	✓	✓		✓	✓
Treadmills	✓	✓			✓		✓	

The Most Important Input Device?



The Most Important Input Device!

The Human Hands!

- ✓ Large proportion of **sensory and motor cortex devoted to the hands**
- ✓ Hand-tracking technology is simply **the mediator that brings the hands into VR**

The Homunculus

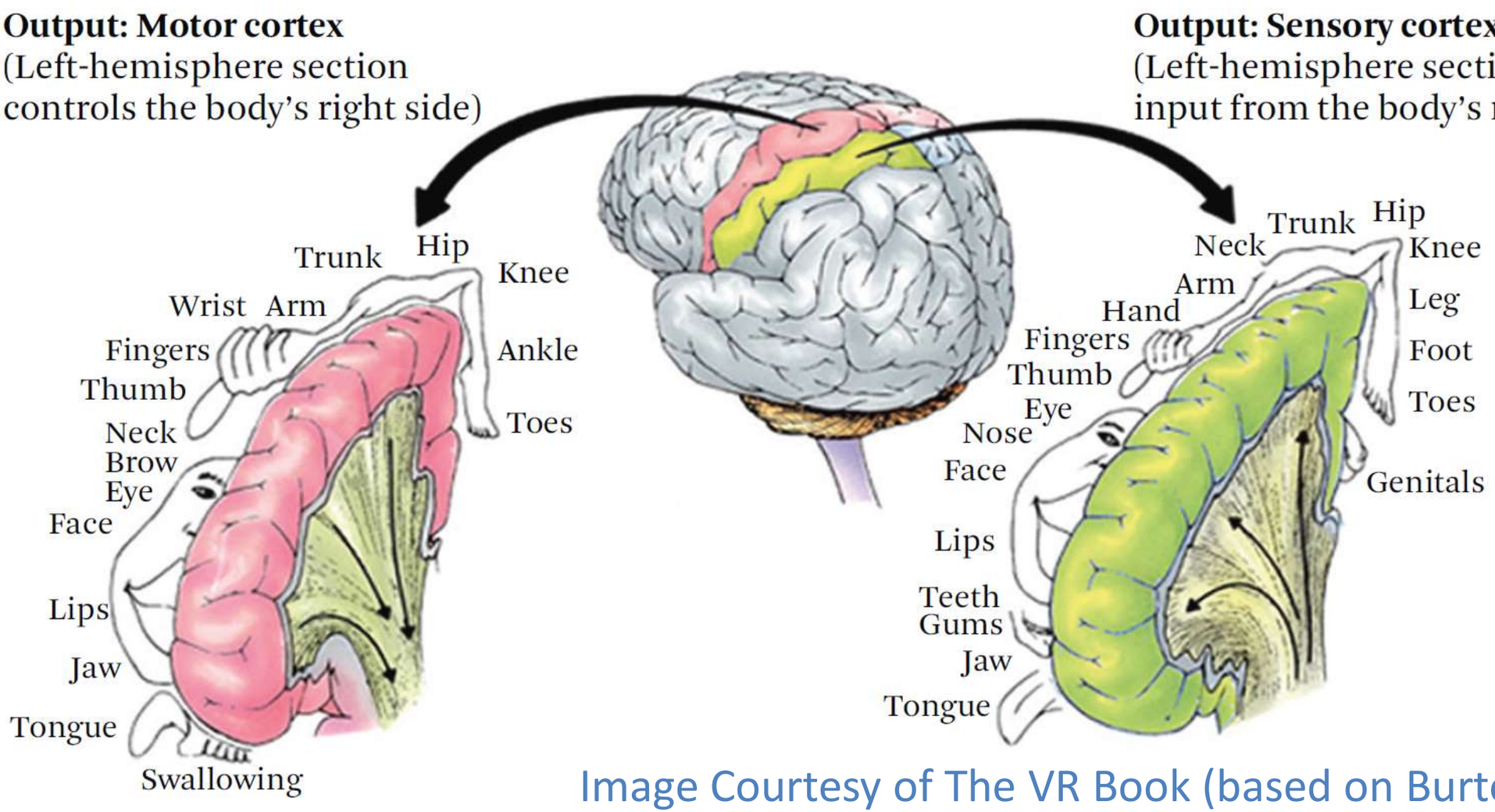
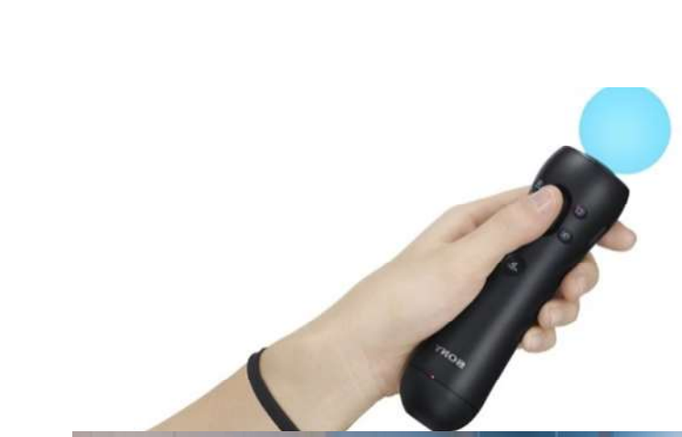
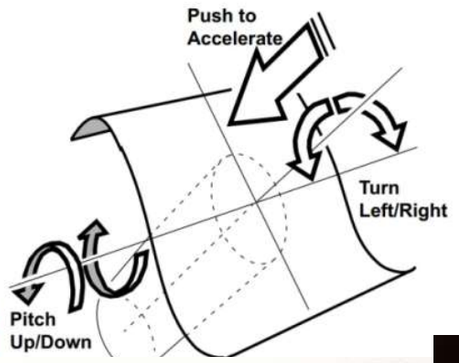
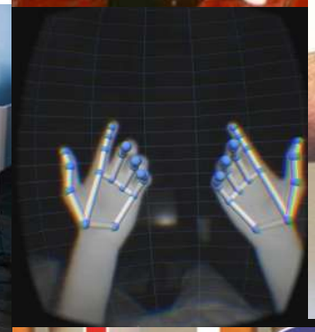


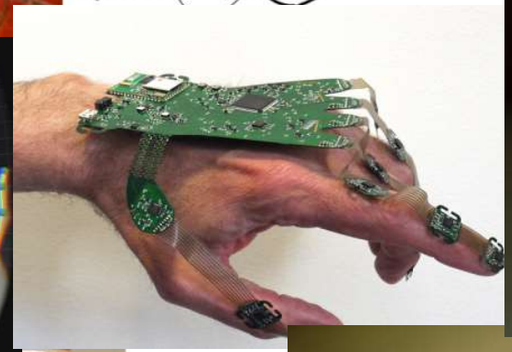
Image Courtesy of The VR Book (based on Burton [2012])

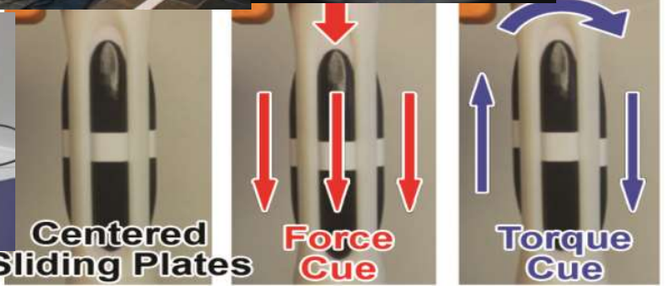
VR Hand Input Devices

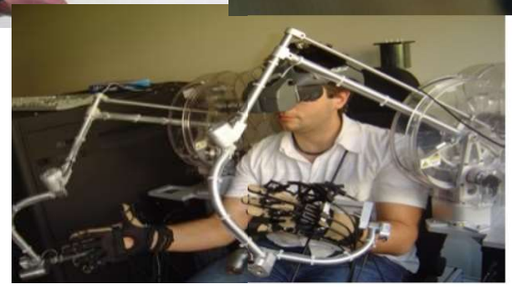


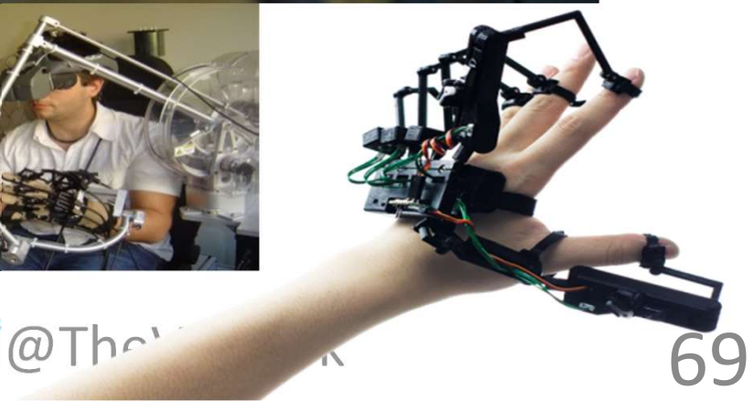












Controllers vs. Bare Hands

Controllers	Bare Hands
+ Highly reliable	+ Can fully touch/interact with physical objects
+ Buttons	– Computationally intense
+ Capability to add haptics	– Physics challenges • Line of sight and volume • lighting
± Physical prop appropriate for some tasks	– Determination of intent • Difficult even if we had perfect systems

Buttons vs. No Buttons

Buttons	No Buttons
± Abstract interactions	± Less abstract
+ Reliable	+ High level of realism
+ Physical feedback	+ Multiple points of continuous motion
+ Immediate	

Direct vs. Indirect Gestures

Direct	Indirect
+ Immediate (no delay)	+ Convey semantic meaning
± Structural (no interpretation)	Symbolic, pathic, and affective info
+ Convey spatial information	– System often interprets over a period of time
	Start of gesture not sufficient
Examples	Examples
Pushing an object	Sign language
Selection via pointing	Marking menus

Bare Hands are Difficult!

Possible answers

- ✓ Choose appropriate use cases
- ✓ Multimodal interaction
- ✓ Lots of experimentation

Bimanual Classifications

Hand Symmetric

Synchronous

- ✓ Pushing on a large object with both hands

Asynchronous

- ✓ Climbing a ladder

Hand Asymmetric

Non-dominant hand

- ✓ Subconsciously provides a comfortable reference frame
- ✓ Gross movements
- ✓ Positioning a piece of paper or peeling a potato

Dominant hand

- ✓ Precise control

Tracked Hand-held controllers

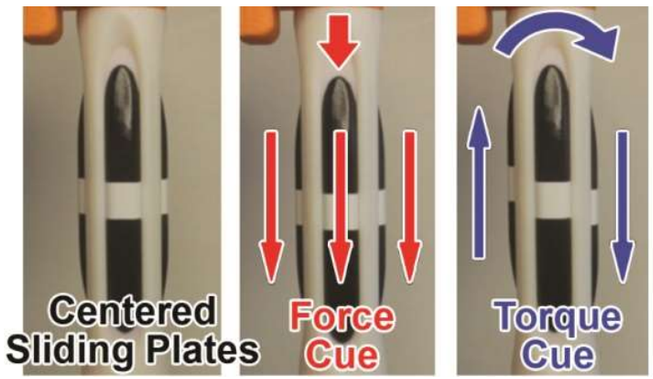
The Evolution of Tracked Controllers

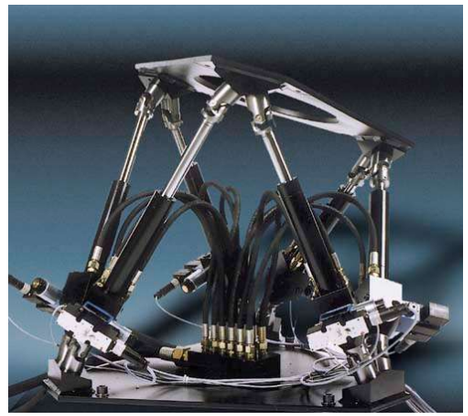


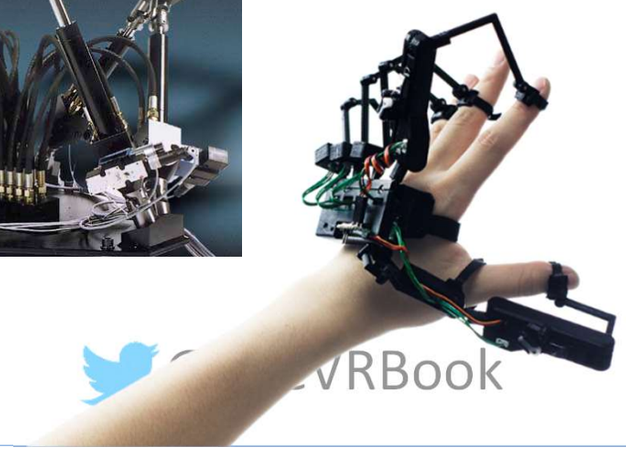




Haptics and Motion Devices







Questions: Hands

What type of hand tech (if any) are you using?

Is that tech the best choice given your situation?

- ✓ Are you trying to force something that does not fit the technology you are using?
- ✓ If you can't change your tech, could you change your goals and interactions to fit that tech?

Reference Frames

- Head
- Torso
- Virtual World
- Real World
- Hands
- Eyes

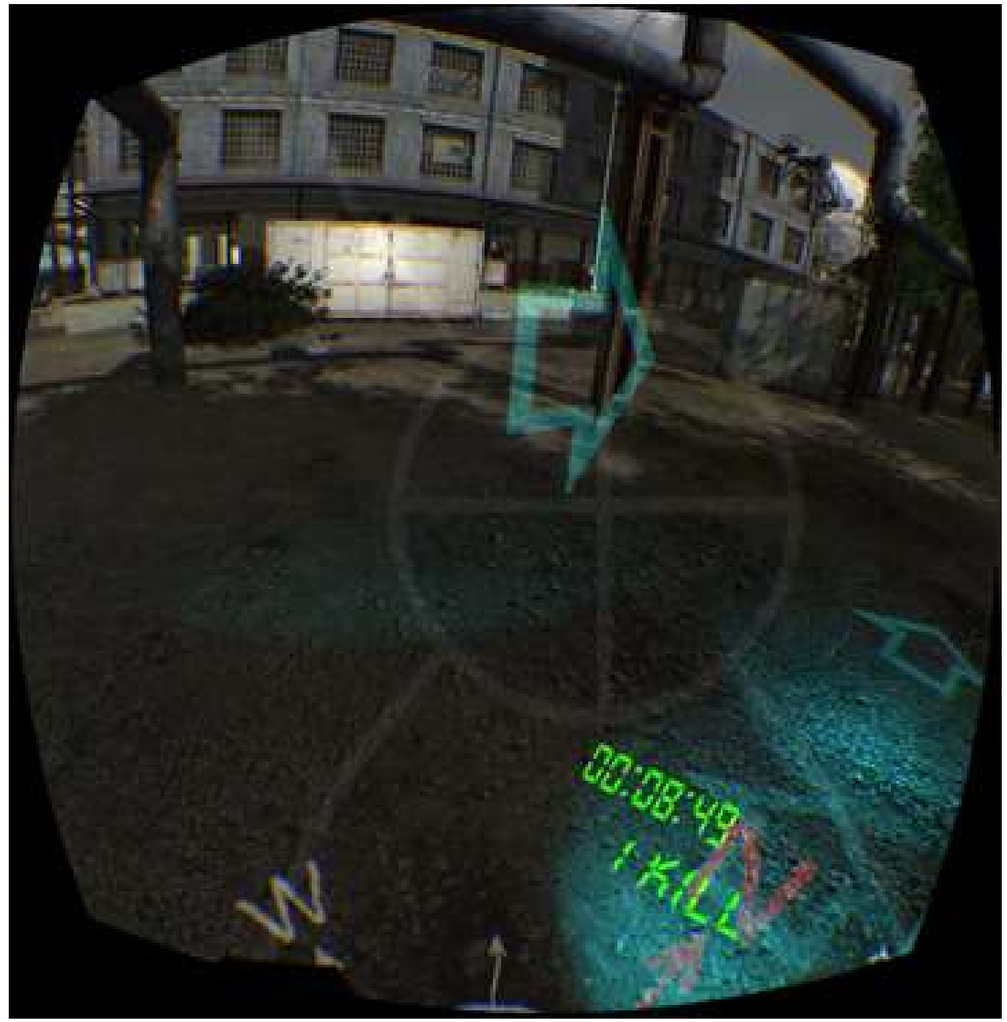


Image Courtesy of NextGen Interactions

Head Reference Frame

- Cyclopean eye & HMD reference Frame
- Gaze-directed selection
- Most often used when hand tracking unavailable
- Minimize visual cues
- Careful of porting game HUDs

Image Courtesy of NextGen Interactions

Torso Reference Frame

- Moves and rotates with the body
  - ✓ Whether virtual or physical motion
- Takes advantage of proprioception
  - ✓ Body Relative Tools
  - ✓ Info displays and utility belts
- Best when Torso tracked, but can be approximated
- Steering
  - ✓ Misunderstanding this can result in Call of Duty Syndrome

Image Courtesy of NextGen Interactions

Virtual World Reference Frame

- Geographic position and direction
- Cognitive maps
- Large scale travel
- Objects difficult to directly grab/interact

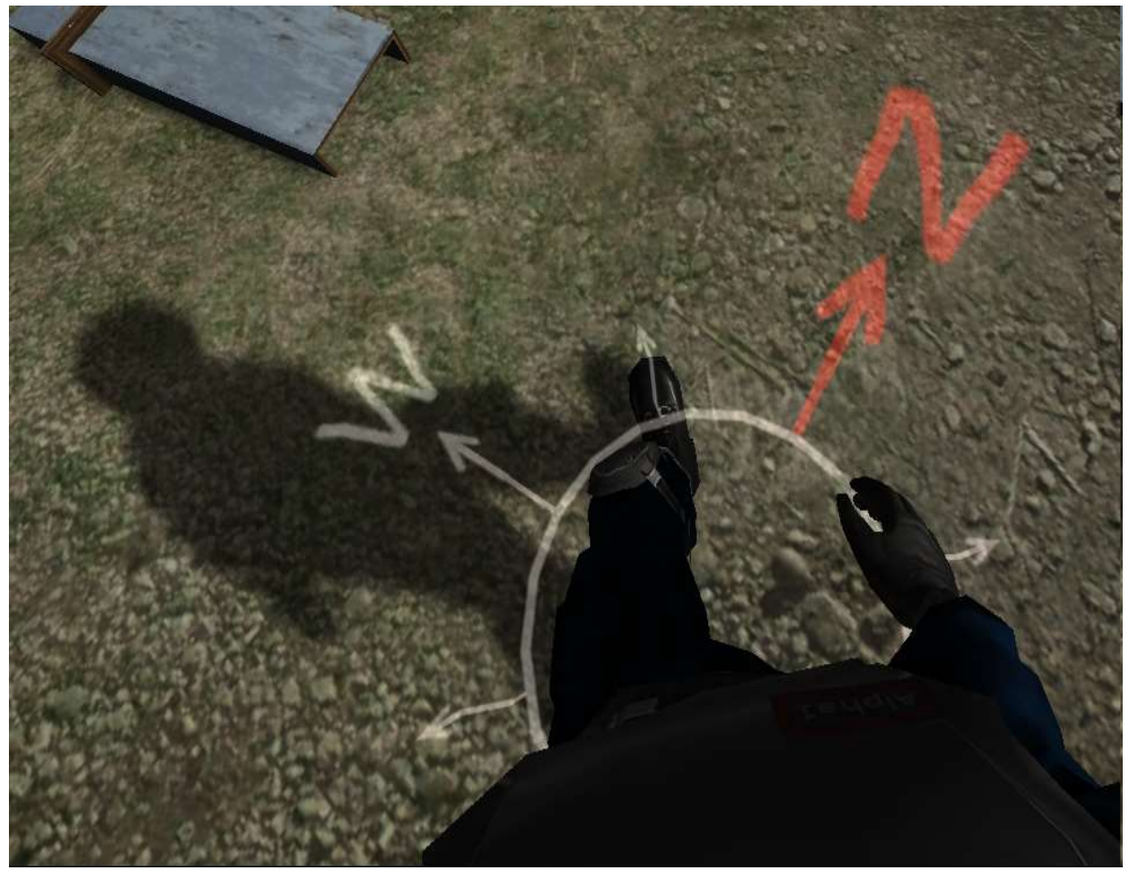


Image Courtesy of NextGen Interactions

Real-World Reference Frame

Independent of user motion

Real World Physical Props

Rest frames

- Reduce sickness
- E.g., a cockpits

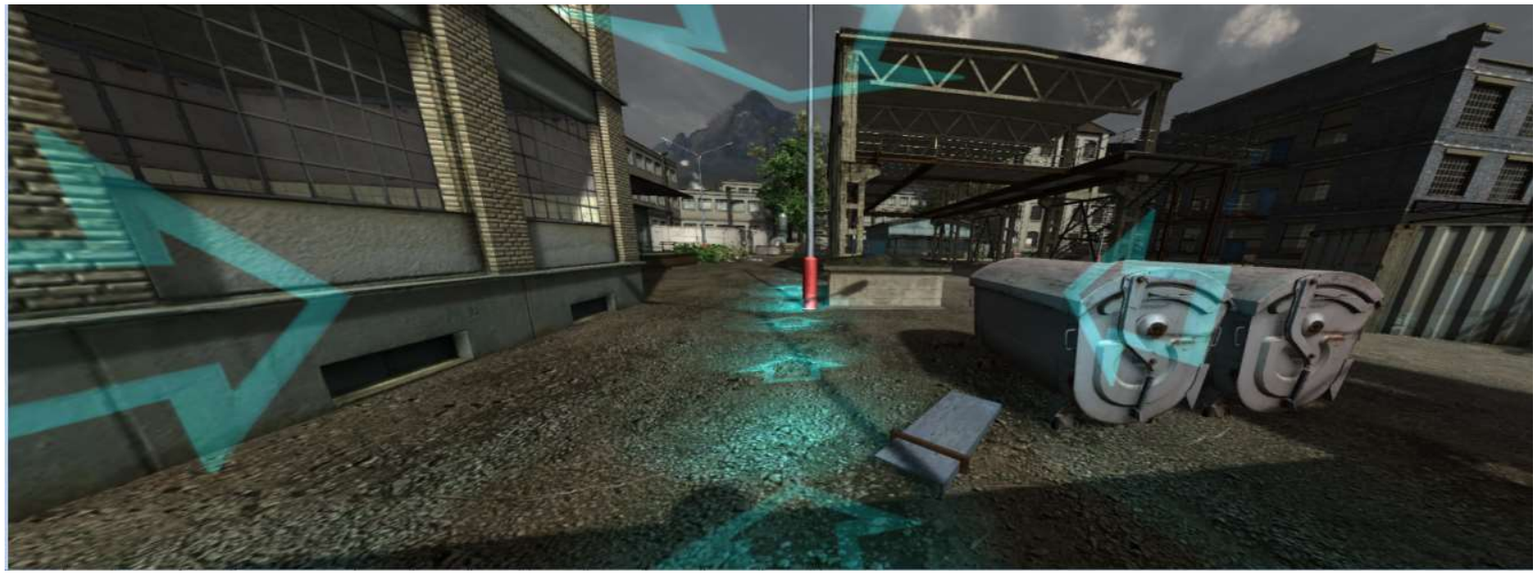


Image Courtesy of NextGen Interactions

Reference Frames Conclusion

Choose wisely what reference frames you put your interfaces in!

Questions: Reference Frames

What reference frames might be useful for you?

What are some disadvantages & advantages of those reference frames for your design?

Interaction Patterns

Selection

- Pointing
- Hand Selection
- Image-Plane
- Volume Based

Manipulation

- Direct Hand
- Proxy
- 3D Tool

Viewpoint Control

- Walking
- Steering
- 3D Multi-Touch
- Automated

Indirect Control

- Widgets & Panels
- Non Spatial

Compound

- Pointing Hand
- World-in-Miniature
- MultiModal

The Pointing Pattern

The First Hand Pointing Technique

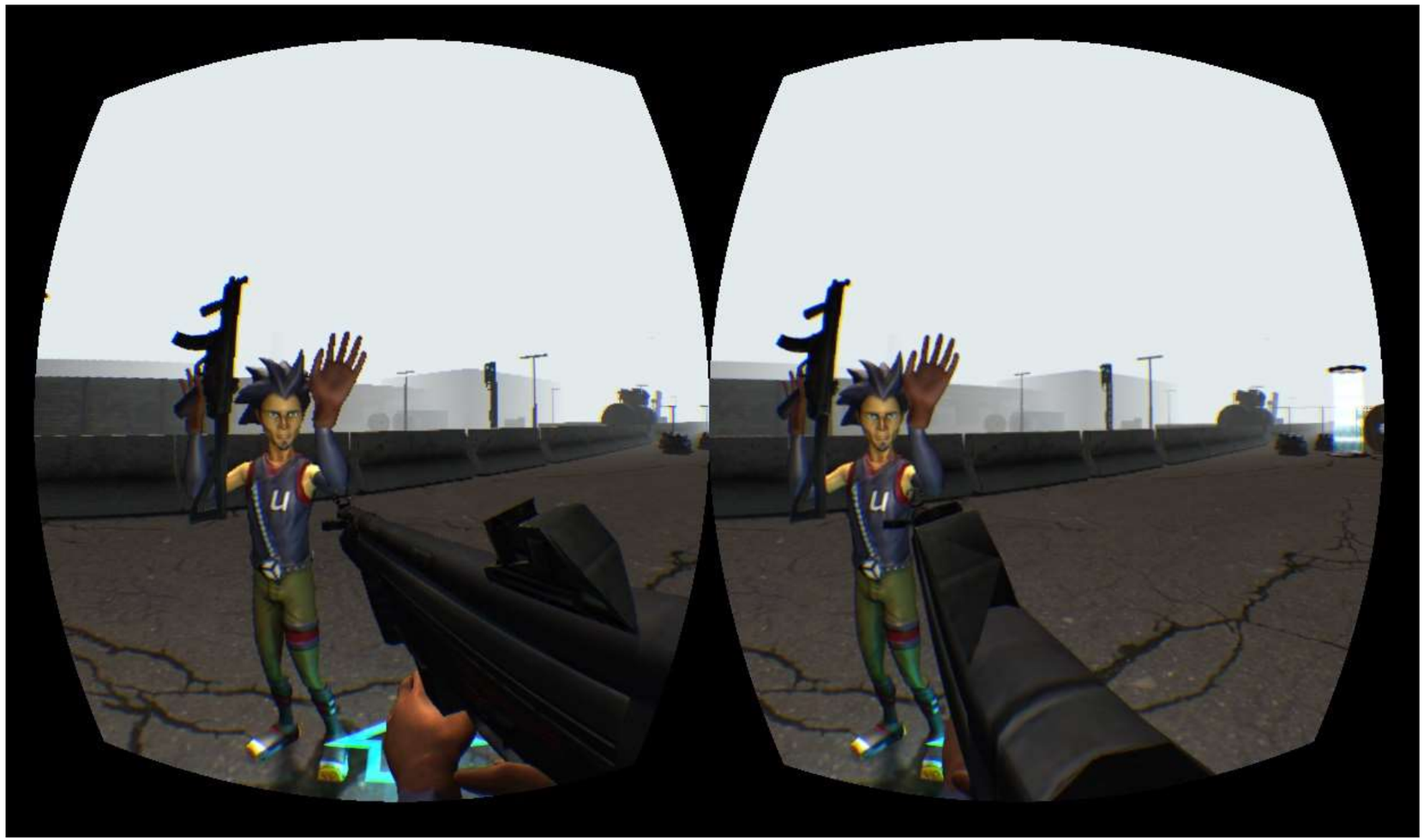


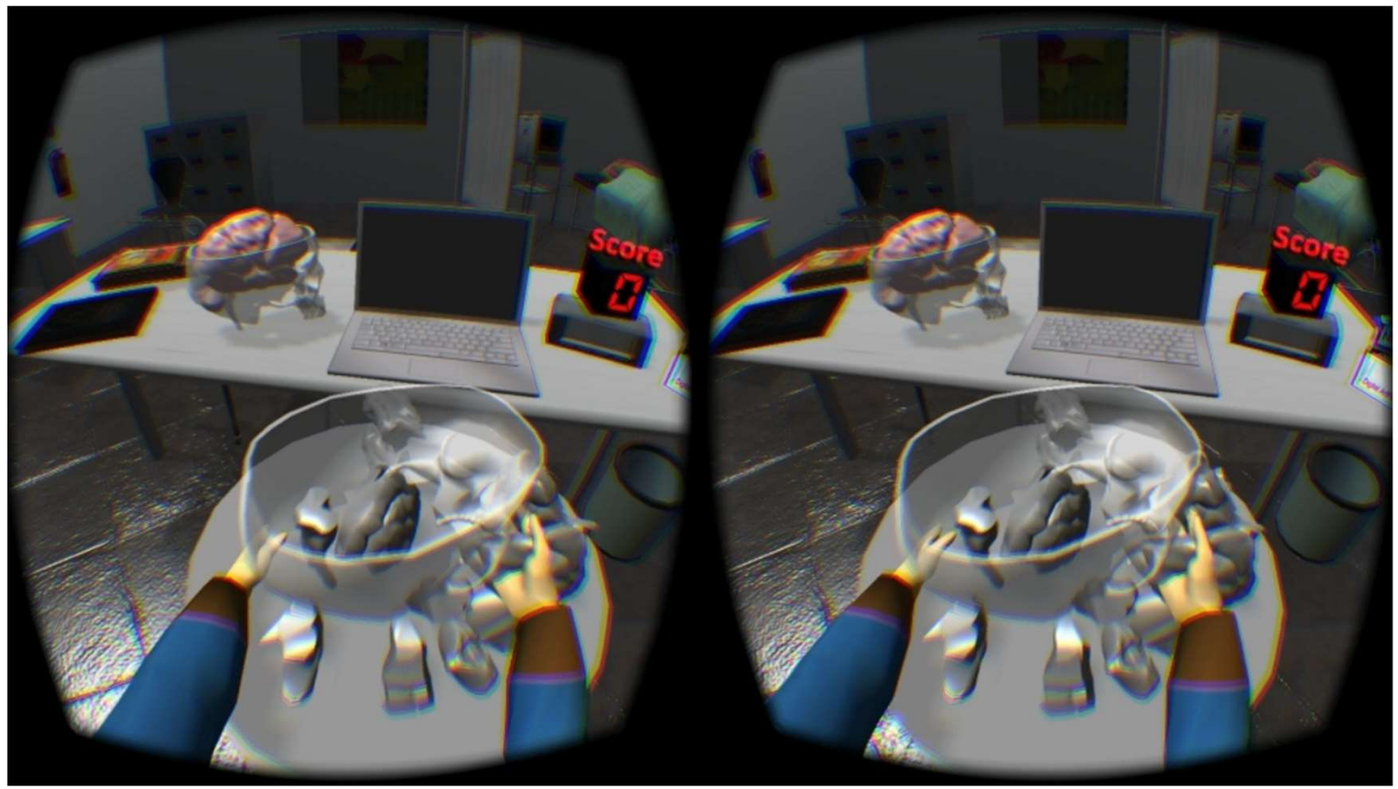
Image courtesy of NextGen Interactions

The Pointing Pattern

Cure Fred by *Digital ArtForms*

Hand Selection/Manipulation Patterns (video)

Hands with Arms



Cure Fred by *Digital ArtForms*

The Image-Plane Pattern

The Head-Crusher Technique

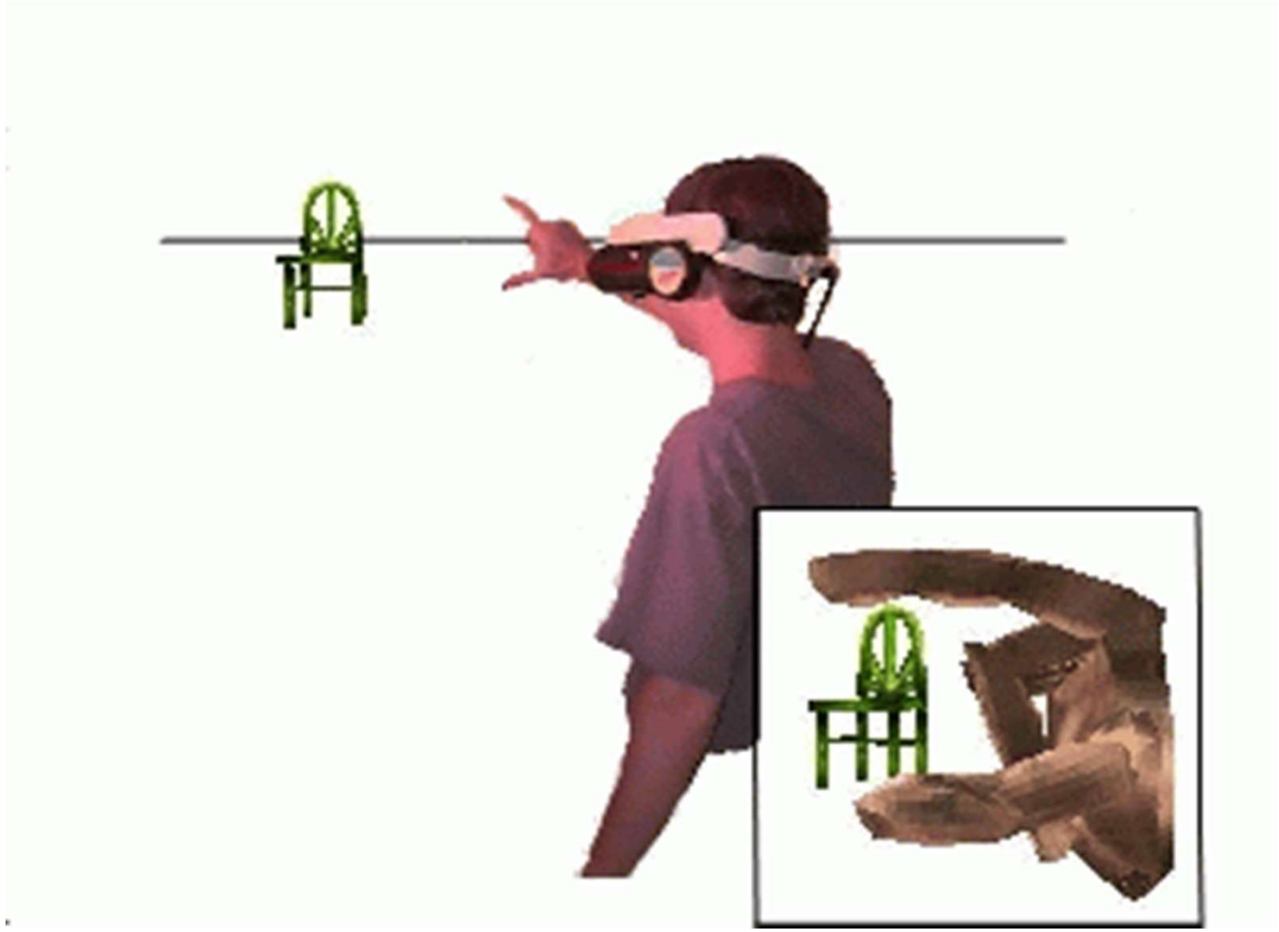


Image Courtesy of The VR Book (from Pierce et al. [1997])

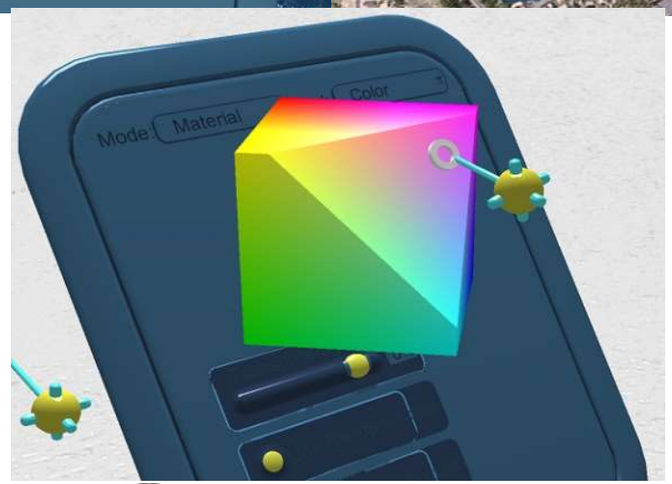
Widgets & Panels Pattern

2D Desktop Integration Technique

Image Courtesy of The VR Book (from Taylor et al. [2010])

Hand-held panels

- Buttons
- Sliders
- Dials
- Color cubes



MakeVR by SIXENSE™ & *Digital ArtForms*

Viewpoint Control Patterns

- Walking
  - Real walking
  - Redirected walking
  - Walking in place
- Steering
  - Dynamic field of view
  - Dynamic rest frames
- 3D Multitouch
  - Pinch, pull/push, rotate, and zoom
- Automated
  - Teleportation

Automated Pattern—Teleportation

Popularized by CloudHead Games

Zero motion sickness

Results in disorientation

Bowman & Hodges (1997)

Budget Cuts by Neat Games

Case Study: Teleportation as Locomotion

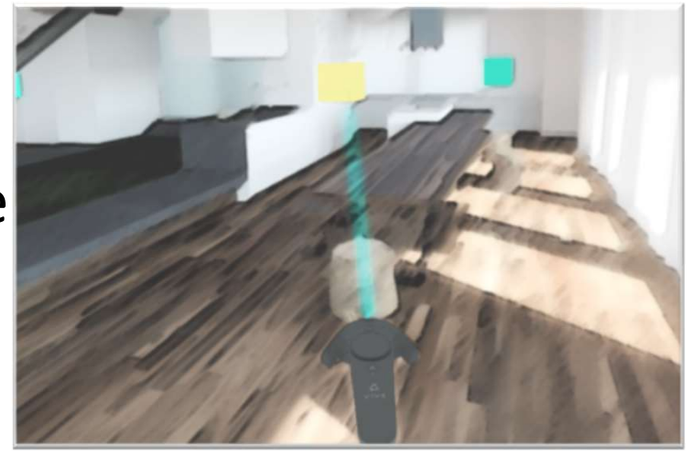
Goal: ArchViz demo with a roomscale Vive experience

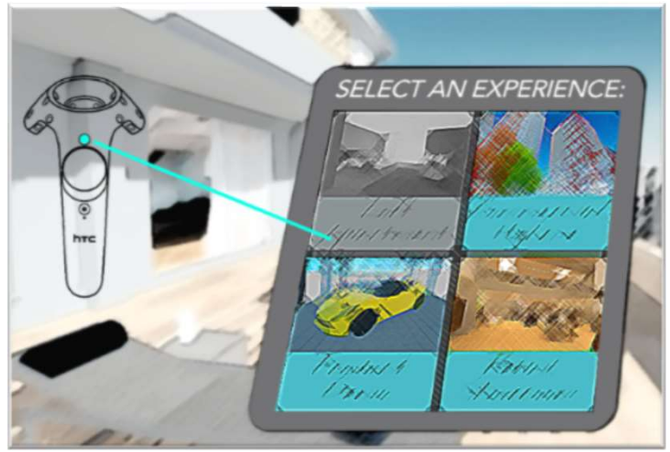
Needed a way for user to navigate through the visualizations past the boundary of the chaperone

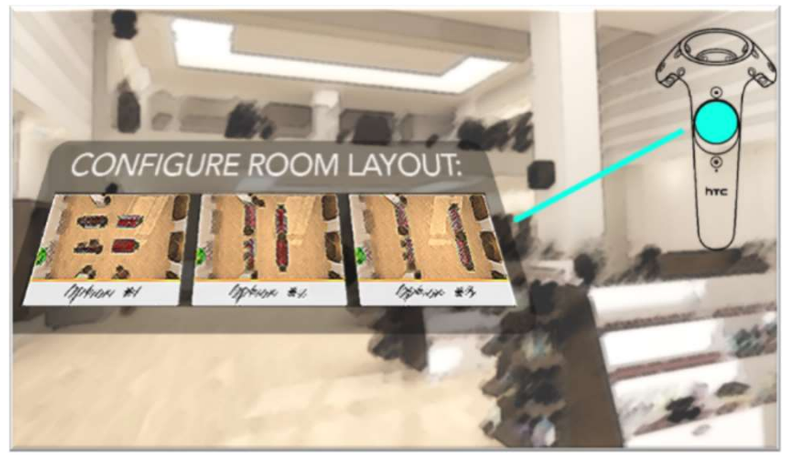
Implemented simple node-based teleportation using a laser emitter from the controller

Used menu button as scene switcher, and thumbpad button as Scene Configurator

Users find laser pointer very intuitive, with low mental load







The Walking Pattern

Walking Pattern

- ✓ A form of viewpoint control
- ✓ Specific walking techniques
  - real-world walking
  - redirected walking
  - walking in place
  - treadmill walking

The Walking Pattern

(video)

The Treadmill Technique

VR Apocalypse by NextGen Interactions with the Virtuix Omni

3D Multitouch Pattern

An extension of **2D Multitouch**

Manipulate the world as an object

- **Reduces sickness**
- **Solves gorilla arm**

Low interaction fidelity

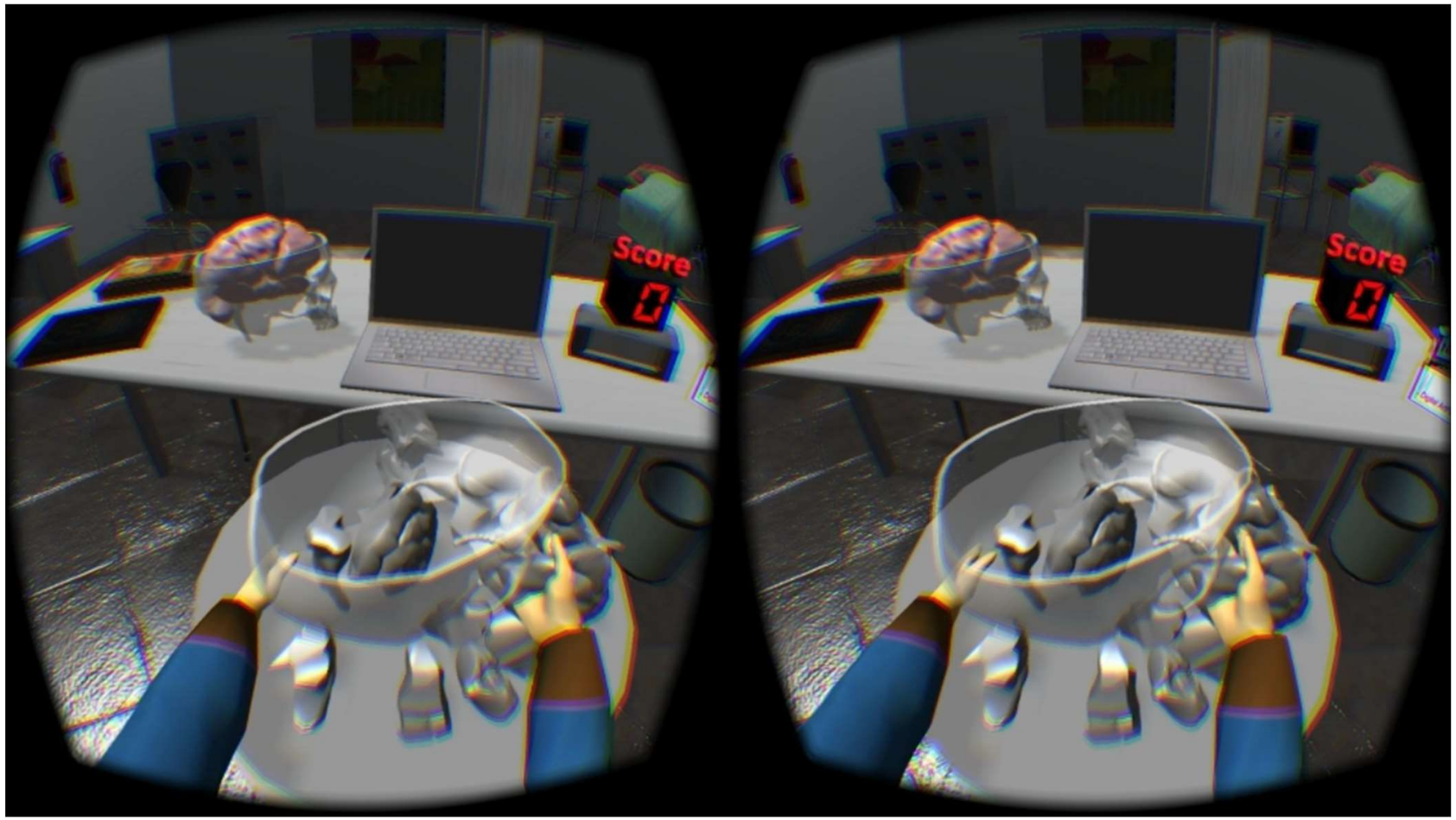
- Appropriate for **abstract non-realistic interactions**

Content/data **independent**

- Emergency preparedness
- Medical Visualization
- MakeVR

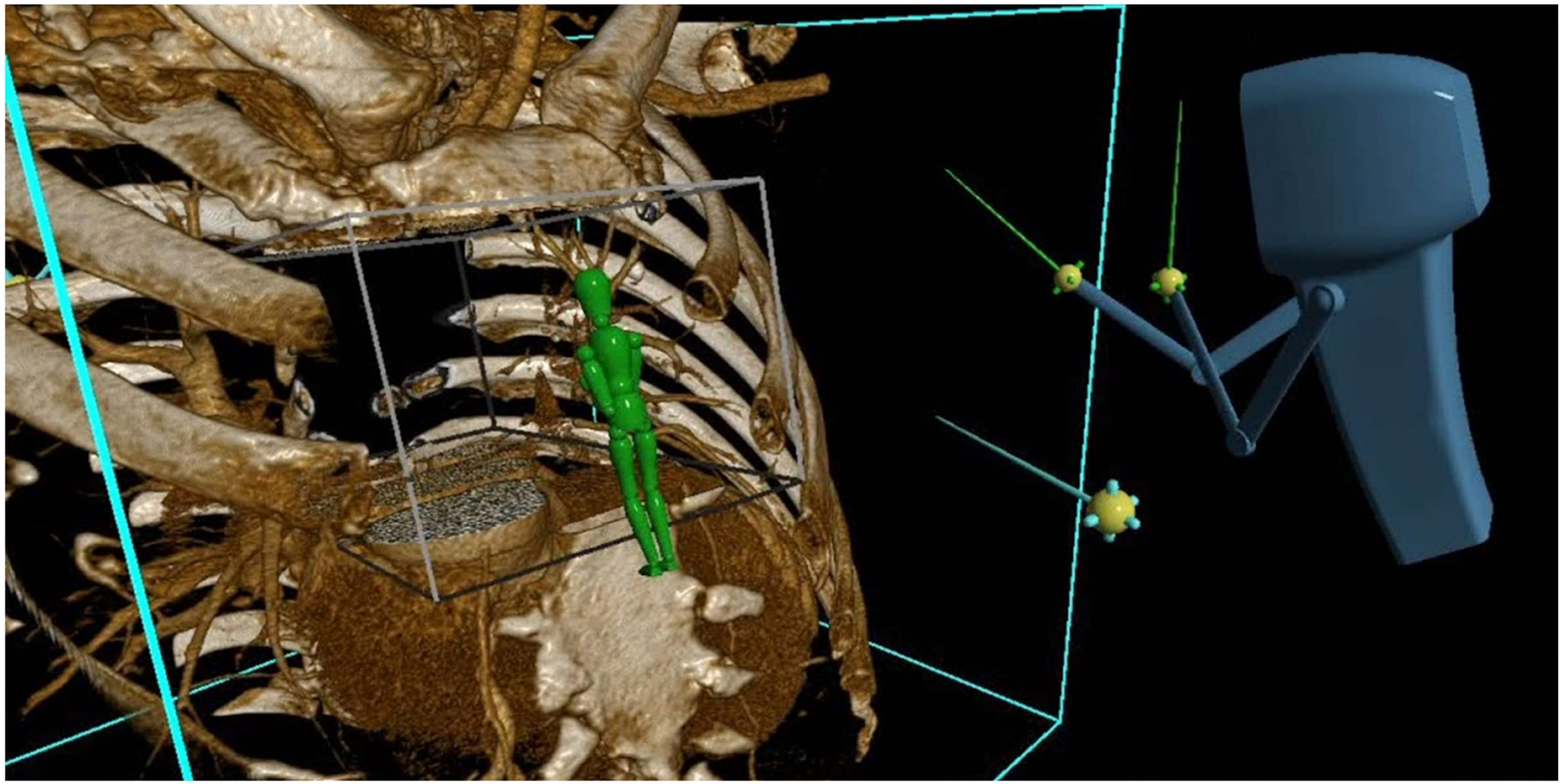
3D Multitouch: Education

(video)



Cure Fred by *Digital ArtForms*

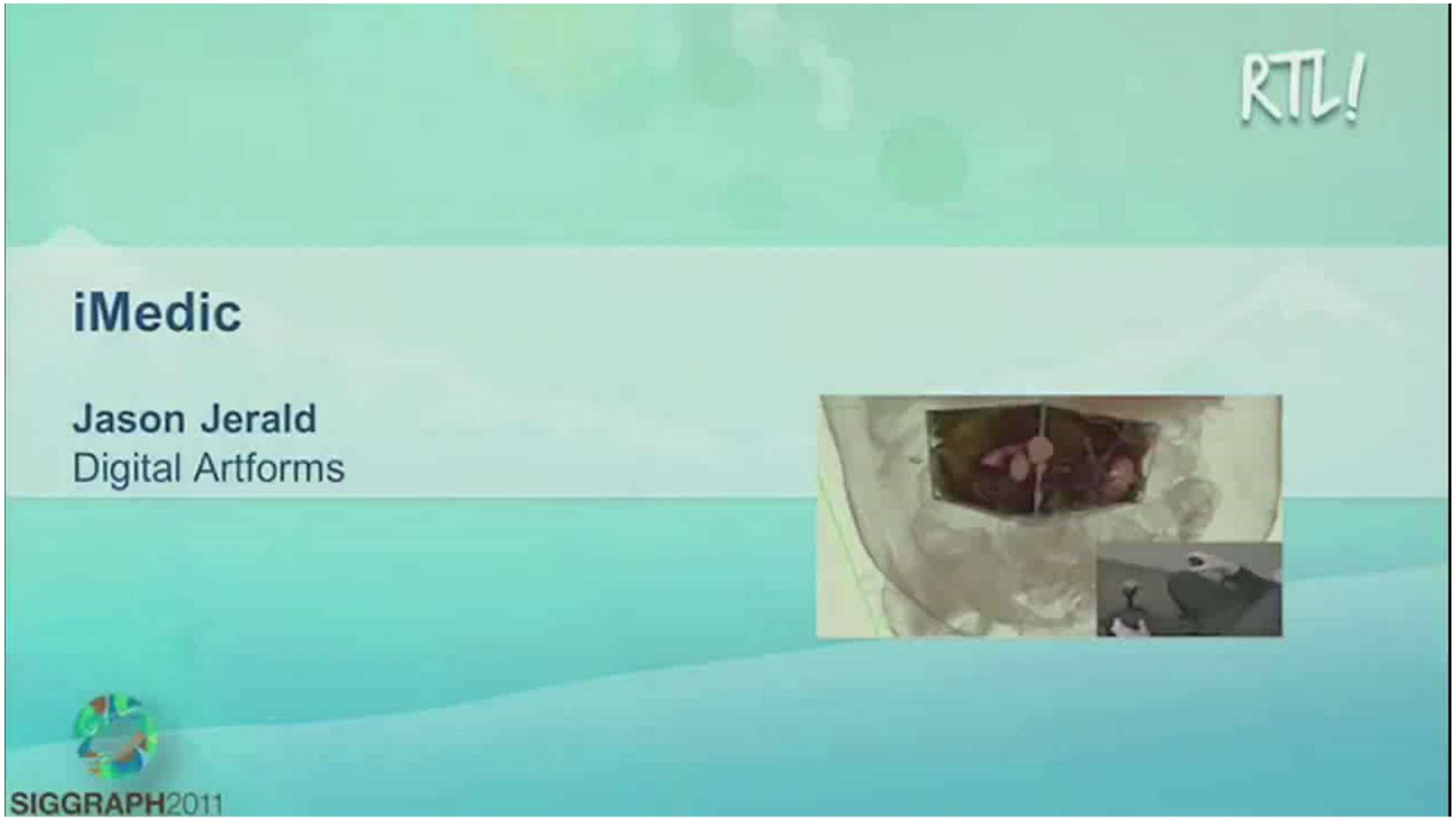
3D Multitouch: Medical Visualization



iMedic by *Digital ArtForms*

3D Multitouch: Medical Visualization

(video)



iMedic by *Digital ArtForms*

3D Multitouch: Computer-Aided Design (video)

MakeVR by SIXENSE™ & *Digital ArtForms*

3D Multitouch: Computer-Aided Design (video)

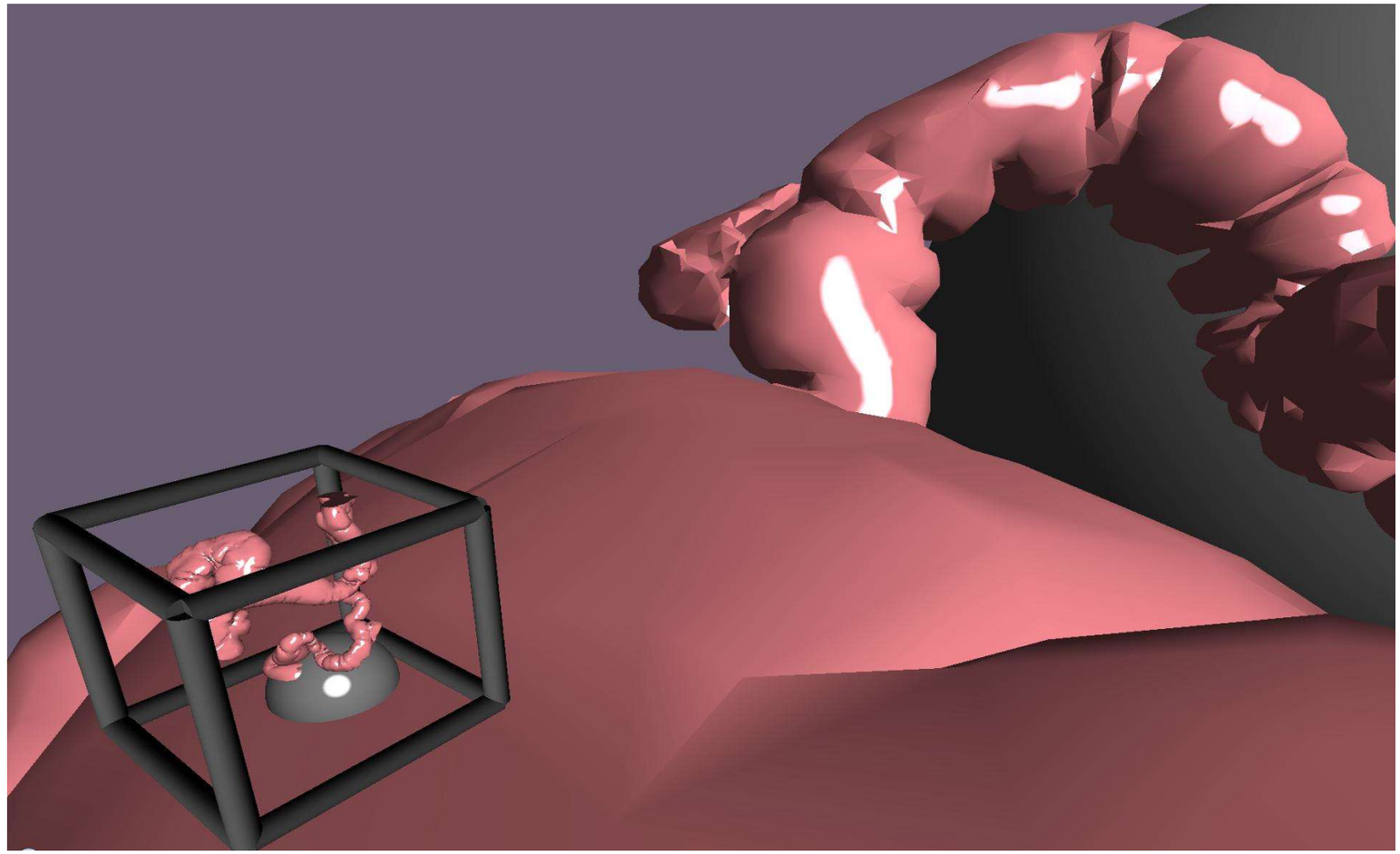
MakeVR by SIXENSE™ & *Digital ArtForms*

3D Multitouch: Computer-Aided Design (video)

MakeVR Collaborative

MakeVR by SIXENSE & *Digital ArtForms*

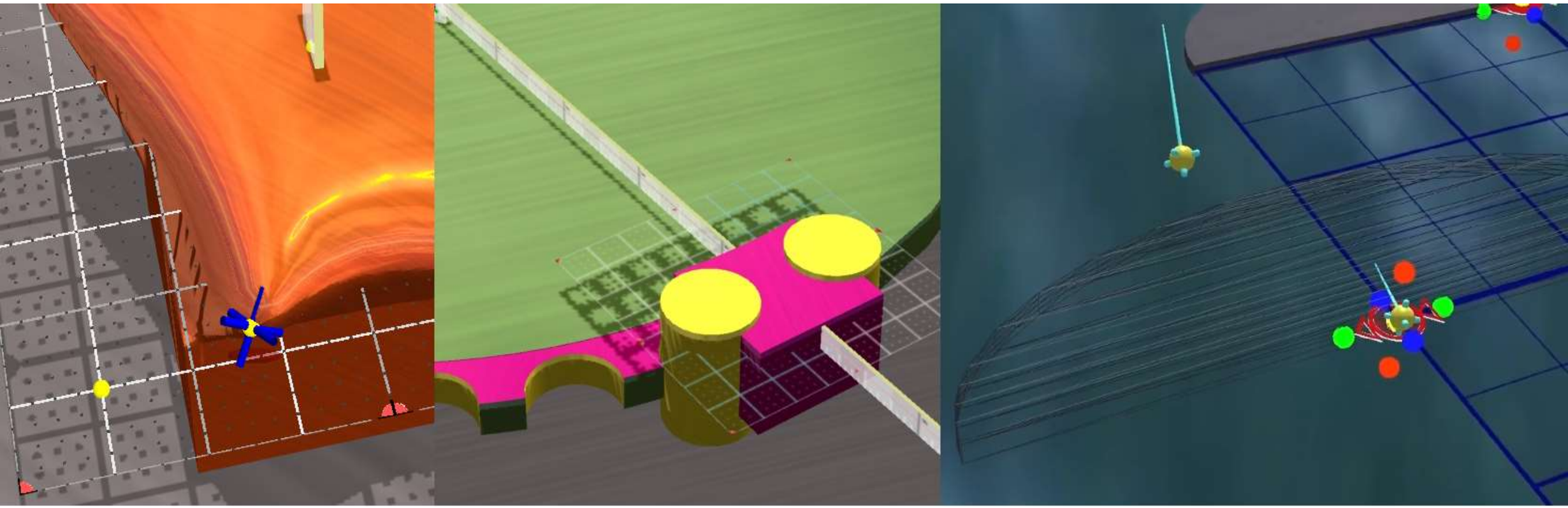
World-in Miniature Pattern



iMedic by *Digital ArtForms*

3D Tools Pattern

The Jigs Technique



MakeVR by SIXENSE™ & *Digital ArtForms*

Questions: Interaction Patterns

Do your interactions fit within any of these patterns? Or they some other pattern?

What additional patterns might you use?

Course Outline

Humans

Interaction

Comfort

Virtual Worlds

Iteration

Comfort

Comfort

Challenges

Safety

VR Sickness

Presence

Examples

Measuring Sickness

Adverse Health Effects—Challenges

Motion sickness

Eye strain

- Flicker
- Accommodation-vergence conflict
- Occlusion-binocular Conflict

Aftereffects

Seizures

Physical Fatigue

Headset Fit

Injury

Hygiene

Cables and Safety

Spend the time to arrange cables nicely. Cable tie them to desk, etc. And then leave them.

Provide harnesses, railing, and/or padding

Constrain/limit haptics

Use a human spotter

Safe audio levels

Sit in a Chair

Warning Grids

Wall collision warnings in real-world reference frame

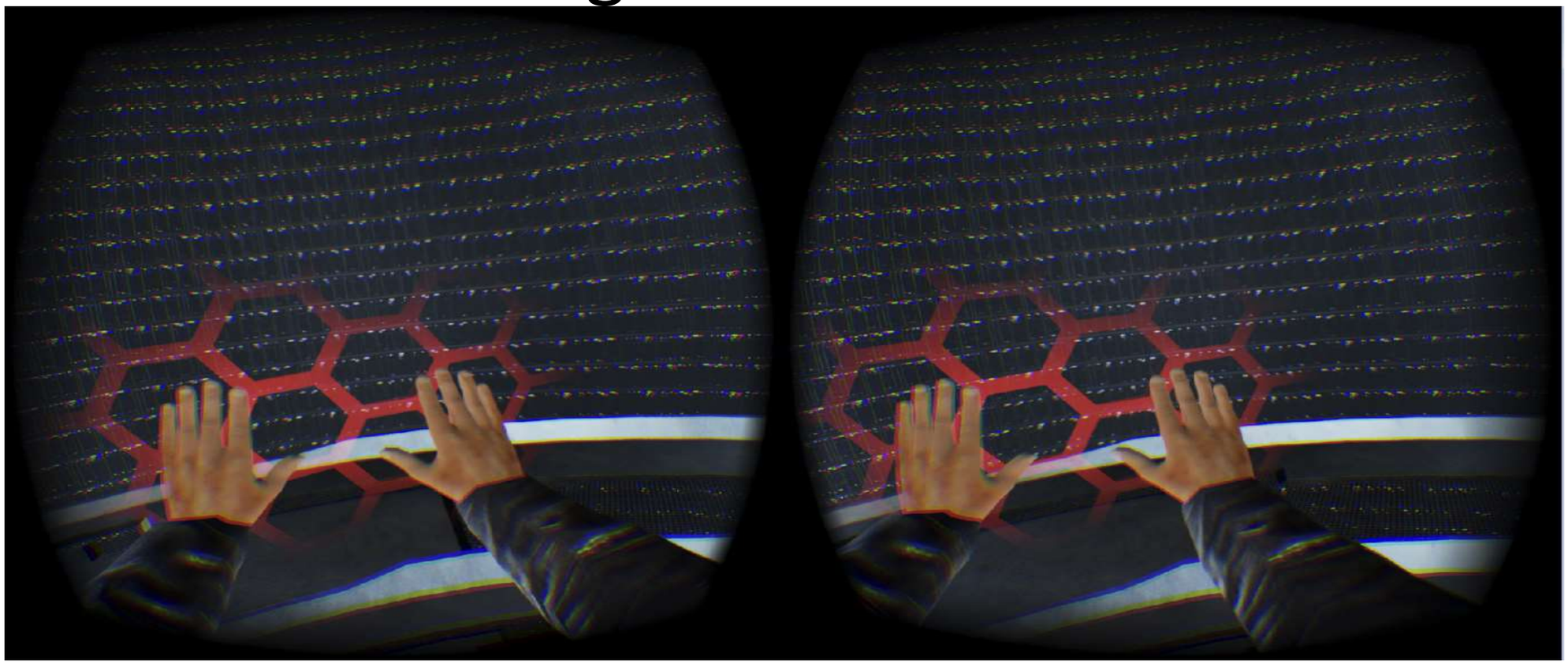


Image Courtesy of Sixense

Factors of Adverse Health Effects

System

Latency
Calibration
Tracking accuracy & precision
Field of View
Refresh rate
Judder & Flicker
Display response & persistence
Vergence/Accommodation
Stereoscopic cues
Real world peripheral vision
Fit/Weight/center of mass
Motion platforms
Hygiene
Temperature
Dirty screens

Individual

History of motion sickness
VR experience
Health
Thinking about Sickness
Belief
Gender
Age
Mental model/expectations
Interpupilary distance
Not knowing
Sense of balance
Flicker fusion frequency threshold
Real-world task experience
Migraine history

Application

Frame rate
Locus of control
Visual acceleration
Physical head motion
Duration
Vection
Binocular-occlusion conflict
Virtual rotation
Gorilla arm
Standing vs sitting
Rest frames
Binocular disparity
VR entrance & exit
Luminance
Repetitive strain

VR Sickness—The Basics

The biggest problem is **motion sickness**

- ✓ **Varies greatly** from person to person

As users:

- ✓ **Stop** at the first sign of sickness
- ✓ Be **well-hydrated** and **not hungry**, **not hung over**

As demoers

- Remind users **not to "tough it out"**
- **Wipe down** equipment periodically

As creators:

- Make interactions **comfortable**
  - Initial signs of discomfort may very well lead to sickness
  - Provide **cues to induce mental models** of motions **that users expect**
- **Minimize accelerations** (e.g., roller coaster motions) and virtual rotations
- Maintain a **high frame-rate** (90Hz)

Motion Sickness Theories

Sensory Conflict

Evolution/Poison Theory

Postural Instability Theory

Rest Frame Hypothesis

Eye Movement Theory

Sensory Conflict

Most widely accepted theory

Sensory modalities don’t match

Occurs mostly from **vestibular-visual conflict**

✓Your eyes see movement but your inner ear doesn’t feel it

Evolutionary/Poison Theory

Treisman 1977

Properly perceiving our body's motion and the motion of the world around us **is critical for survival**.

If we get conflicting information from our senses, it means something is not right with our perceptual system

The **brain interprets sensory mismatch as a sign of intoxication**, and triggers a **nausea/vomiting defense** program to **protect** itself.

Protection occurs by

- **discouraging movement** (e.g., laying down until we recover)
- **ejecting the poison** via sweating and vomiting
- **causing nausea and malaise** (a slight or general feeling of not being healthy or happy) in order to **discourage us from ingesting similar toxins** in the future

Postural Instability Theory

Riccio and Stoffregen 1991

Claims

- ✓ **Predicts sickness occurs when we have don't have strategies** for maintaining postural stability
- ✓ Postural instability both **precedes motion sickness** and is necessary to produce symptoms
- ✓ **Length and magnitude of unstableness** are predictors of motion sickness and the intensity of symptoms.

Example:

- ✓ Visual scene moving towards user
- ✓ User leans forward to compensate
- ✓ User becomes less balanced
- ✓ Motion sickness increases

Rest Frame Hypothesis Prothero and Parker, 2003

Claims

- ✓ Conflicting orientation and motion cues are not the problem
- ✓ **Unstable frames of reference** implied by cues are the problem

For AR, the real world is the rest frame. Most people do not get sick with AR.

Content creation tips

- ✓ **Make rest frame cues consistent** whenever possible rather than being overly concerned with making all orientation and all motion consistent.
- ✓ **Set user expectations** of what will and will not move

Rest Frames

Stabilized cues relative to real world

Reduces sensory conflict between what you are seeing and what you are feeling

Example: Cockpit

EVE Valkyrie by CCP Games

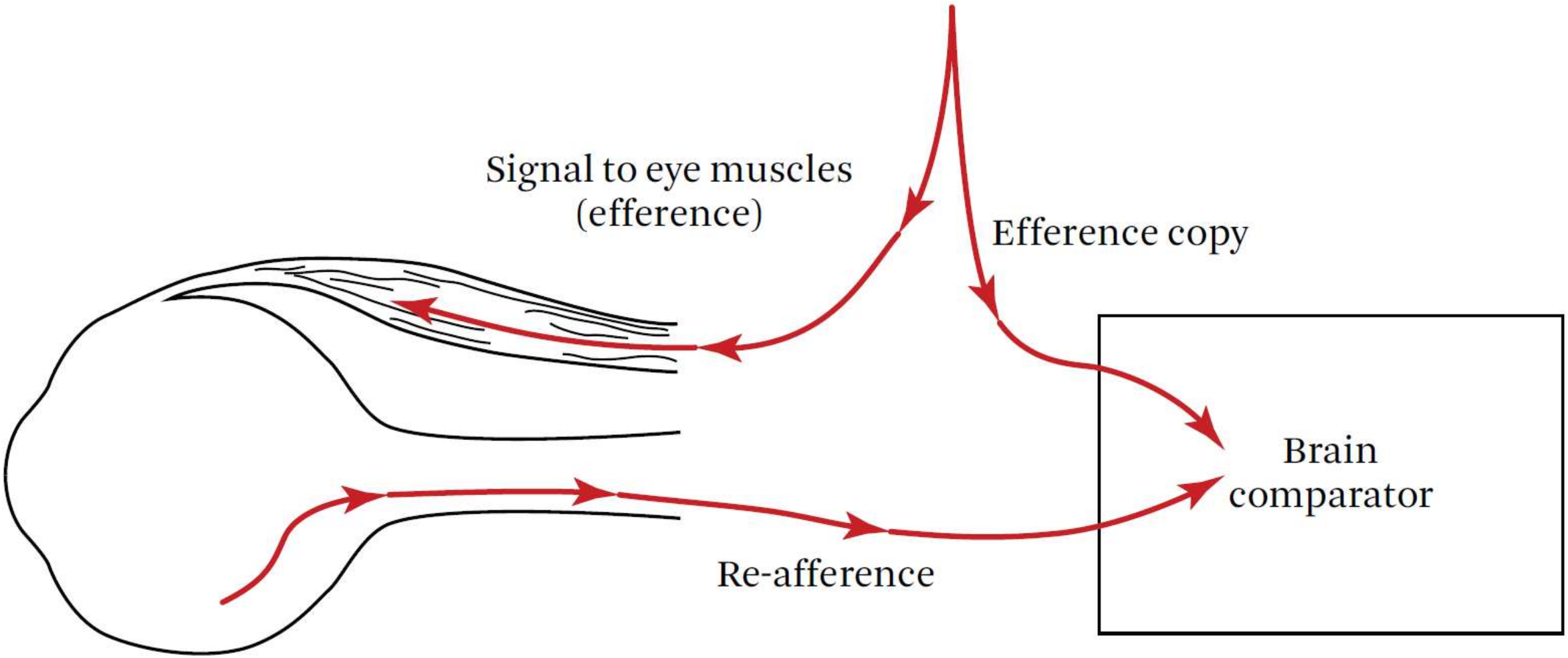
Eye Movement Theory

Problems occur from unnatural eye motion required to keep the scene's image stable on the retina

Do the eyes follow the motion of an unstable scene or does the scene motion move on the eyes?

Likely some combination of both depending on the situation and individual

Afference and Efference



A Unified Model of Motion Sickness

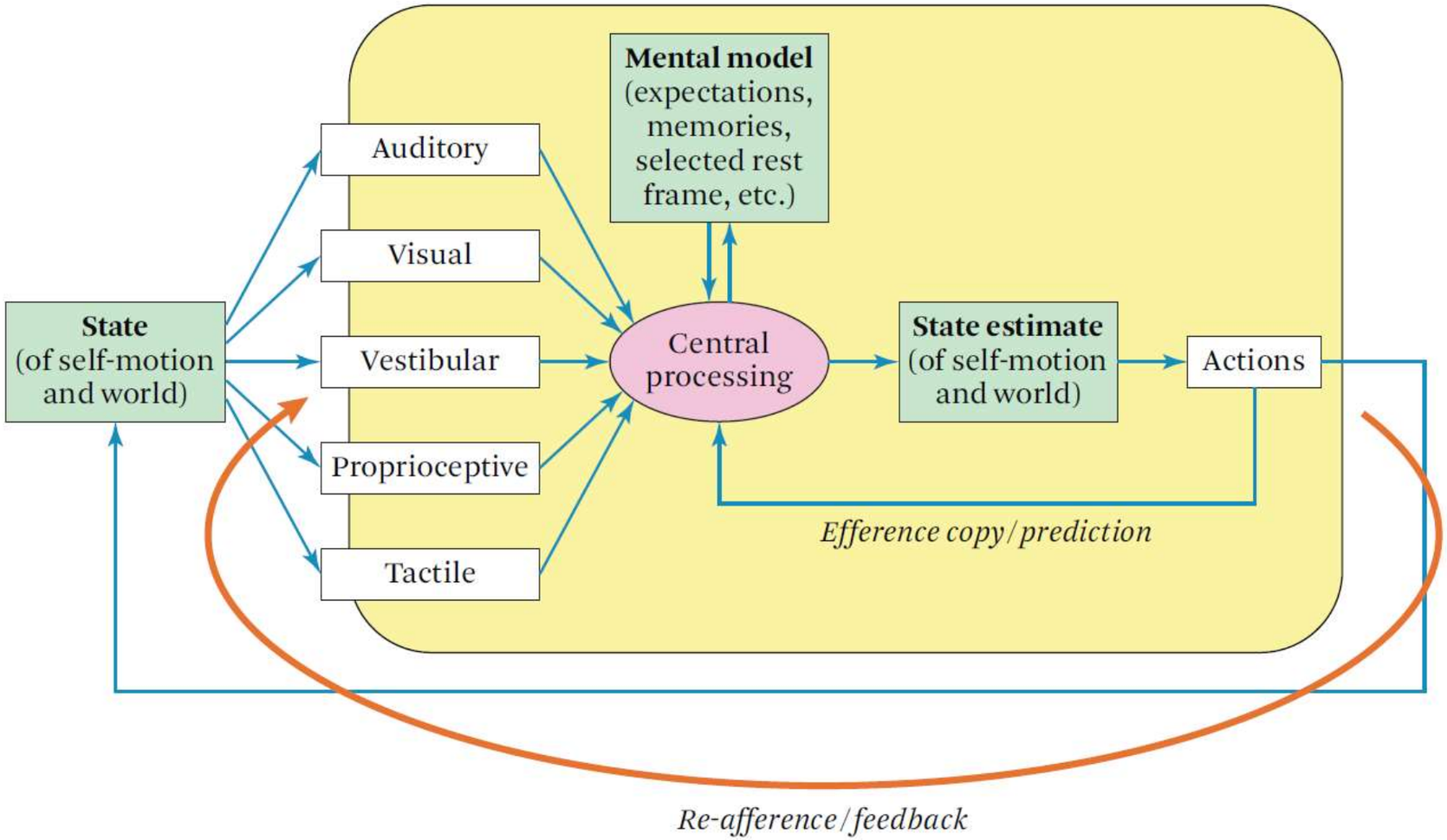


Image Courtesy of The VR Book (adapted from Razzaque [2005])

Locomotion

Physical walking

Teleportation

Dynamic field of view

Dynamic rest frames

Physical Walking

Real-world one-to-one walking

Treadmill walking

Redirected walking

Walking in place

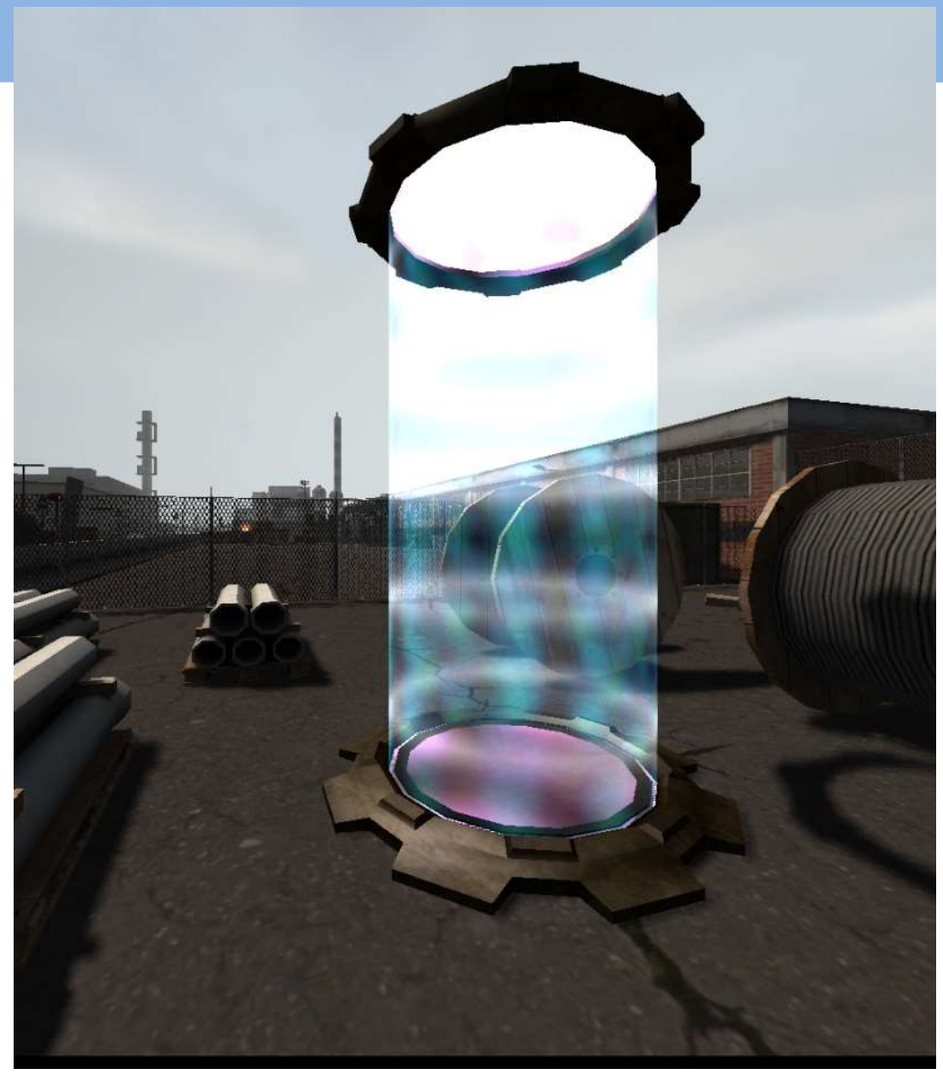
Teleportation

Popularized by CloudHead Games

Zero motion sickness

Results in disorientation

Bowman & Hodges 1997



Trainexus by NextGen Interactions

Dynamic Field of View

Fernandes & Feiner 2016

Image Courtesy of NextGen Interactions

Rest Frames

Stabilized cues relative to real world Prothero & Parker (2003)

Reduces sensory conflict between what you are seeing and what you are feeling

Example: Cockpit

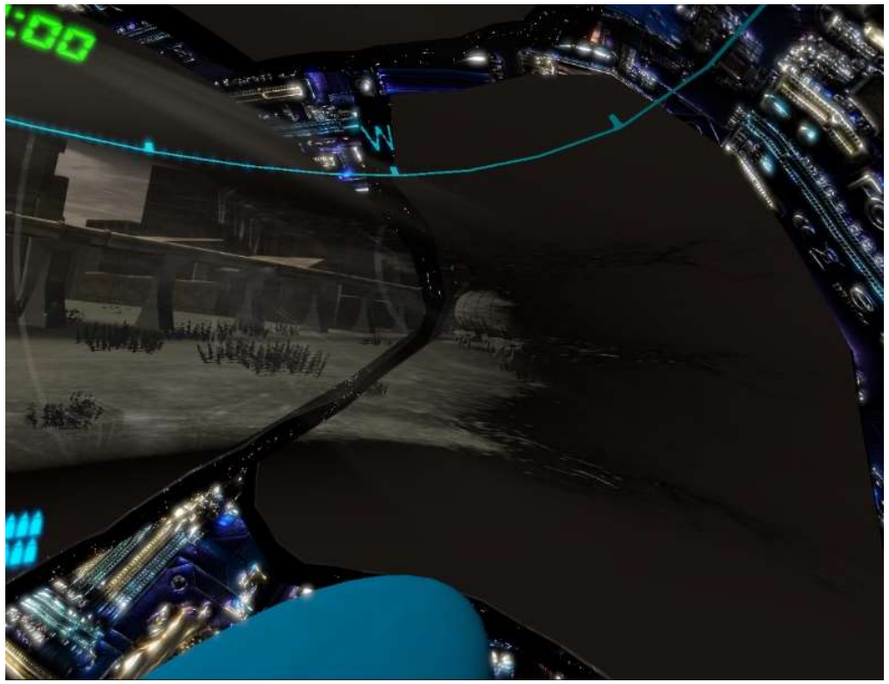
EVE Valkyrie by CCP Games

360 Rest Frame Example

Dynamic Rest Frames

Looking ahead no DRF

Looking ahead with DRF



Looking to Right with DRF

VR APOCALYPSE by NEXTGEN Interactions

Questions: Comfort

What might you do to increase comfort?

Measuring sickness

Kennedy Simulator Sickness Questionnaire

Observation

In-app questionnaires

Physiological measures

Kennedy SSQ Kennedy et al. 2003

Nausea

- General discomfort
- Increased salivation
- Sweating
- Nausea
- Difficulty concentrating
- Stomach awareness
- Burping

Disorientation

- General Discomfort
- Fatigue
- Headache
- Eyestrain
- Difficulty focusing
- Difficulty concentrating
- Blurred vision

Nausea

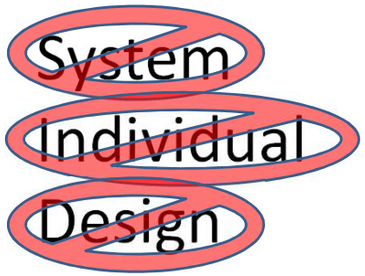
- Difficulty focusing
- Nausea
- Fullness of Head
- Blurred Vision
- Dizzy (eyes open)
- Dizyy (eyes closed)
- Vertigo
- Stomach awareness
- Burping

Kennedy SSQ

The standard

But there are problems

- ✓ 3 factors of adverse health affects



- ✓ Large variance
  - Requires a large number of participants
- ✓ Subjective / Biased
- ✓ No score criteria of what is acceptable

In-App Questions

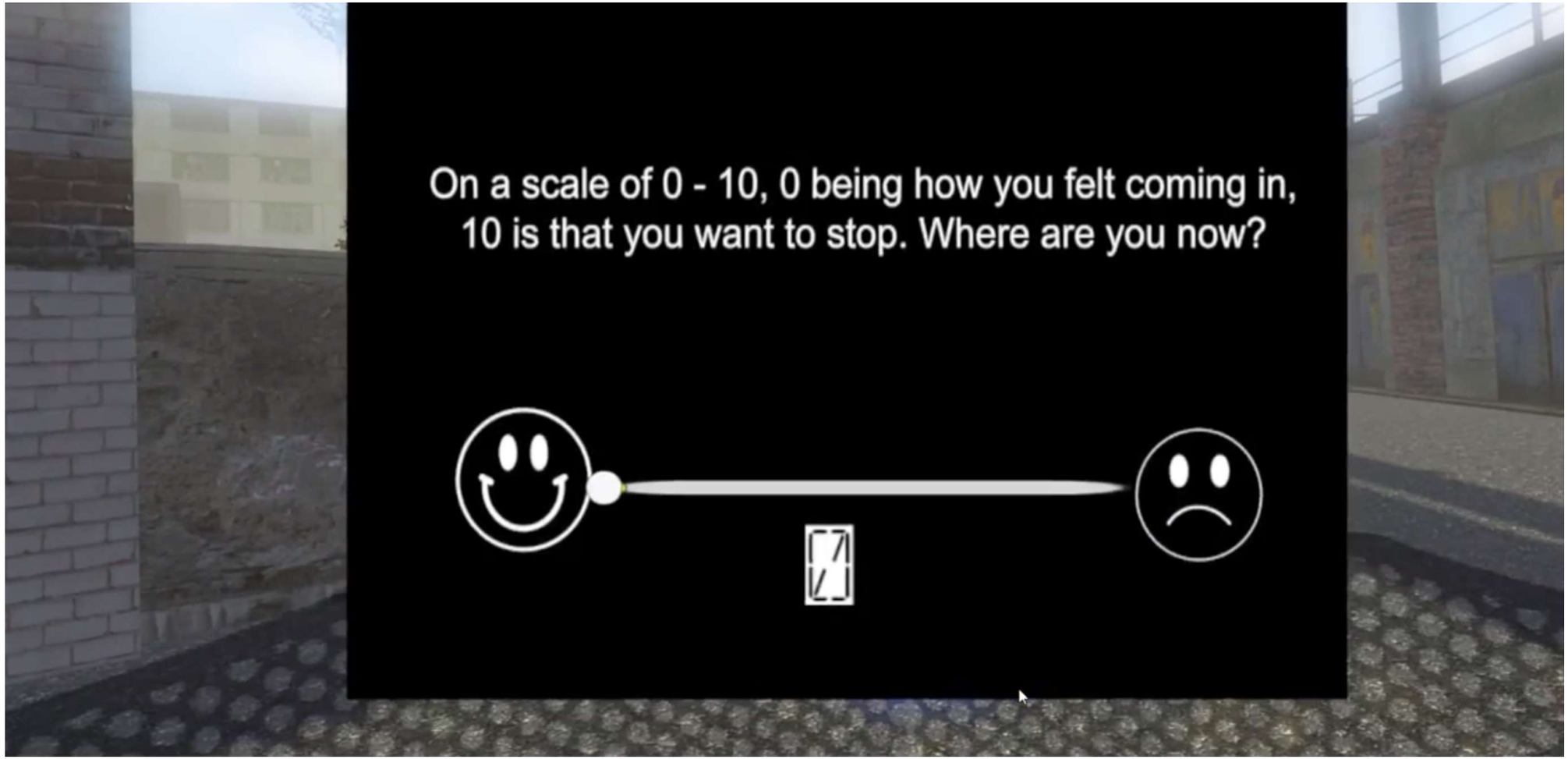


Image Courtesy of NextGen Interactions & Duke University

Physiological Measures

A wide open research area (i.e., your PhD!)

- Postural stability?
- Heart rate?
- Skin conductance?
- EEG?

Conclusions for Comfort

We **know a lot** about adverse health effects

We **don't know a lot** about adverse health effects

Expect to do **LOTS of experimentation & iteration!**

Questions: Comfort

How might you measure comfort?

What would those numbers tell you?

Course Outline

Humans

Interaction

Comfort

Virtual Worlds

Iteration

Virtual Worlds

Virtual Worlds

Scene space

Depth

Environmental structure

Audio

Collaboration

Story

Art

The Scene

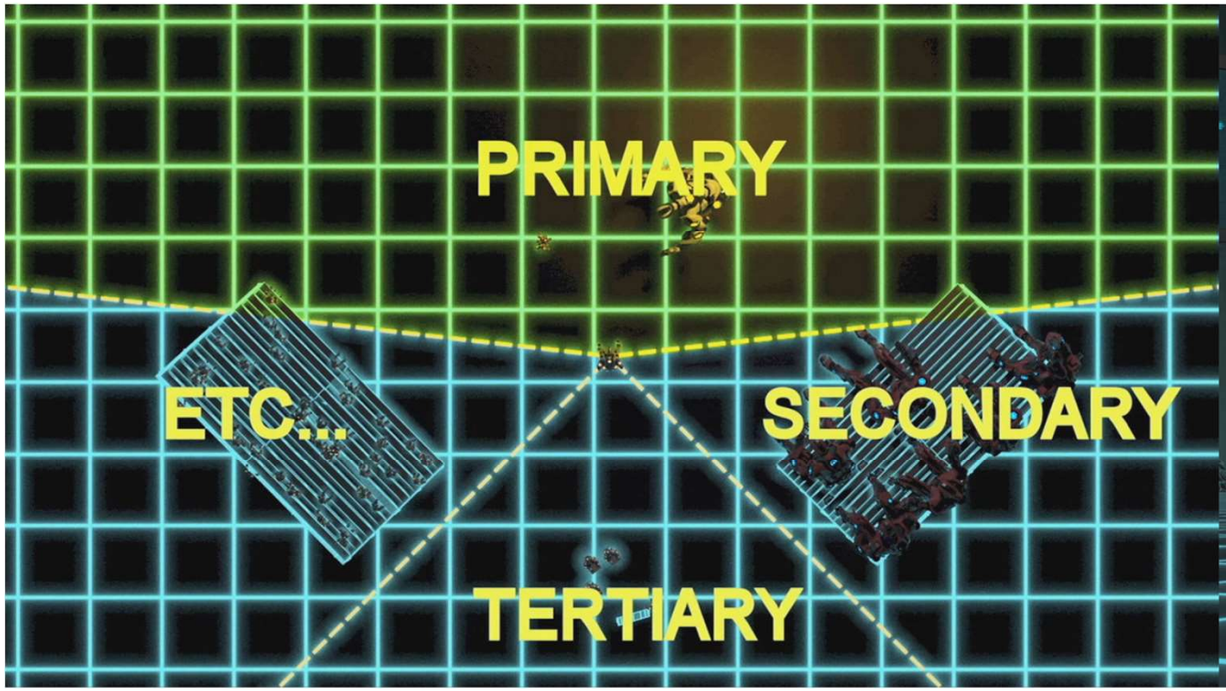
Background

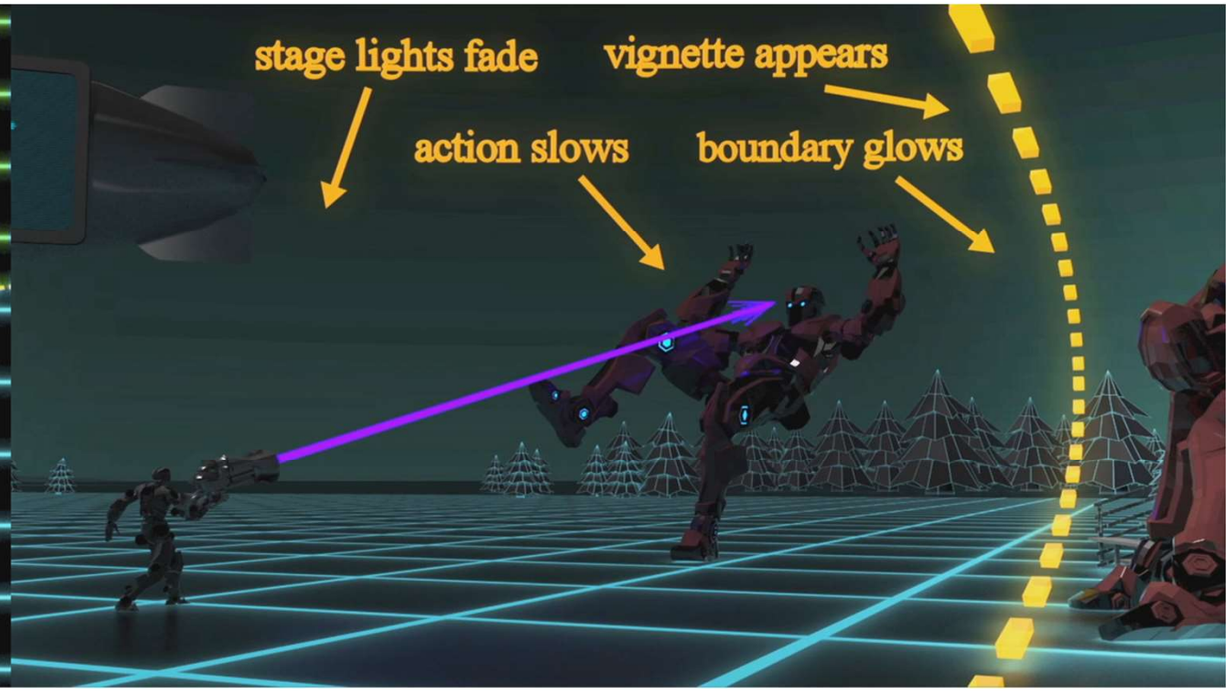
Contextual Geometry

Fundamental Geometry

Interactive Objects

Action Space





Segmenting Space

Personal Space
- ✓ Within ~2 meters
- ✓ Intimate
- ✓ Withins arm's reach
- ✓ Direct Interaction

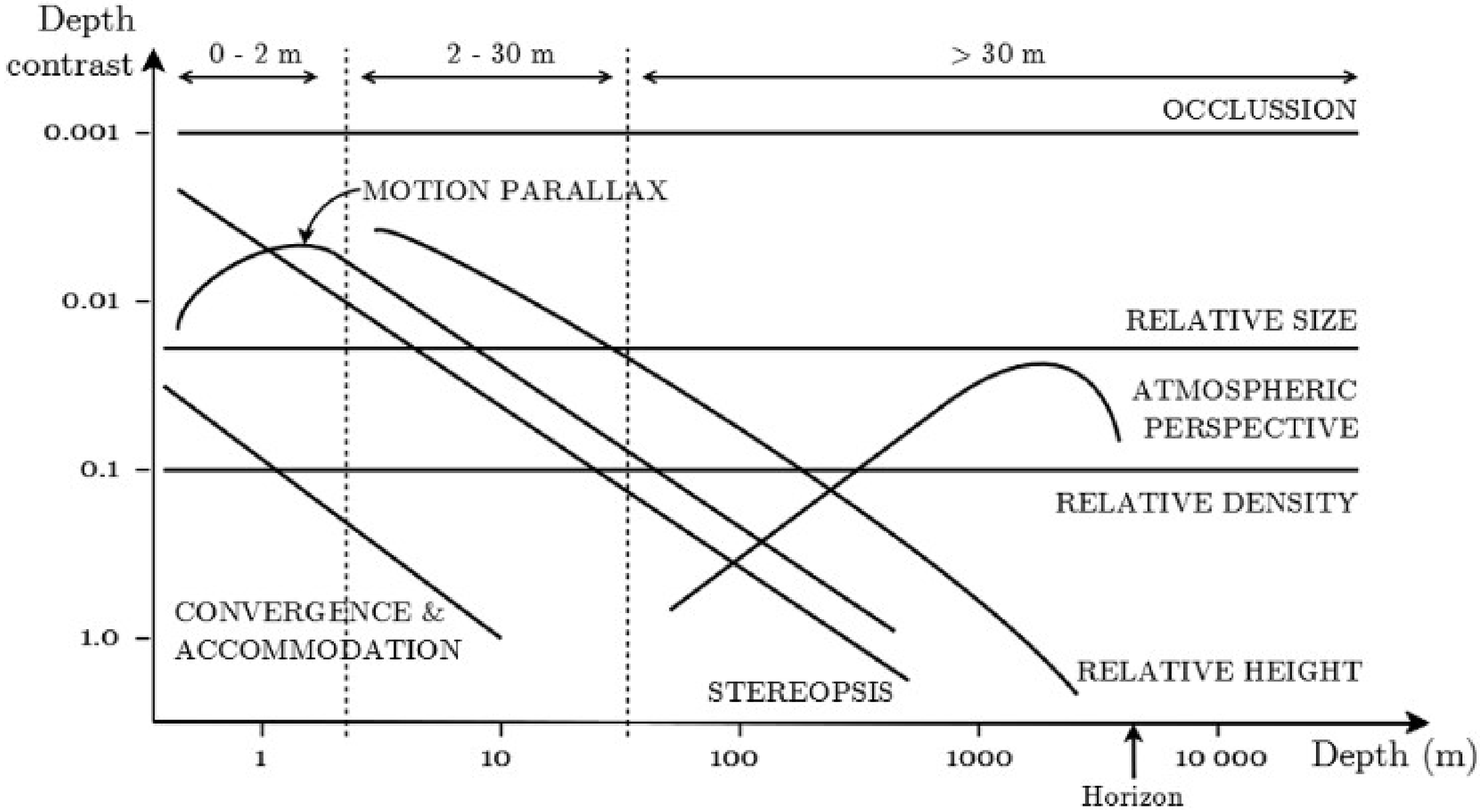
Action Space
- ✓ ~2-20 meters
- ✓ Move, speak, throw

Vista Space
- ✓ Little immediate control
- ✓ Limited Depth cues

Depth Cues

- Pictorial Depth Cues
  - Occlusion
  - Linear perspective
  - Relative/familiar size
  - Shadows/shading
  - Texture gradient
  - Height relative to horizon
  - Aerial perspective
- Motion Depth Cues
  - Motion parallax
  - Kinetic depth effect
- Binocular Depth Cues
- Oculomotor Depth Cues
  - Vergence
  - Accommodation
- Contextual Distance Factors
  - Intended action
  - Fear

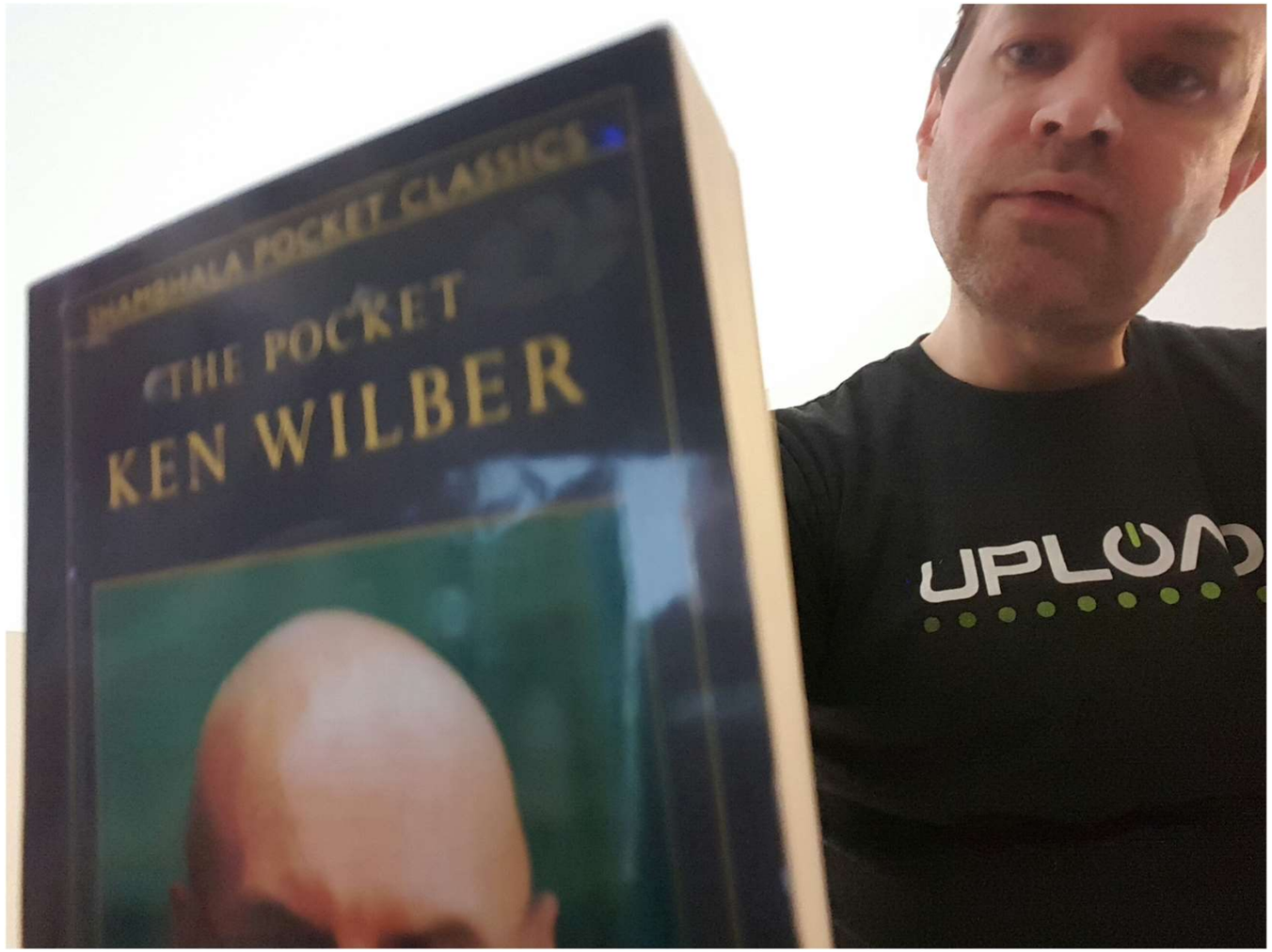
Depth Cue Importance



Depth Cue Importance

Source of Information	Space		
	Personal Space	Action Space	Vista Space
Occlusion	1	1	1
Binocular	2	8	9
Motion	3	7	6
Relative/familiar size	4	2	2
Shadows/shading	5	5	7
Texture gradient	6	6	5
Linear perspective	7	4	4
Oculomotor	8	10	10
Height relative to horizon	9	3	3
Aerial perspective	10	9	8

Depth perception



Depth Perception

Gestalt Perceptual Organization

Simplicity

Continuity

Proximity

Similarity

Proximity

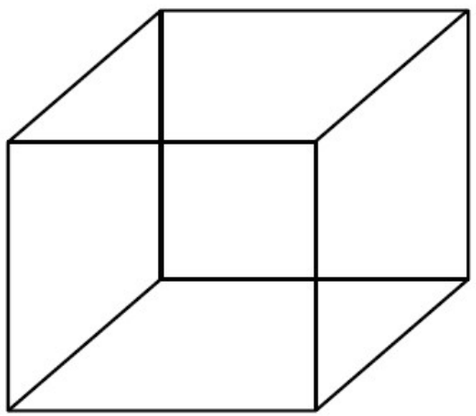
Closure

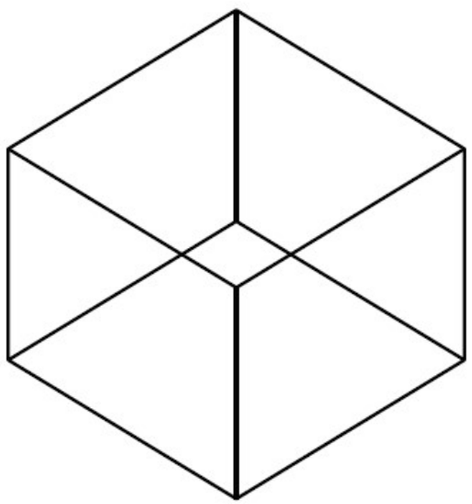
Common Fate

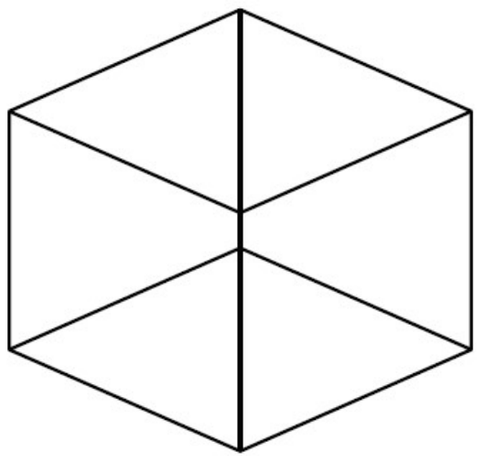
Simplicity

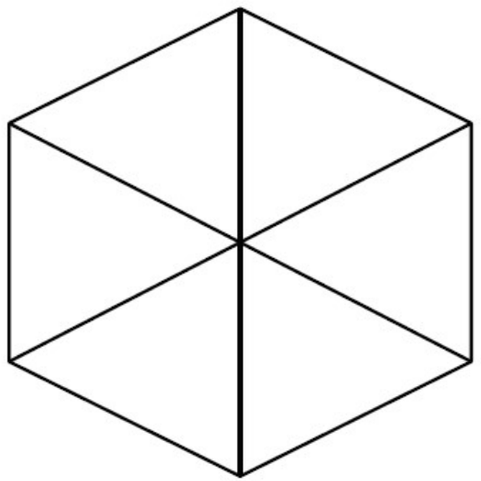
Figures tend to be perceived in their simplest form,

whether 2D or 3D



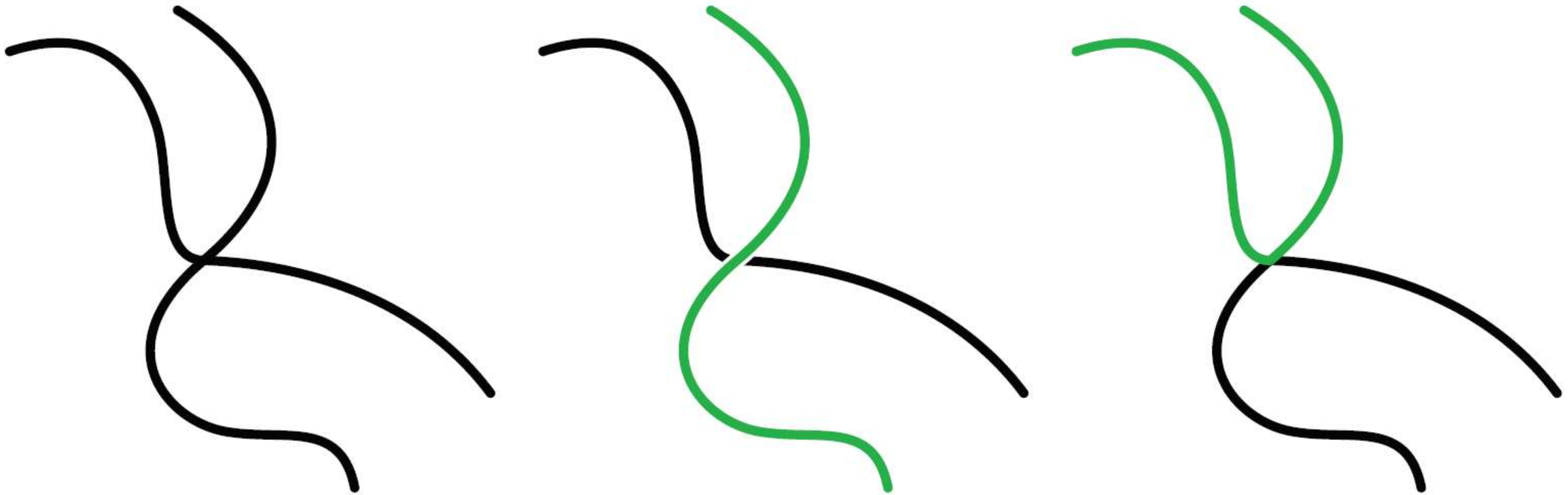




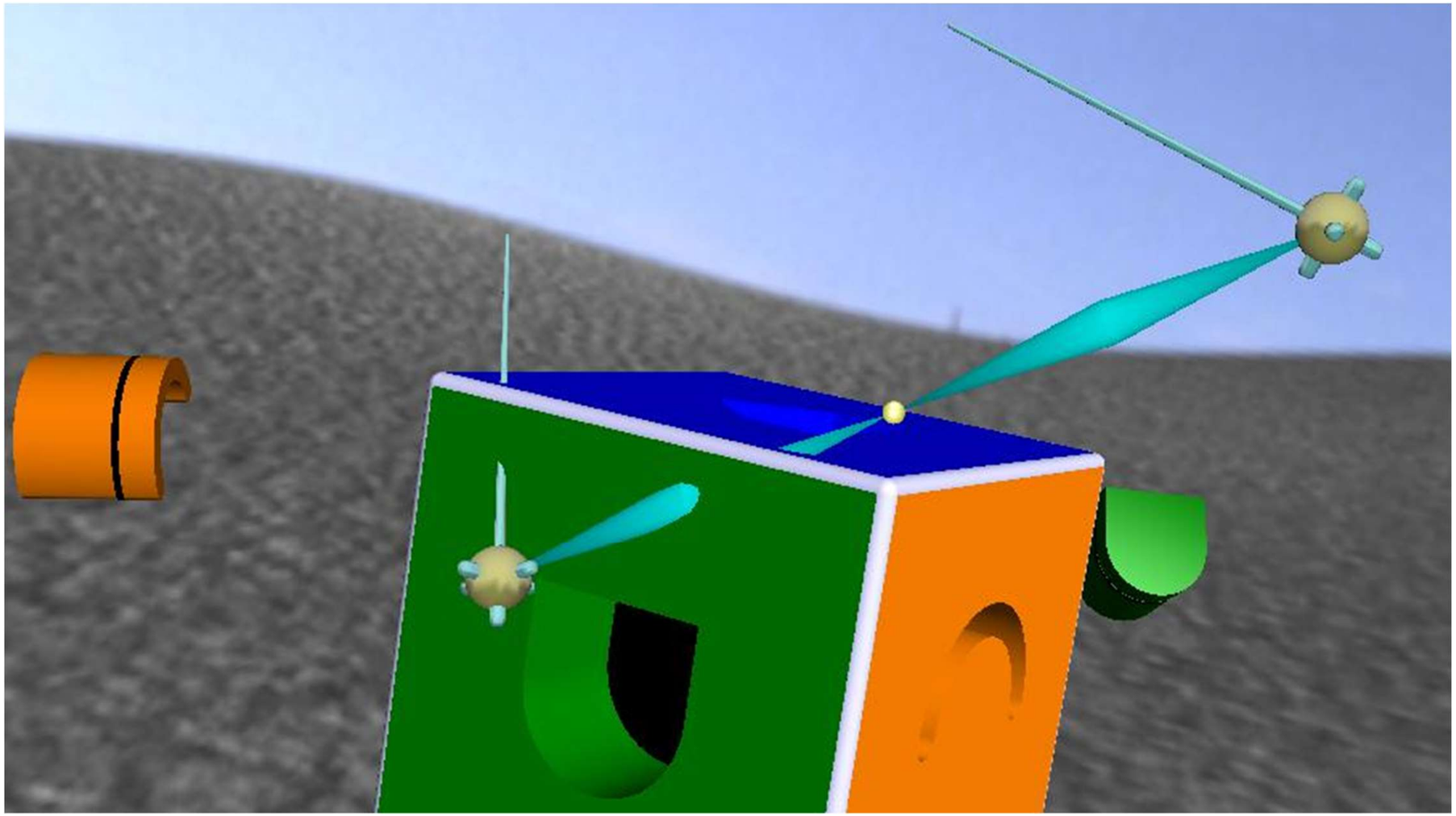


Continuity

Elements tend to be perceived as following the most aligned or smoothest path.

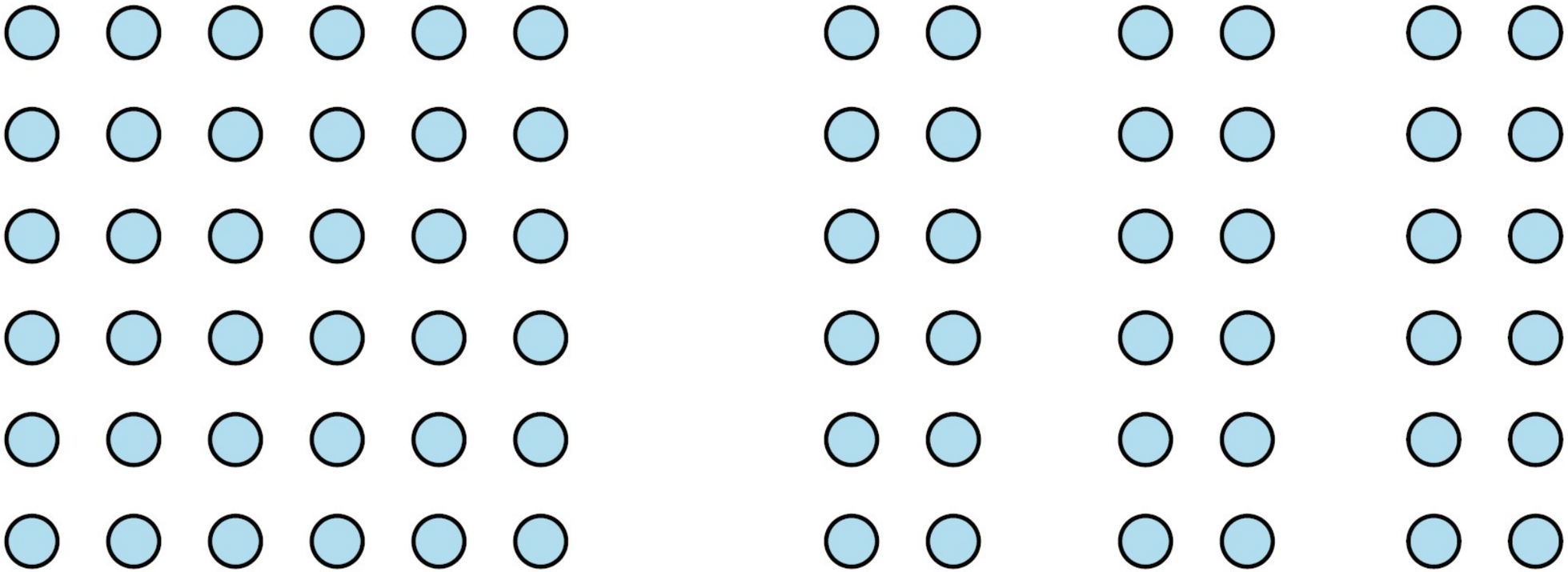


Continuity



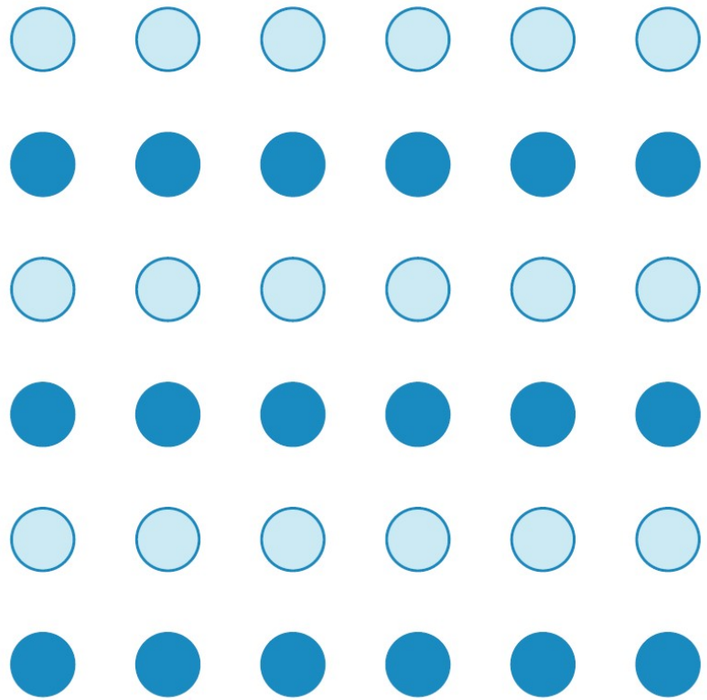
Proximity

elements close together tend to be perceived as a shape or group groups

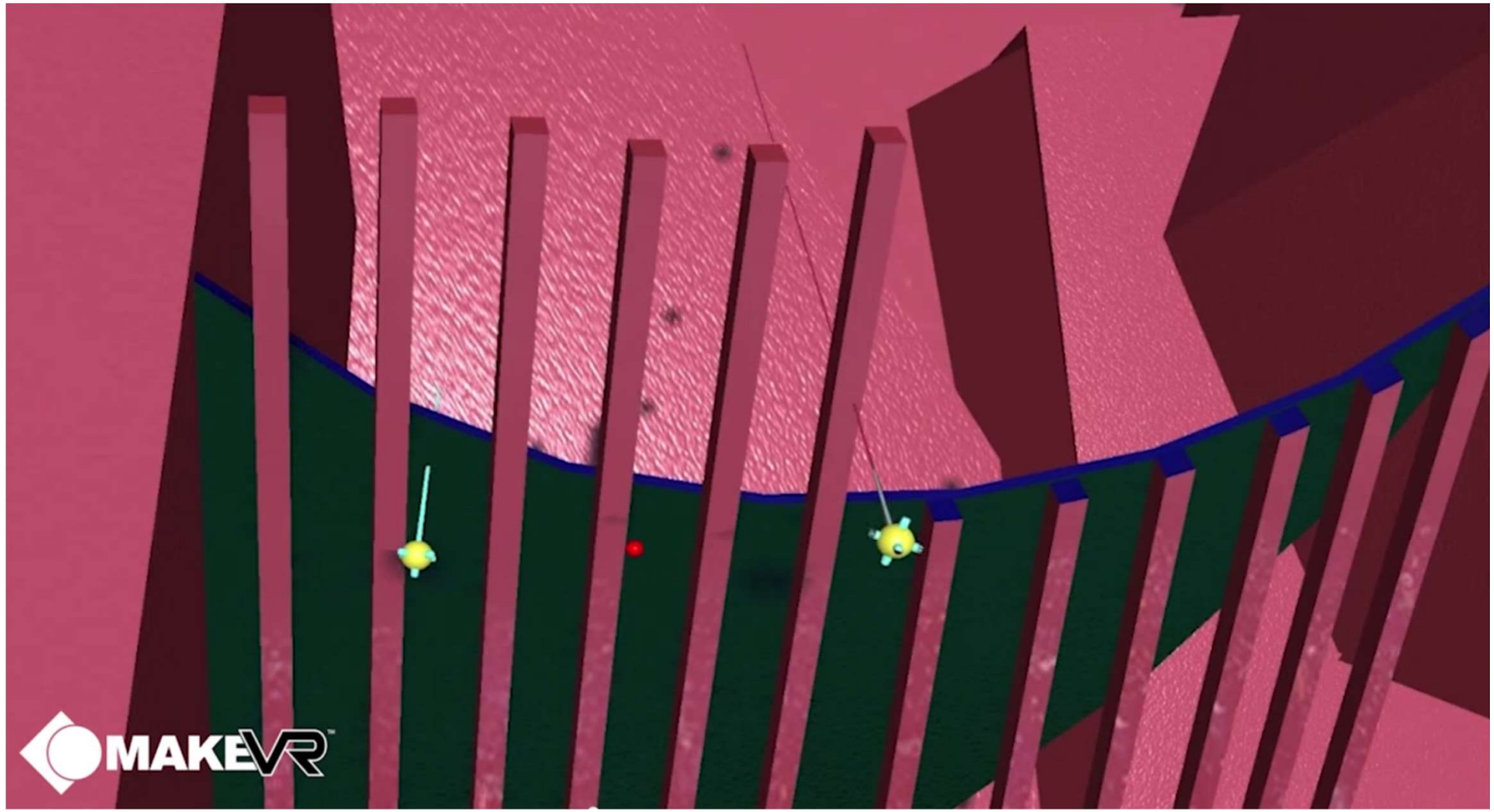


Similarity

Elements with similar properties tend to be perceived as being grouped together.



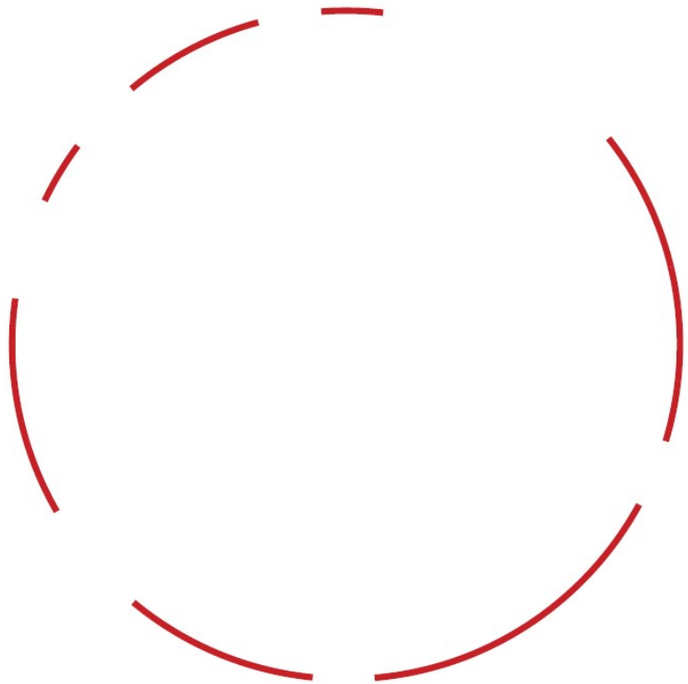
Similarity



Proximity & Similarity

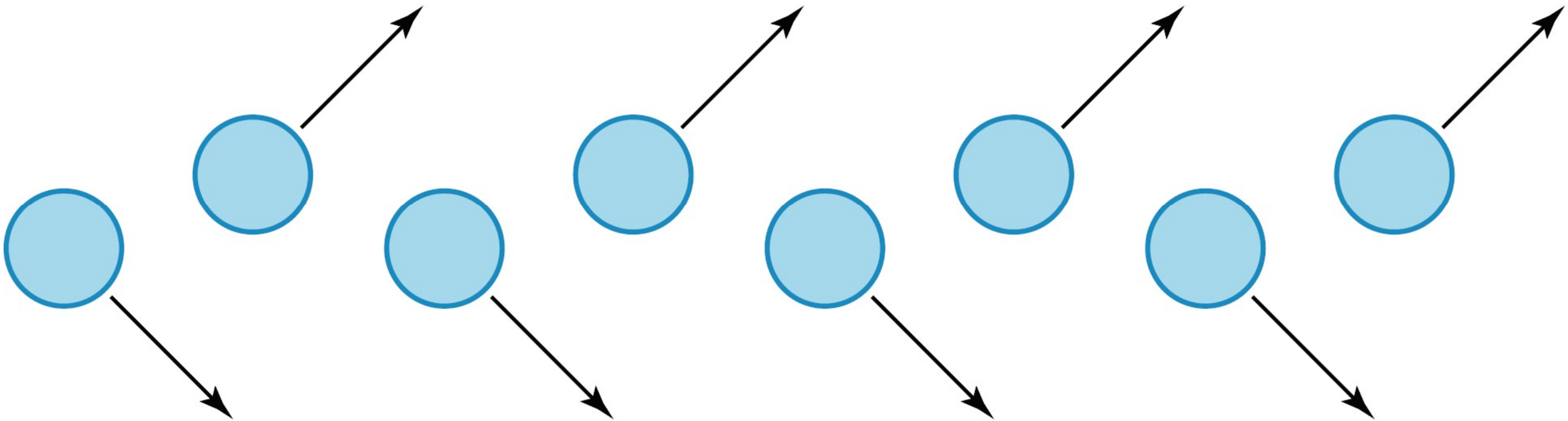
Closure

When a shape is not closed, the shape tends to be perceived as being a whole recognizable figure or object



Common Fate

Elements moving in a common way tend to be perceived as being grouped together



Environmental Wayfinding Aids

Landmarks

Regions

Routes

Channels

Nodes

Edges

Visual handrails

Environmental Wayfinding Aids

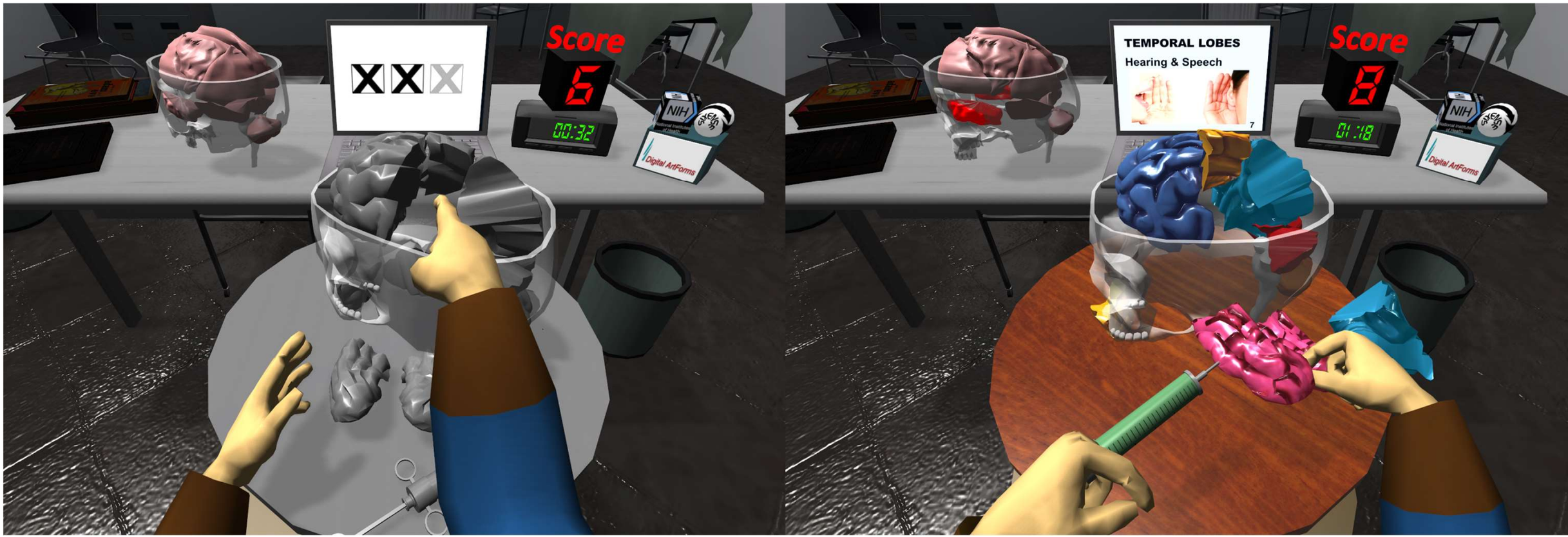
Markers

Breadcrumbs

Trails

Measurement

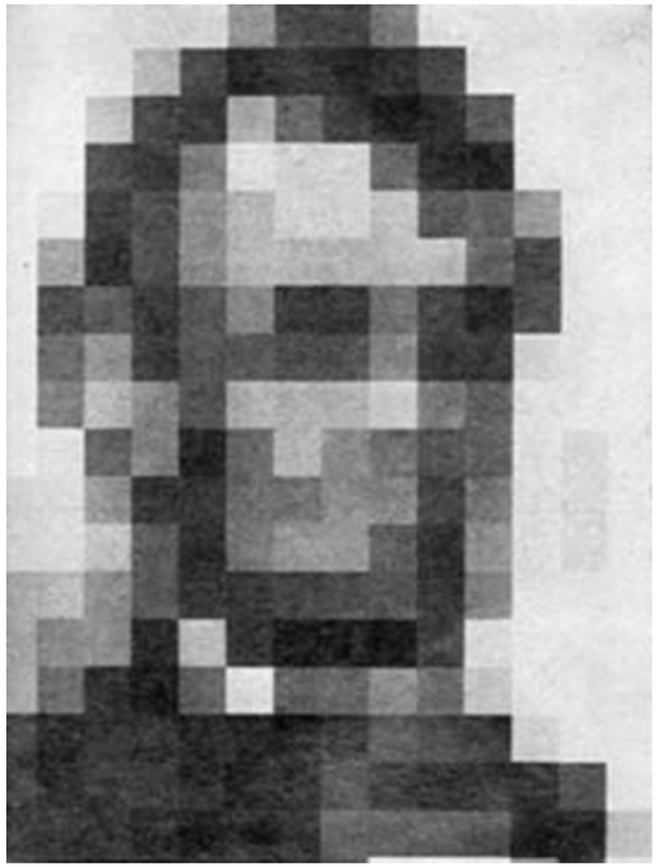
Salience


XXX
Score
6
00:32
NIH
Digital ArtForms
TEMPORAL LOBES
Hearing & Speech
7
Score
8
01:18
NIH
Digital ArtForms

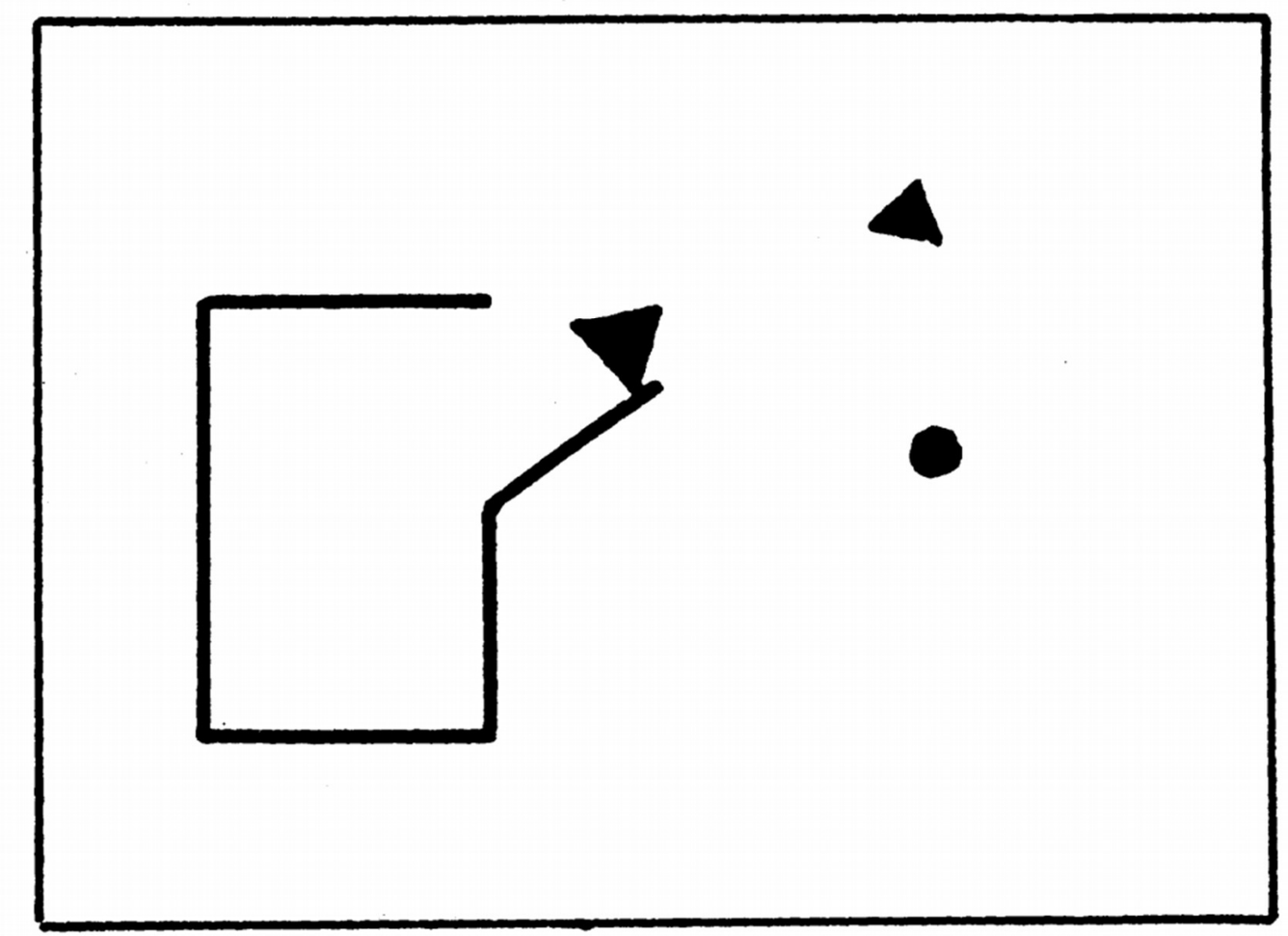
Facts Tell, Stories Sell

- Backwards rationalization
  - Emotions run us—engineers included!

Story > Details



Story



A New Artistic Medium

The screen disappears

The best VR Games will be designed from the beginning for VR

Today the technology is being sold

Tomorrow the story and emotion will be sold

Collaboration in VR

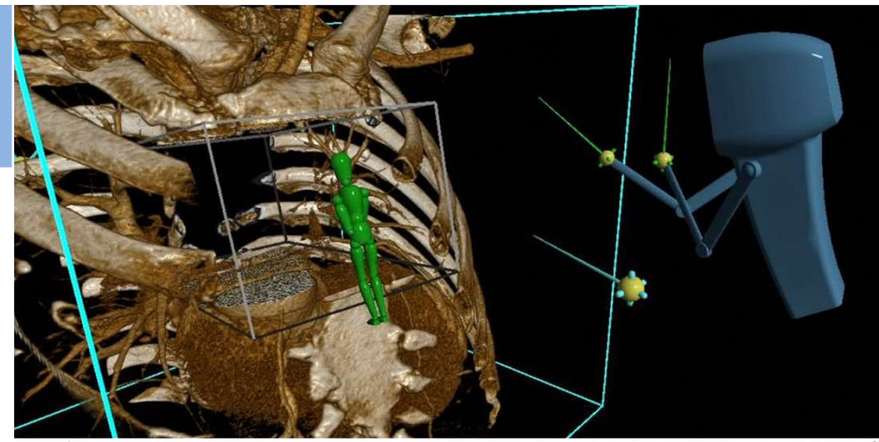
VR is a powerful tool for **collaboration**

Feeling present with others is a major part of why we fly across the country & world to work together

Shared experiences **increase presence** & make collaboration easier

Medical, ArchViz, Industrial Design

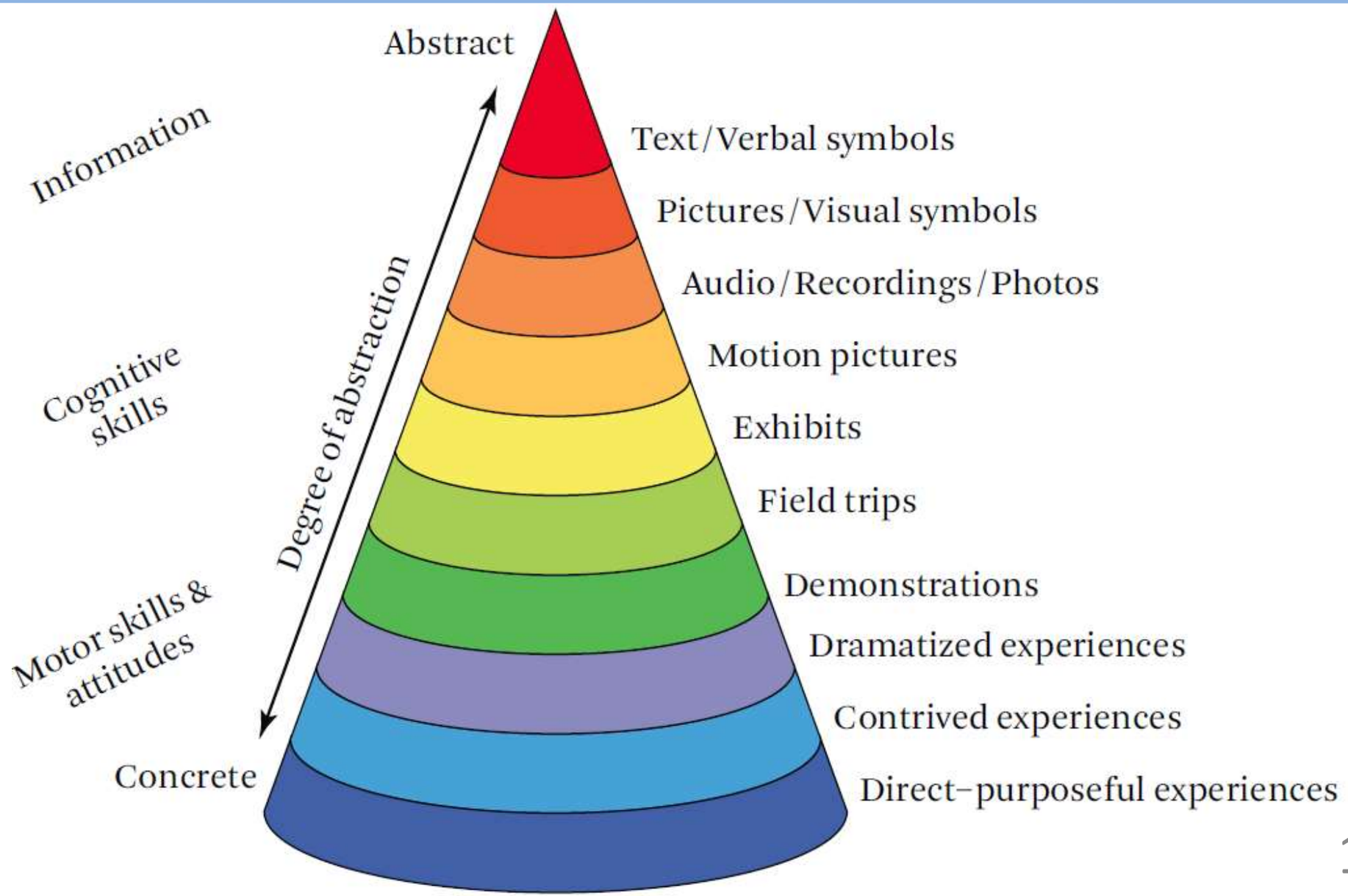
Many more potential fields to explore



Early Attempts at Intuiting VR Apps

Trainexus by NextGen Interactions

A Learning Model



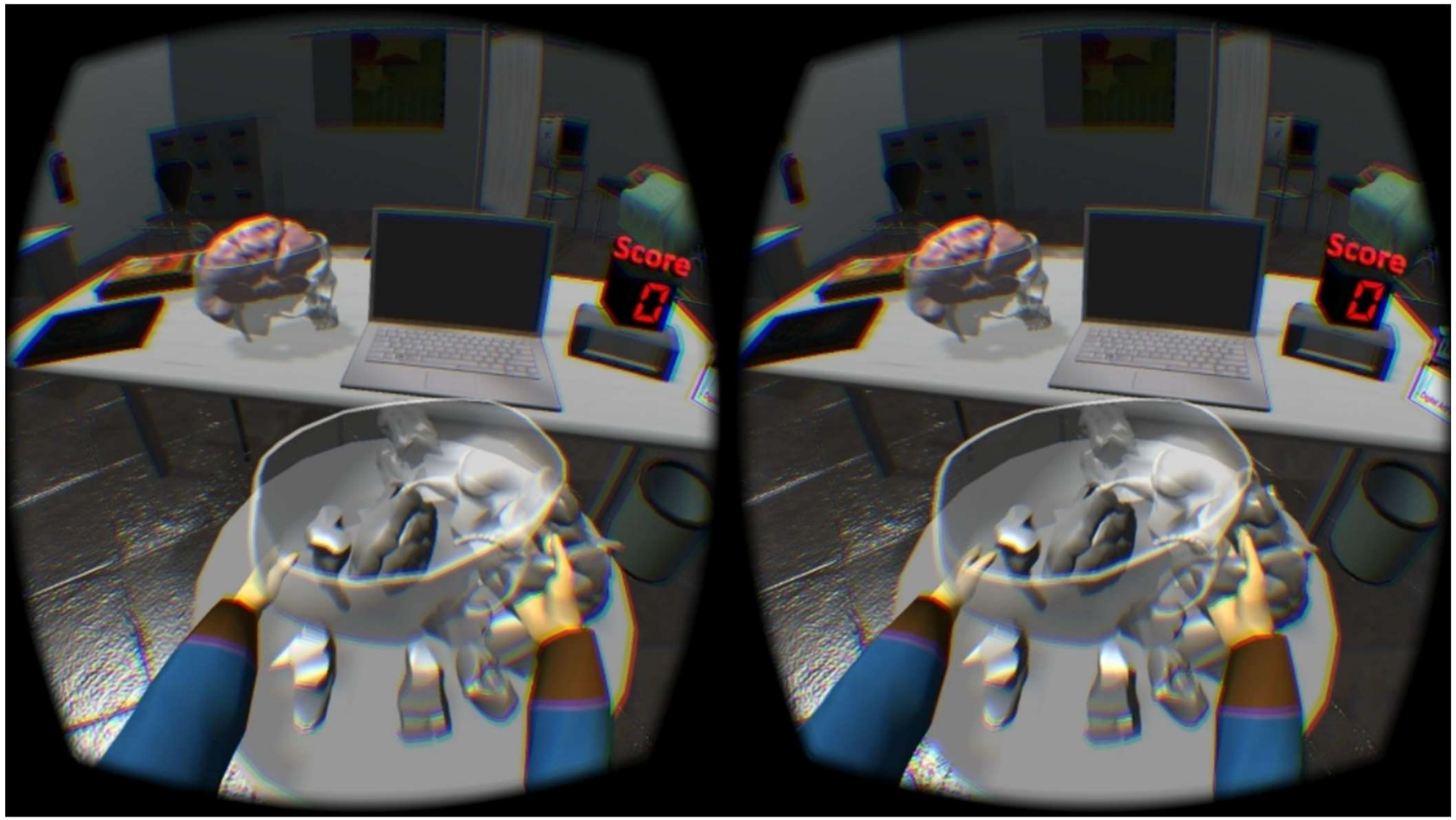
In-App Tutorials

Shipped VR experiences **don't have the luxuries** of in-person demos

Users must **quickly grasp interaction concepts** without an expert to explain the interface, answer questions, and correct mistakes

Tutorial Example #1: Cure Fred

(video)



Cure Fred by *Digital ArtForms*

In-App Tutorials

Help to convey consistent conceptual models in the mind of users by teaching **affordances** through **signifiers** and **feedback**

Simplify!

- Simplifying tasks is often more difficult to implement than complex tasks

Hierarchical steps

- Some steps are consecutive and some are concurrent

Completion criteria

- Do not continue until user has taken some specific action

Repeated audio

- Essential for users who didn't get it the first time

In-App Tutorials: Story Integration

How can we incorporate abstract interfaces into the story of our games?

We be creative!

Tutorial Example #2: VR APOCALYPSE (video)

VR APOCALYPSE by NEXTGEN Interactions

Tutorial Example #2: VR APOCALYPSE (video)

VR APOCALYPSE by NextGen Interactions

Tutorial Example #3: MAKEVR™ (video)

MAKEVR™ by VIVE STUDIOS, SIXENSE™, & Digital ArtForms

Tutorial Example #3: MAKEVR™ (video)

MAKEVR™ by VIVE STUDIOS, SIXENSE™, & Digital ArtForms

Summary for Intuiting Interactions

By default, VR is not intuitive

✓ Intuitive applications are a result of

- Creativity
- Design thinking
- Experimentation
- User feedback
- Lots of iteration

Questions: Tutorials

Might tutorials work for your design?

- If not, might some tutorial concepts apply?

Exercise

Draft a tutorial script

Course Outline

Humans

Interaction

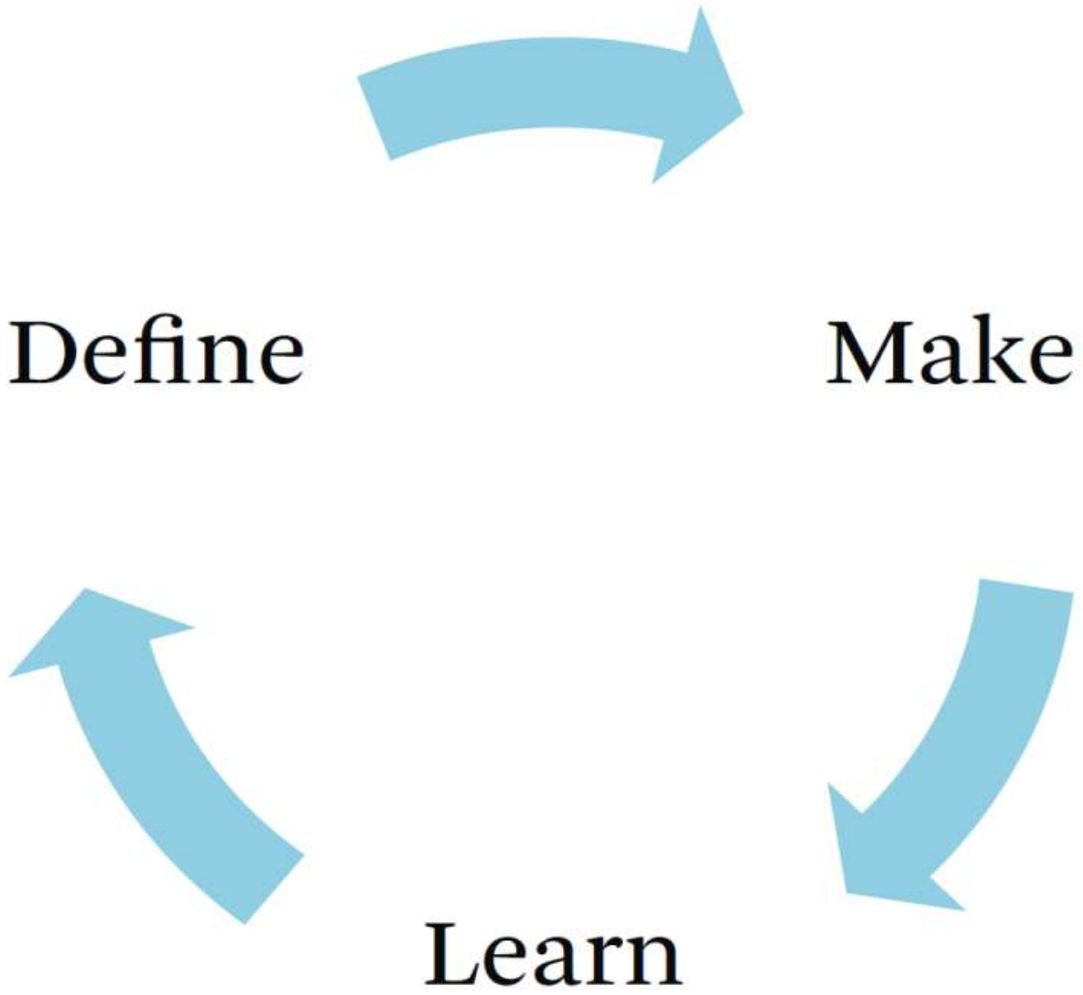
Comfort

Virtual Worlds

Iteration

Iteration

Iteration



The Define Stage

- Define the vision
- Ask questions
- Assess and determine feasibility
- High-level considerations
- State the Objectives
- Identify key players
- Identify risks
- Explicitly state assumptions
- Determine constraints
- Create personas
- Create user stories
- Draw Storyboards
- Determine scope
- List requirements

What's Your Vision?

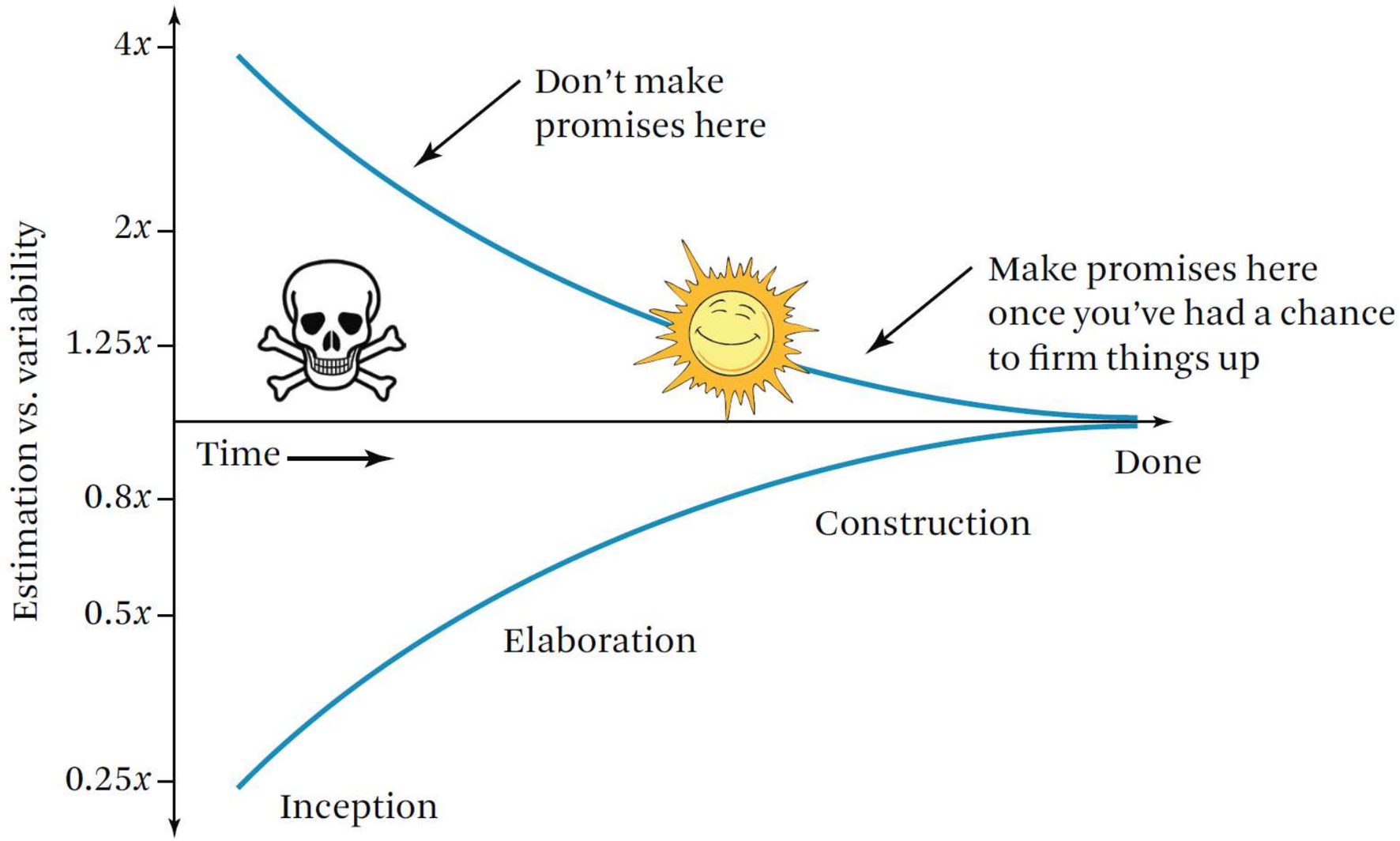
What is your vision?

A fun game or changing the world?

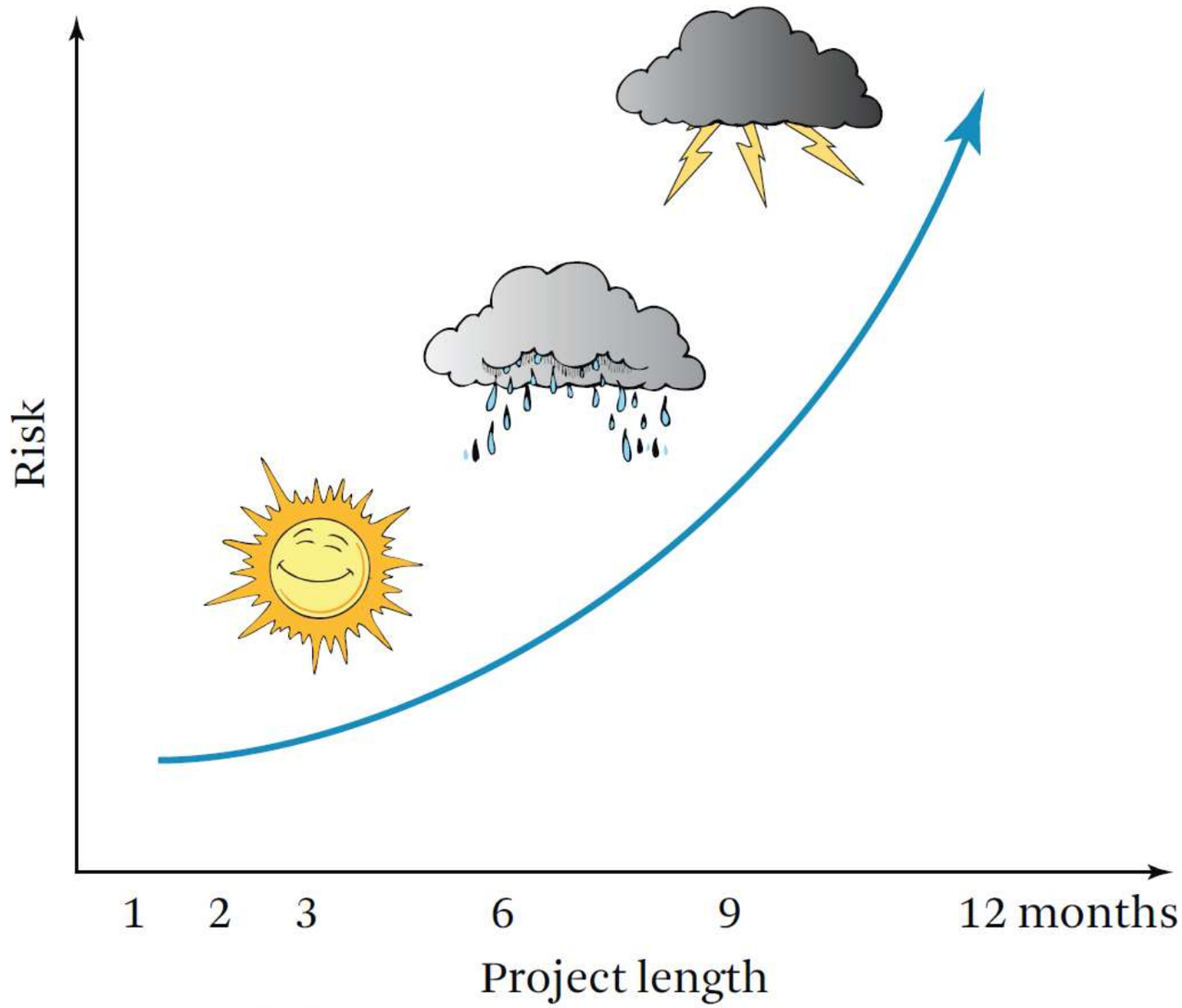
Its not where we you are at, its where you are going

What are two action items that you can start taking on ***TODAY***?

Estimating Costs



Long Projects Increase Risks



Personas

 Name	• Job • Experience • Activities • Attitude • Competencies • Age
• Problems • Pain points • Needs • Concerns • Fears • Desires	• Knowledge of VR • Dream VR system • Vision of VR • VR hardware access • Budget for VR • Activities that fit VR

The Make Stage

- Task analysis
- Design specification
  - ✓ Sketches
  - ✓ Block diagrams
  - ✓ Use cases
  - ✓ Classes
  - ✓ Software design patterns
- System considerations
  - ✓ Tradeoffs and making decisions
  - ✓ Supporting different hardware
  - ✓ Frame rate and latency
  - ✓ Sickness guidelines
  - ✓ Calibration
- Simulation
  - Separate simulation from rendering
  - Physics
    - Fighting policies
    - Jittering objects
    - Flying objects
- Networked environments
  - Ideals
  - Message protocols
  - Determinism and local estimation
  - Reducing network traffic
  - Simultaneous interactions
  - Networking physics
- Prototype forms
- Final production
- Delivery

Example decisions

Decision	Example Choices
Hand input hardware	None, Leap Motion, Sixense STEM
Number of participants	Single user, multiplayer, massively multiplayer
Viewpoint control pattern(s)	Walking, steering, world-in-miniature, 3D multi-touch, automated
Selection pattern(s)	Hand selection, pointing, image-plane, volume-based
Manipulation pattern(s)	Direct hand manipulation, proxy
Realism	Real-world capture, cartoon world
Vection	None, short periods of self-motion, linear motion only, active, passive
Intensity	Relaxing, heart-thumping
Sensory cues	Visual, auditory, haptics, motion platform
Posture	Sitting, standing, walking around

The Cycle of Interaction

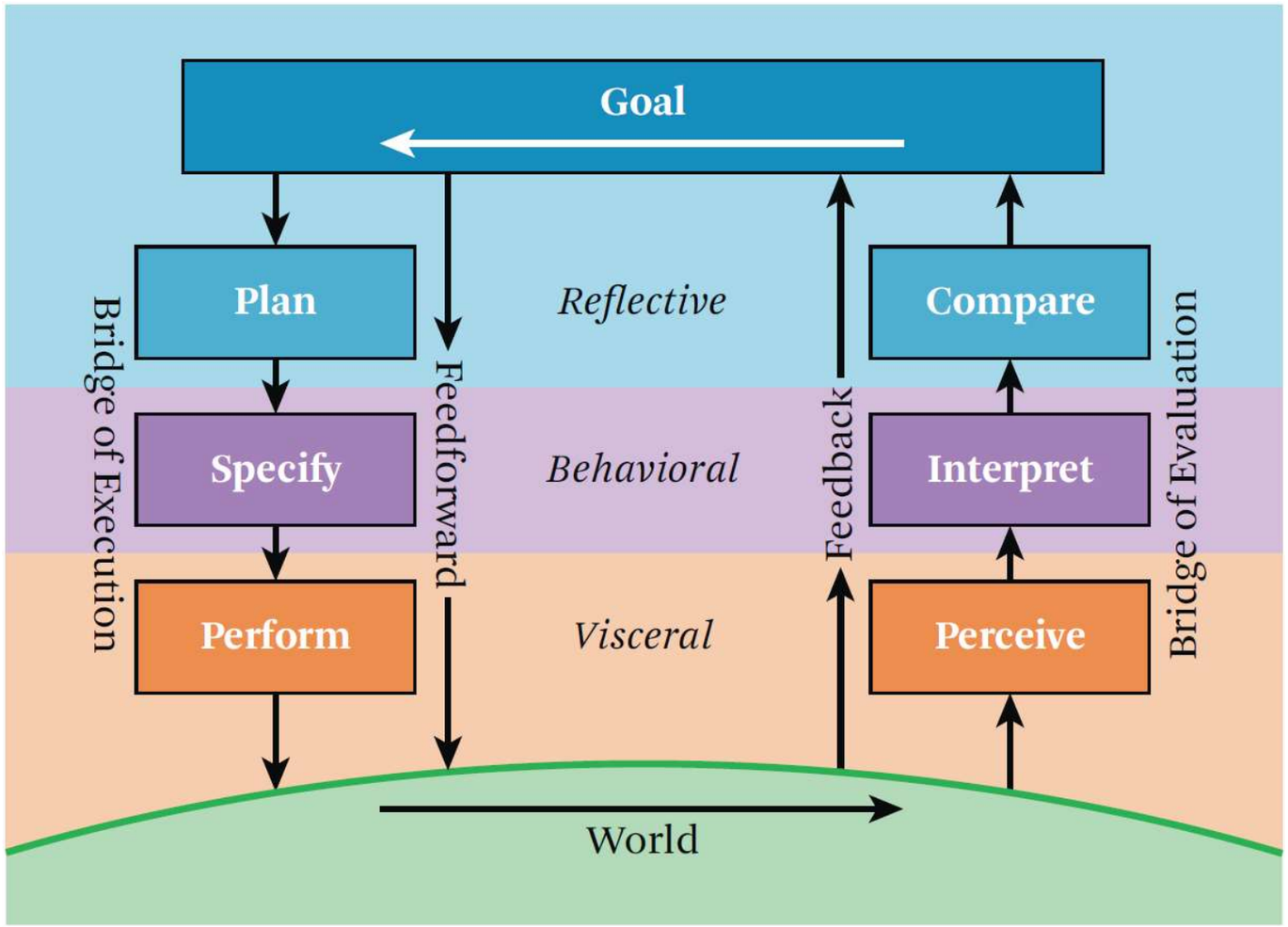
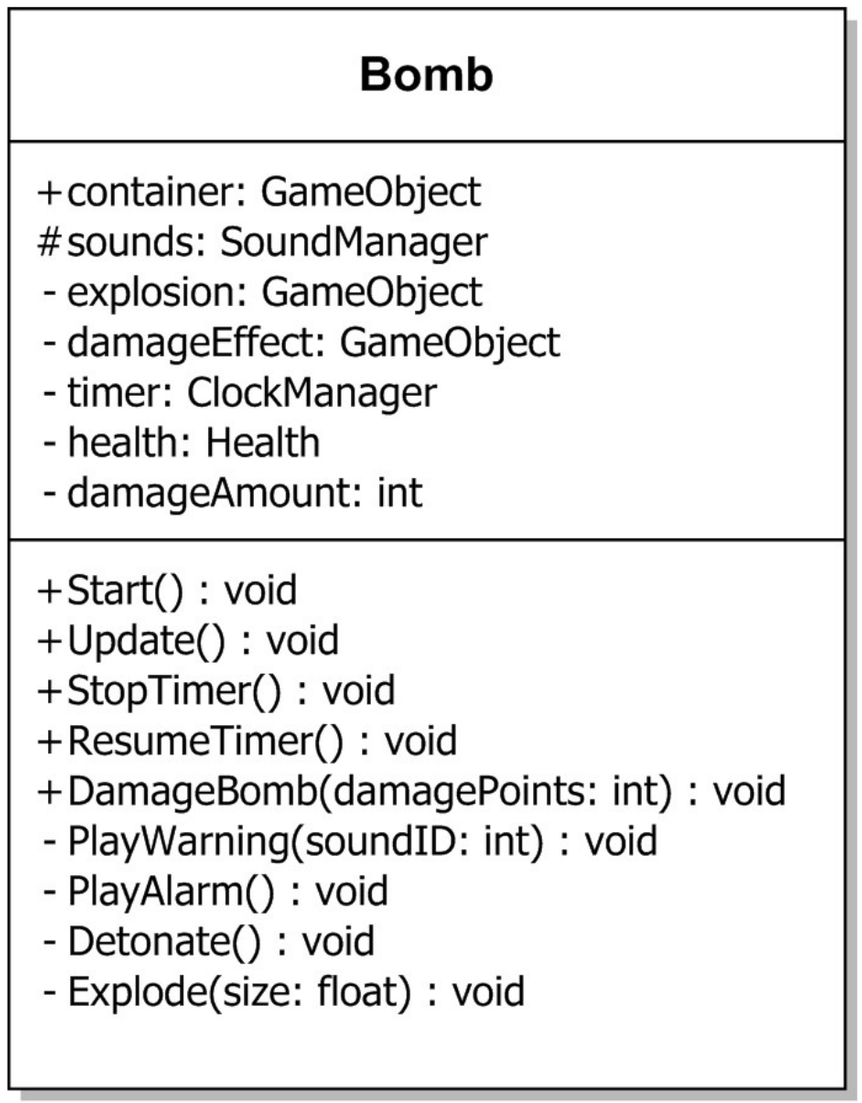


Image Courtesy of The VR Book (adapted from Norman [2013])

Class Diagrams



The Learn Stage

- Communication and attitude
- Research concepts
  - Data collection
  - Reliability
  - Validity
  - Sensitivity
- Constructivist approaches
  - Mini-retrospectives
  - Demos
  - Interviews
  - Questionnaires
  - Focus groups
  - Expert evaluations
  - After action reviews

The scientific method

- ✓ Experimental design
- ✓ True experiments vs quasi-experiments

Data analysis

- ✓ Making sense of the data
- ✓ Statistical concepts
- ✓ Correlation
- ✓ Statistical and practical significance

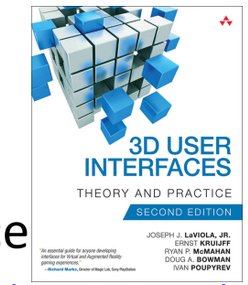
Want to Learn More?

Books

The VR Book: Human-Centered Design for Virtual Reality

http://TheVRBook.net

3D User Interfaces: Theory and Practice



http://www.pearsoned.co.uk/bookshop/detail.asp?item=100000000595951

Courses/Workshops

http://TheVRWorkshops.net

In-App Tutorial Examples

VR APOCALYPSE

http://NextGenGameStudio.com

MAKEVR

http://MakeVR.com.com

Conclusion

Few have the chance to change the world

We have the opportunity!

Lets not blow it!

Questions

References

Alonso-Nanclares, L., Gonzalez-Soriano, J., Rodriguez, J. R., and DeFelipe, J. (2008). Gender Differences in Human Cortical Synaptic Density. *Proceedings of the National Academy of Sciences USA, 105*, 14615–14619.

Bowman, D. A., and Hodges, L. (1997). An Evaluation of Techniques for Grabbing and Manipulating Remote Objects in Immersive Virtual Environments. In *ACMS ymposium on Interactive 3D Graphics2* (pp. 35–38). ACM Press.

Bowman, D. A., McMahan, R. P., and Ragan, E. D. (2012). Questioning Naturalism in 3D User Interfaces. *Communications of the ACM*, *55*(9), 78–88.

Burton, T. M.W. (2012). Robotic Rehabilitation for the Restoration of Functional Grasping Following Stroke. Dissertation, University of Bristol, England.

Davis, S., Nesbitt, K., and Nalivaiko, E. (2014). A Systematic Review of Cybersickness. In *Proceedings of the 2014 Conference on Interactive Entertainment* (pp. 1–9). Newcastle, NSW, Australia: ACM. Goldstein, E. B. (2007). *Sensation and Perception* (7th ed.). Belmont, CA: Wadsworth Publishing.

Jerald, J. (2015) The VR Book: Human-Centered Design for Virtual Reality. Morgan & Claypool Publishers and ACM Books.

Kennedy, R. S., Lane, N. E., Berbaum, K. S., and Lilienthal, M. G. (1993). A Simulator Sickness Questionnaire (SSQ): A New Method for Quantifying Simulator Sickness. International Journal of Aviation Psychology, 3(3), 203–220.

LaViola, J. Kruijff, E., McMahan, R., Bowman, D. and Poupyrev, I. (2017). 3D User Interfaces: Theory and Practice, Second Edition, Addison Wesley.

Laviola, J. (1999). Whole-Hand and Speech Input in Virtual Environments. Providence, RI: Brown University Press.

Lindeman, R., and Beckhaus, S. (2009). Crafting Memorable VR Experiences Using Experiential Fidelity. Proceedings of the 16th ACMSymposium on Virtual Reality Software and Technology, 187–190.

Marois, R., and Ivanoff, J. (2005). Capacity Limits of Information Processing in the Brain. *Trends in Cognitive Sciences*.

Martin, J. (1998). TYCOON: Theoretical Framework and Software Tools for Multimodal Interfaces. In J. Lee (Ed.), *Intelligence and Multimodality in Multimedia Interfaces*. AAAIPress.

Norman D. (2013) The Design of Everyday Things, Expanded and Revised Edition. Basic Books.

Pierce, J., Forsberg, A., Conway, M., Hong, S., Zeleznik, R., and Mine, M. R. (1997). Image Plane Interaction Techniques in 3D Immersive Environments. In ACM Symposium on Interactive 3D Graphics (pp. 39–44). ACM Press.

Prothero, J. D., and Parker, D. E. (2003). A Unified Approach to Presence and Motion Sickness. In L. J. Hettinger and M. Haas (Eds.), *Virtual and Adaptive Environments* (pp.47–66). Boca Raton, FL: CRC Press.

Fernandes, Ajoy S., and Steven K. Feiner. "Combating VR sickness through subtle dynamic field-of-view modification." *2016 IEEE Symposium on 3D User Interfaces (3DUI)*. IEEE, 2016.

Additional Slides

Value of AR/VR

Lower product design times

Increase quality

Increase confidence

Reduce risks

Increase innovation

Cost savings

Test product acceptability

Ergonomics/usability

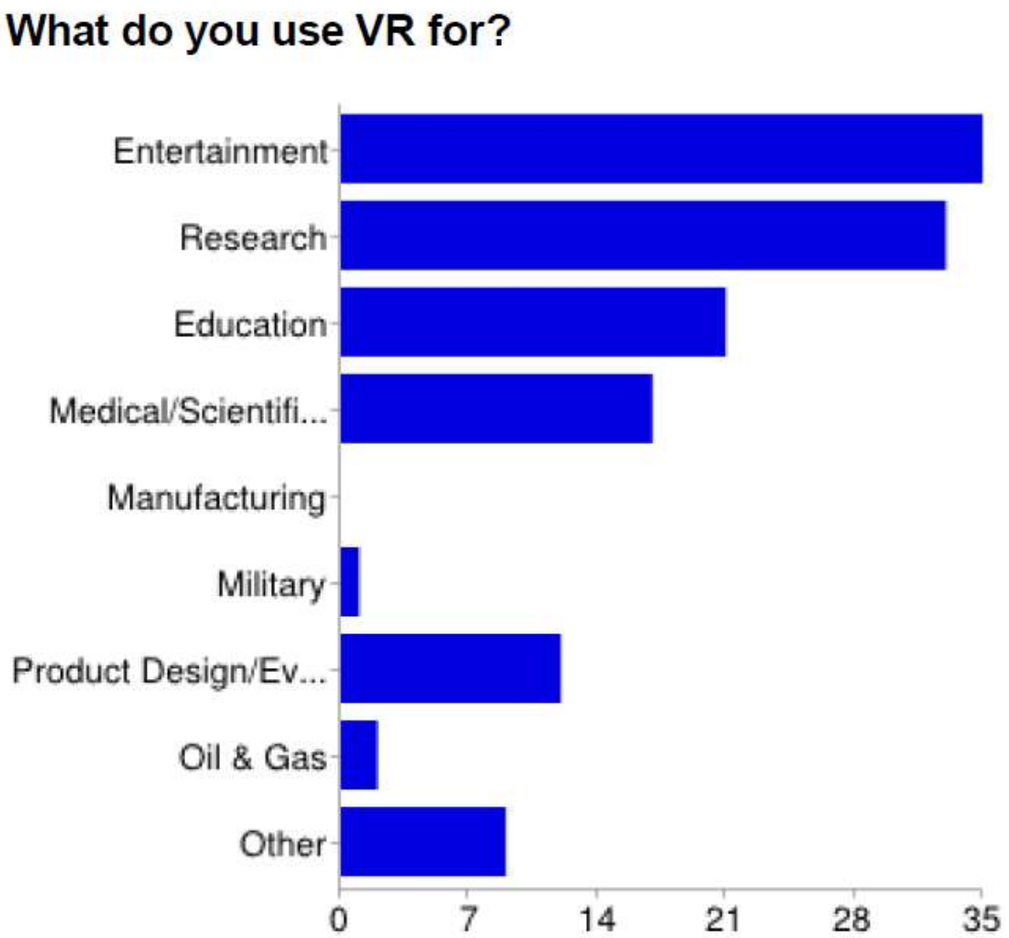
Validate interactions

Explore human behavior

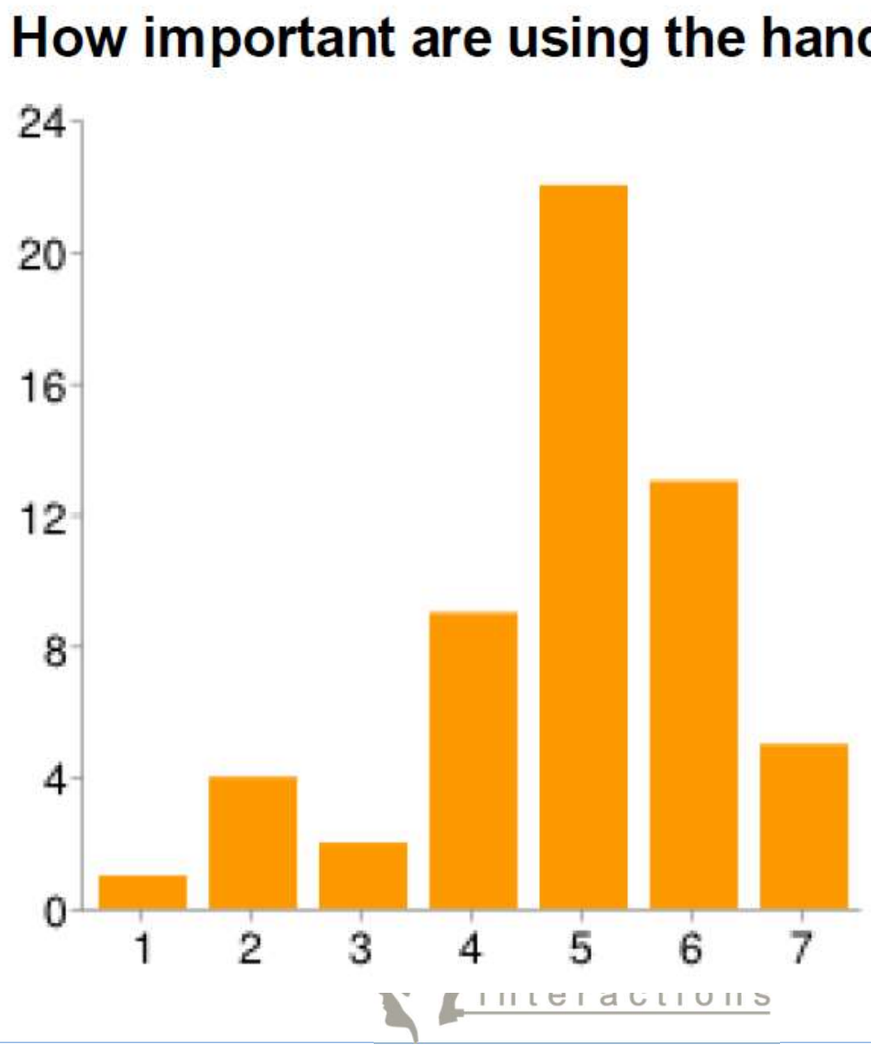
Increase motivation

Increase understanding

Survey Results From VR Experts



Survey Results From VR Experts



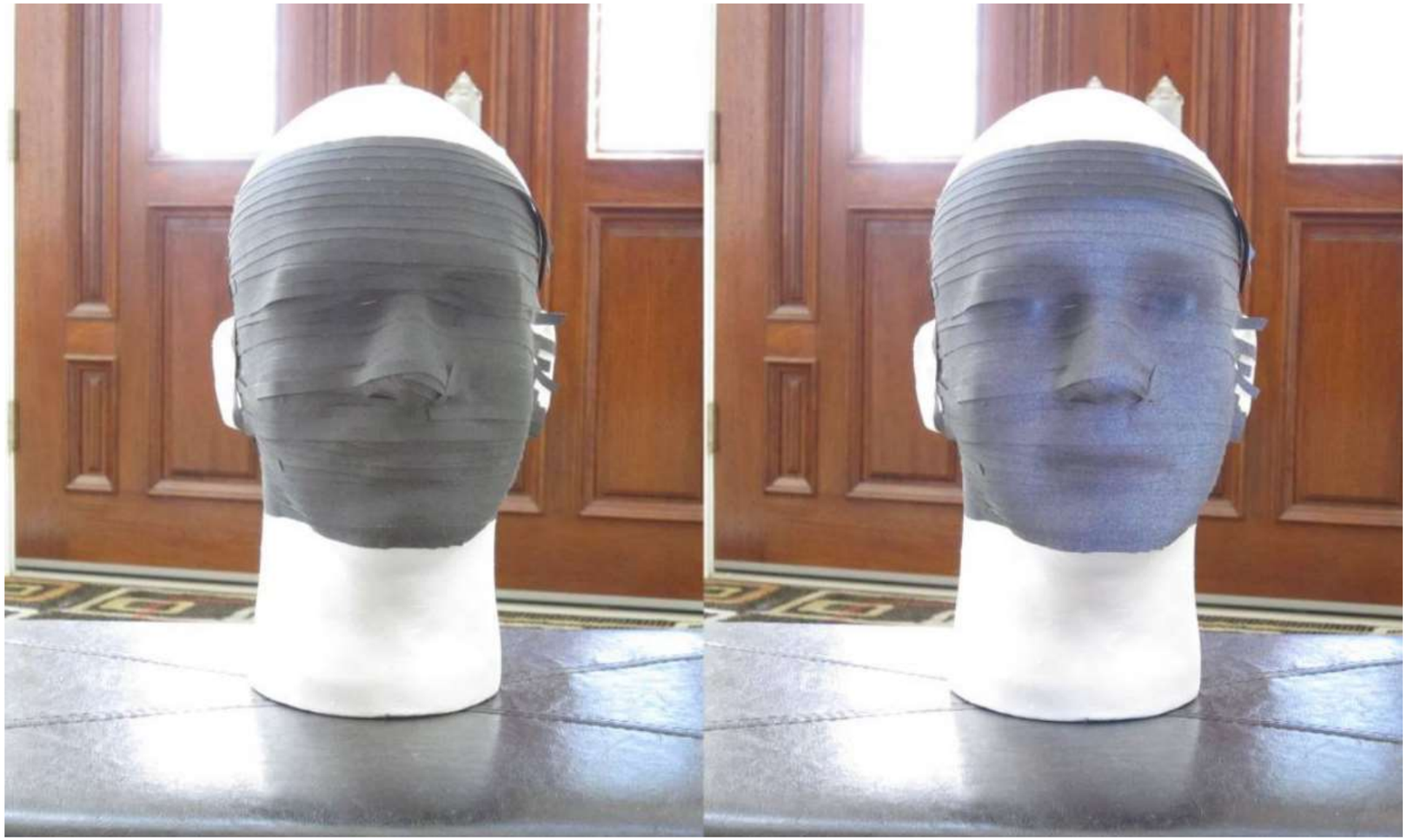
Example Applications

- Marketing
- Retail
- Training
- Education
- Architecture/construction/real estate
- Data Visualization
- Empathy
- Rehabilitation
- Distraction from pain
- Driving/Flight simulation
- Medical Visualization
- Location-based Entertainment
- Immersive film
- Crime scene investigation
- Emergency preparedness
- Telepresence and Tourism
- 3D printing


Training Room
Pit Room

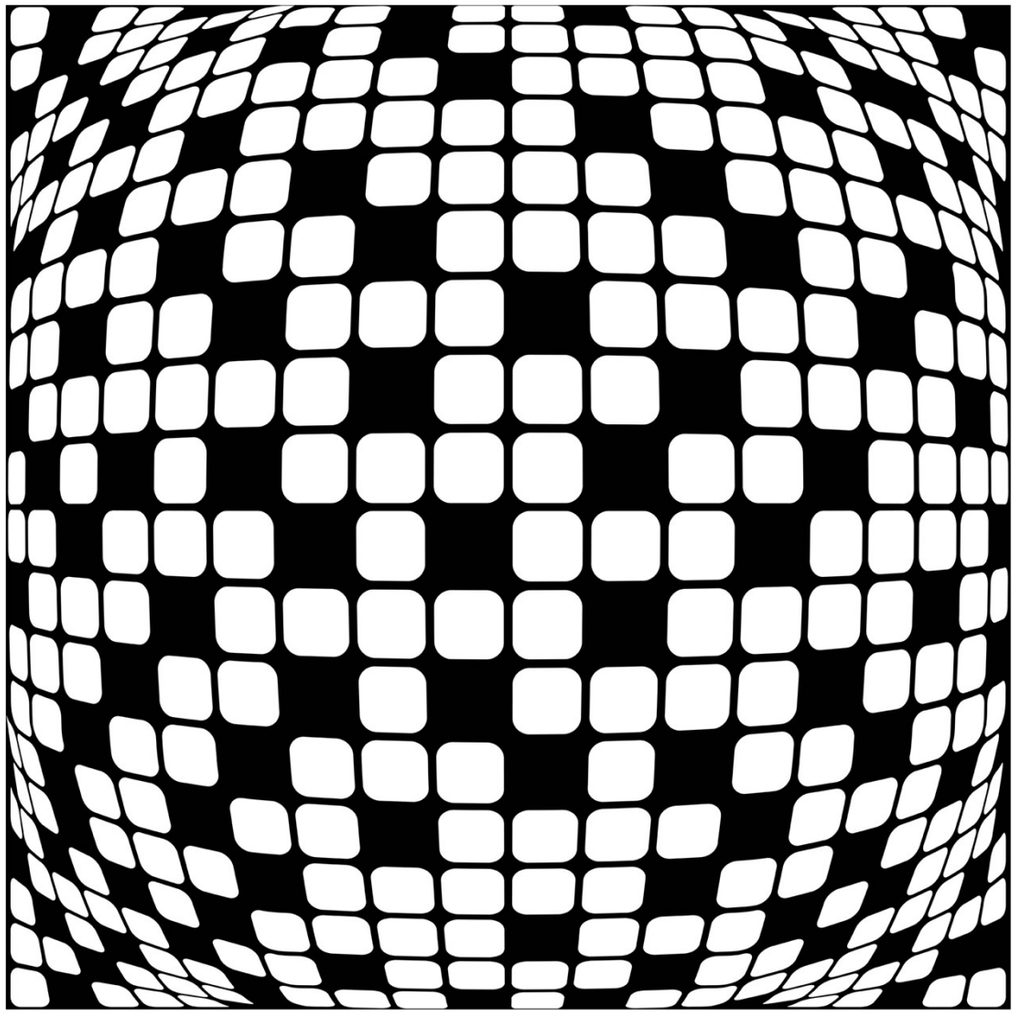
USC ICT Retroreflection

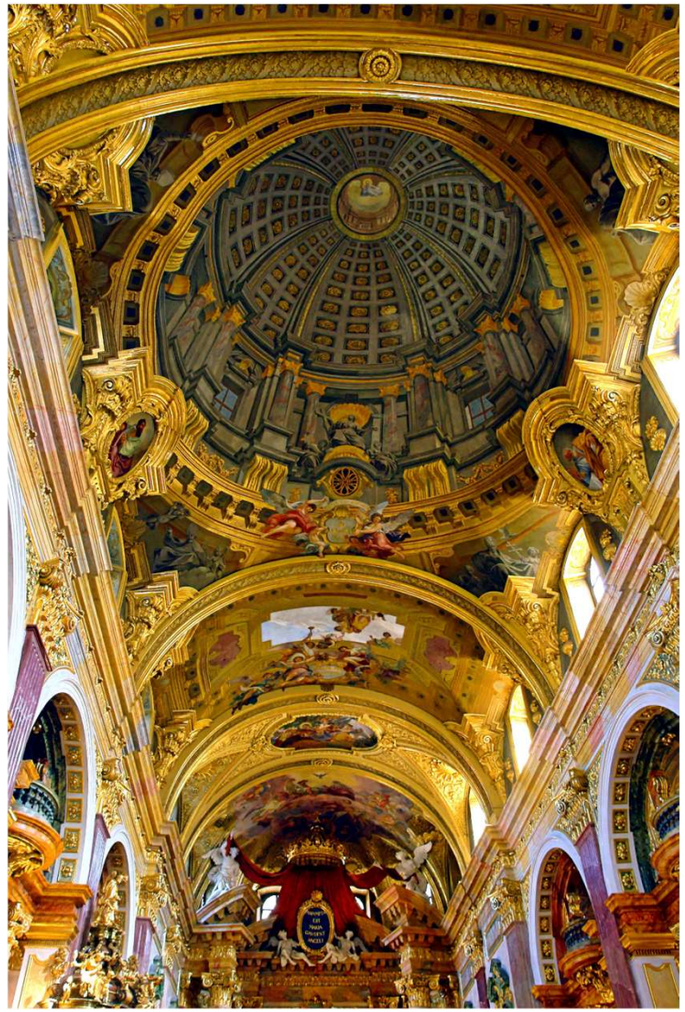
David Krum, Evan Suma, & Mark Bolas




Person A
Person B


FIRST LOOKS
EMERGENCE DAY 2006



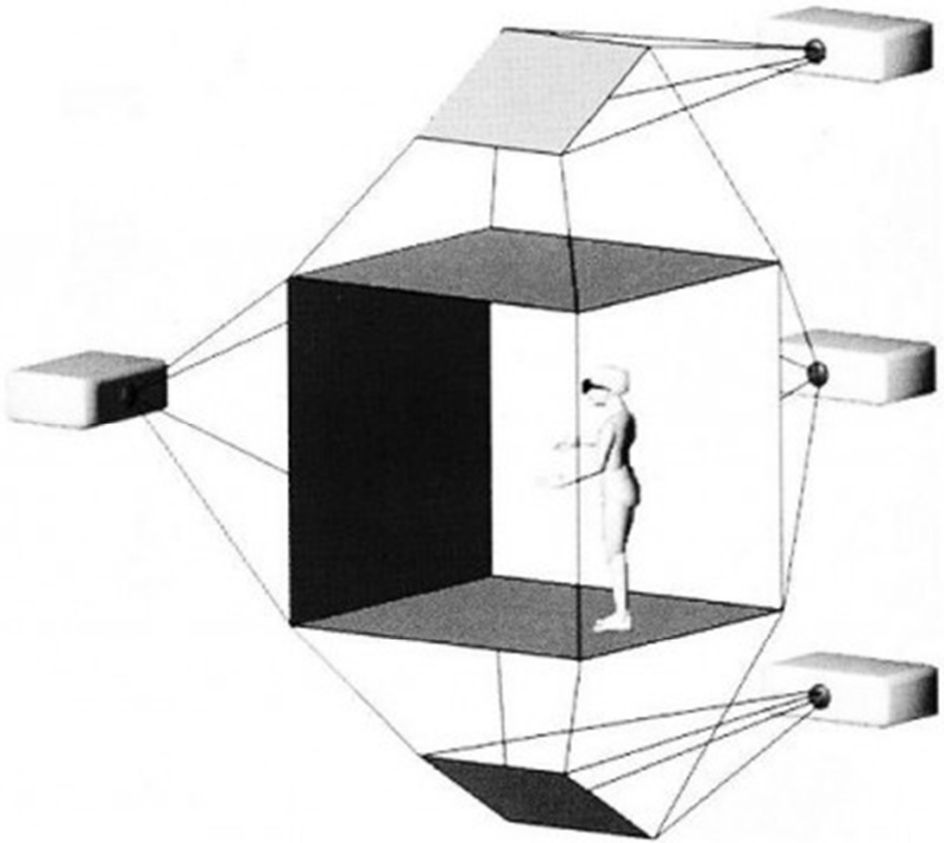


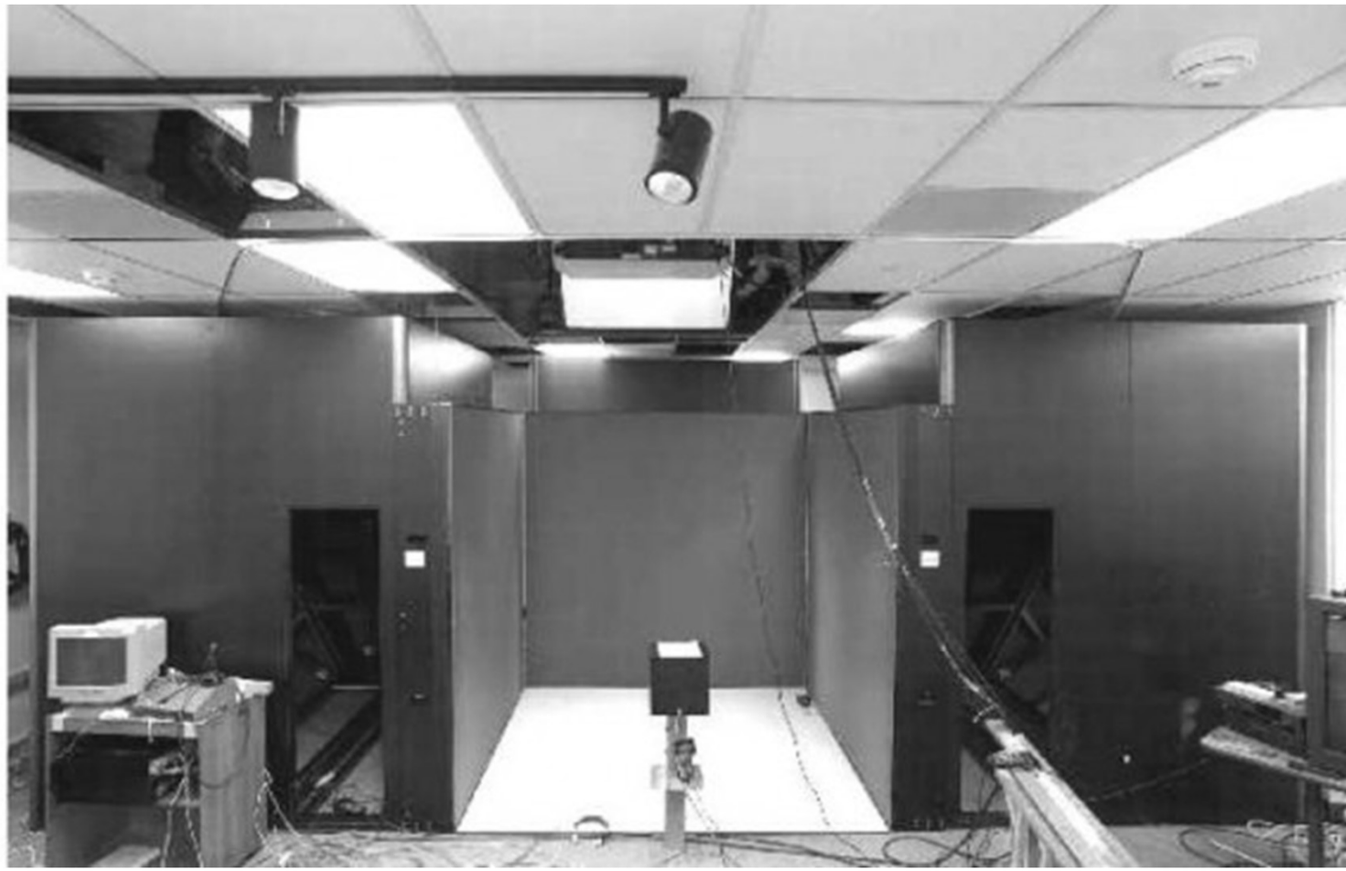
Aeriel Perspective

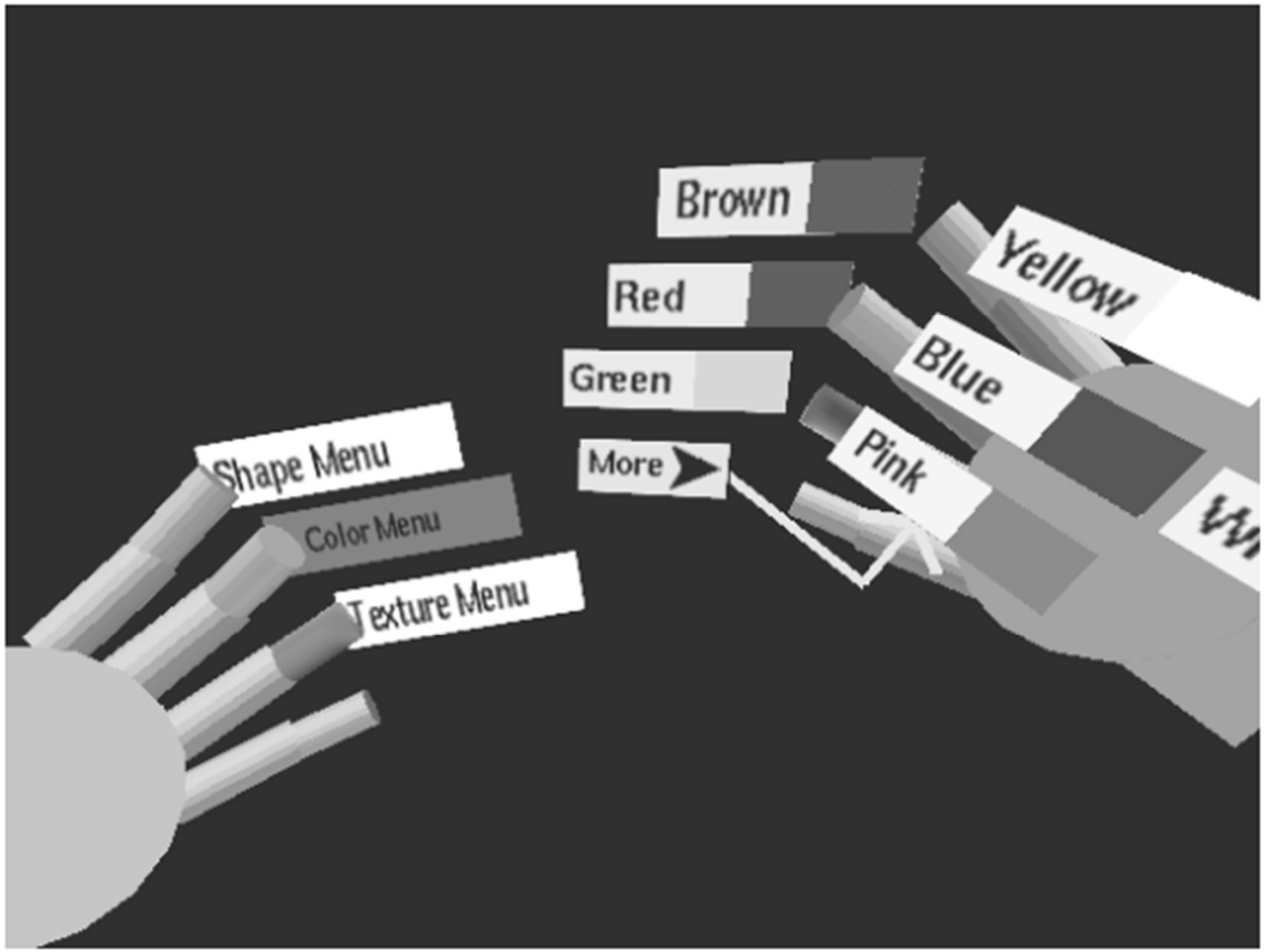
Diversity Training

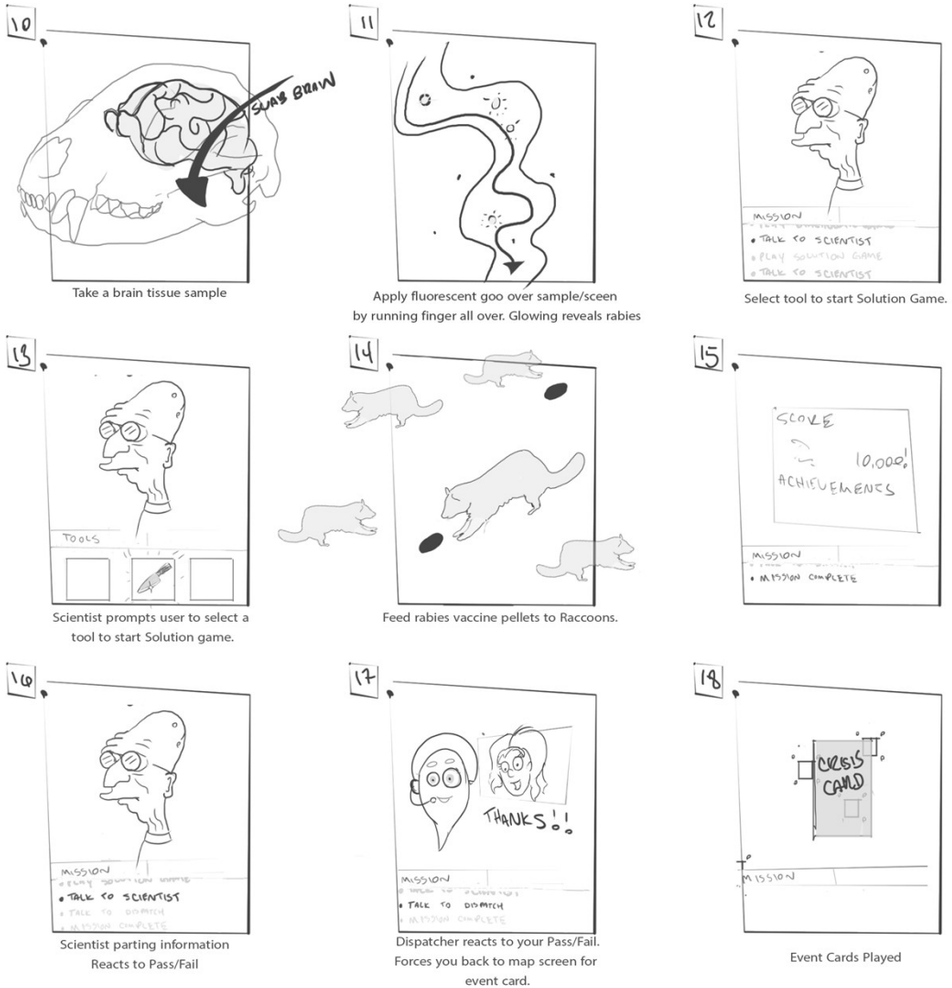
NC STATE UNIVERSITY

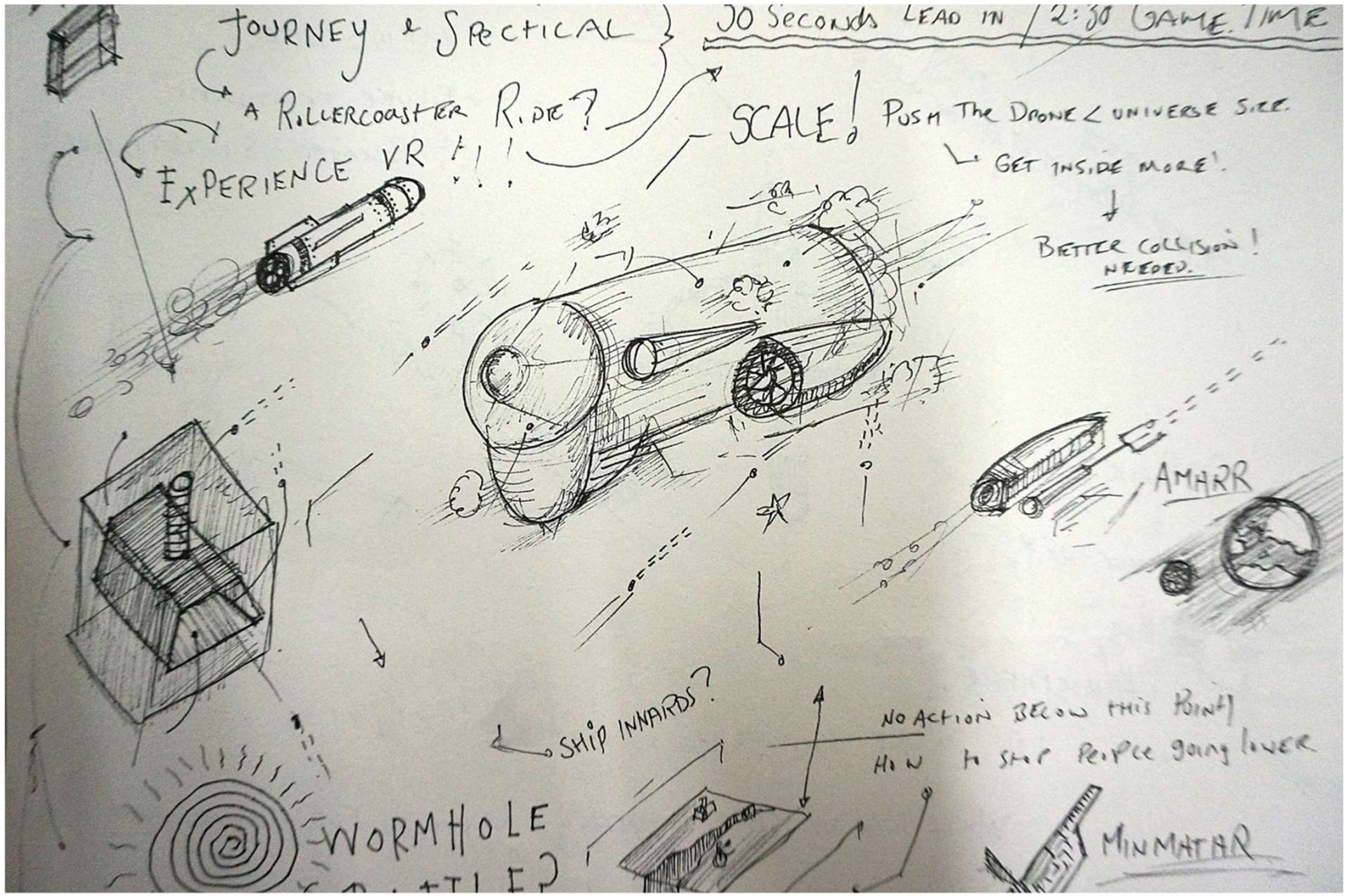

N
W
E
Track Filter
Transport Platform
Sub Surface
Surface
Air
Missile
Friendly
Other
Neutral
info
BackgroundAndLights



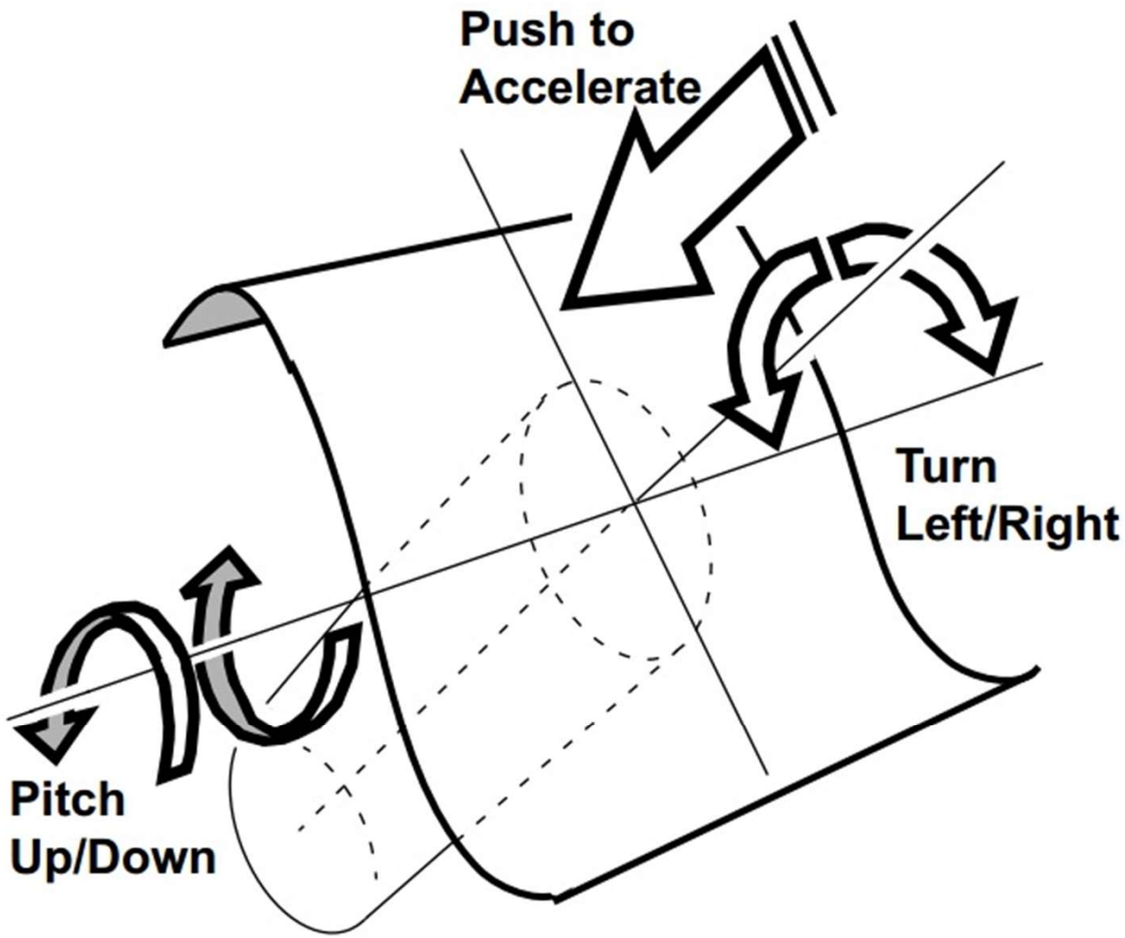



Brown
Yellow
Red
Blue
Green
Pink
More
Shape Menu
Color Menu
Texture Menu


10
SLICE BRAIN
Take a brain tissue sample
11
Apply fluorescent goo over sample/sceen
by running finger all over. Glowing reveals rabies
12
MISSION
• TALK TO SCIENTIST
• PLAY SOLUTION GAME
• TALK TO SCIENTIST
Select tool to start Solution Game.
13
TOOLS
Scientist prompts user to select a
tool to start Solution game.
14
Feed rabies vaccine pellets to Raccoons.
15
SCORE
10,000!
ACHIEVEMENTS
MISSION
• MISSION COMPLETE
16
MISSION
• TALK TO SCIENTIST
Scientist parting information
Reacts to Pass/Fail
17
THANKS!!
MISSION
• TALK TO DISPATCH
Dispatcher reacts to your Pass/Fail.
Forces you back to map screen for
event card.
18
CRISIS CAMP
MISSION
Event Cards Played

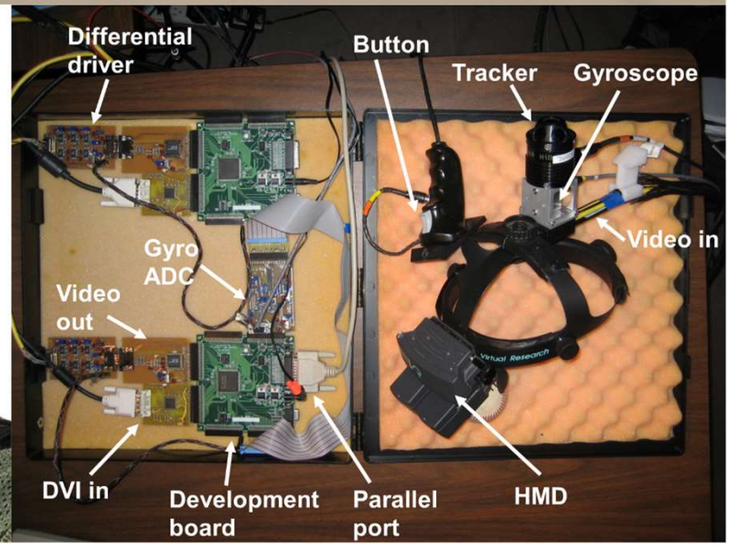

JOURNEY & SPECTICAL
A ROLLERCOASTER RIDE?
EXPERIENCE VR !!!
30 SECONDS LEAD IN / 2:30 GAME TIME
SCALE! PUSH THE DRONE < UNIVERSE SIZE.
GET INSIDE MORE!
BETTER COLLISION! NEEDED.
AMARR
SHIP INNARDS?
NO ACTION BELOW THIS POINT!
HOW TO STOP PEOPLE GOING LOWER
WORMHOLE
MINMATAR



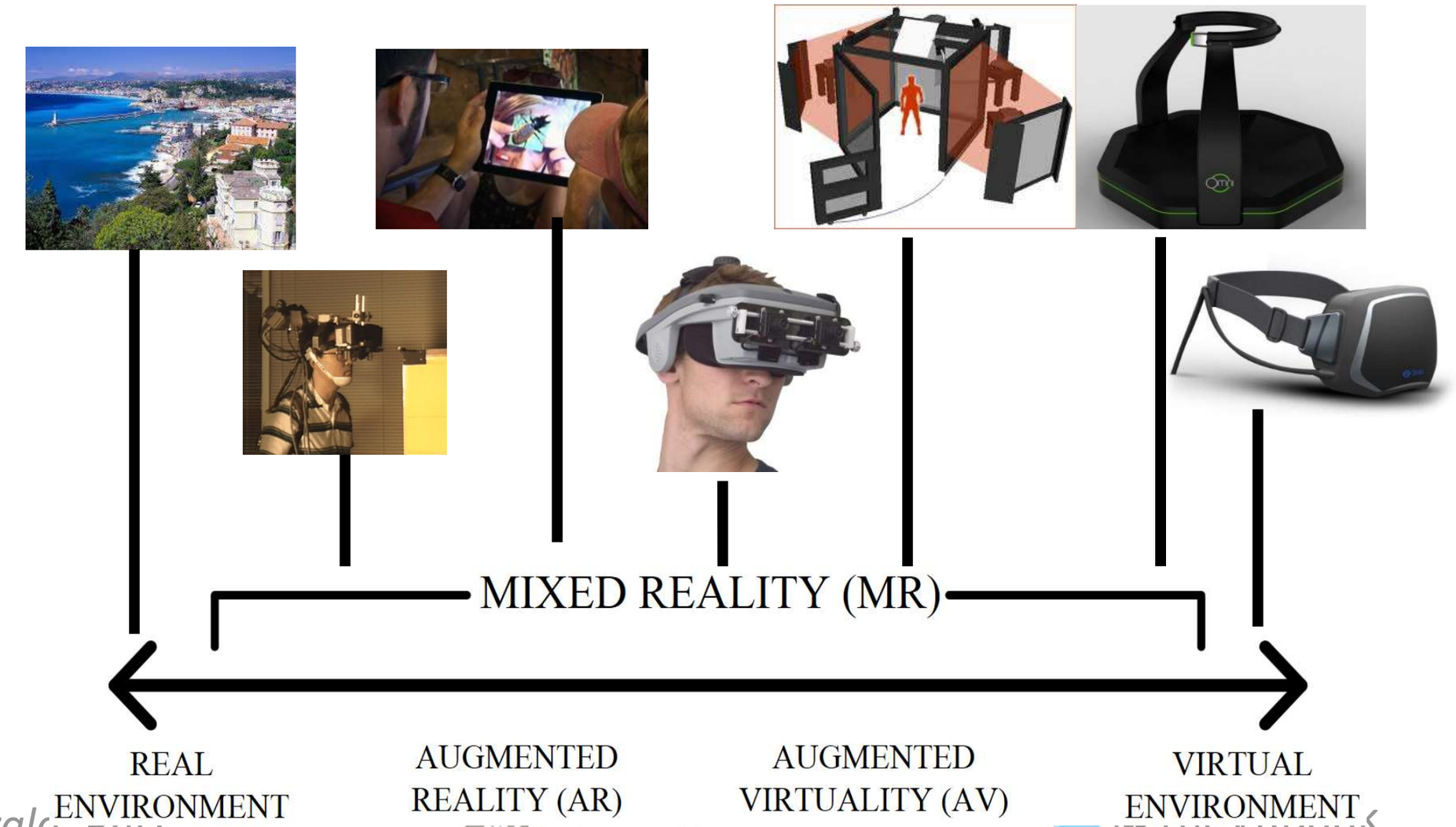

Push to
Accelerate
Turn
Left/Right
Pitch
Up/Down


castAR

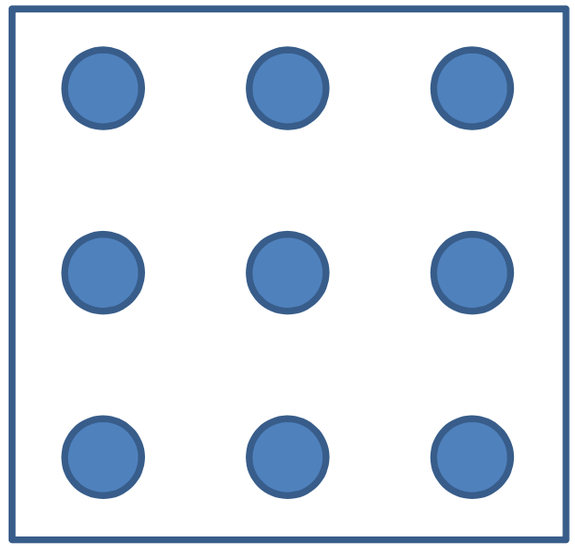

Active Matrix Liquid Crystal Display image display
Sensor fusion
Binocular 40 degree by degree field-of-view
Integrated day and night camera
Ejection Safe to 600 knots equivalent air speed


Differential driver
Button
Tracker
Gyroscope
Video in
Gyro ADC
Video out
DVI in
Development board
Parallel port
HMD

What is Reality?

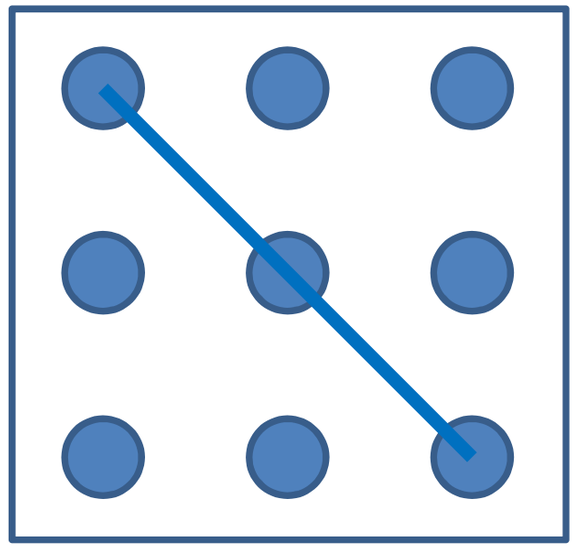


A Puzzle



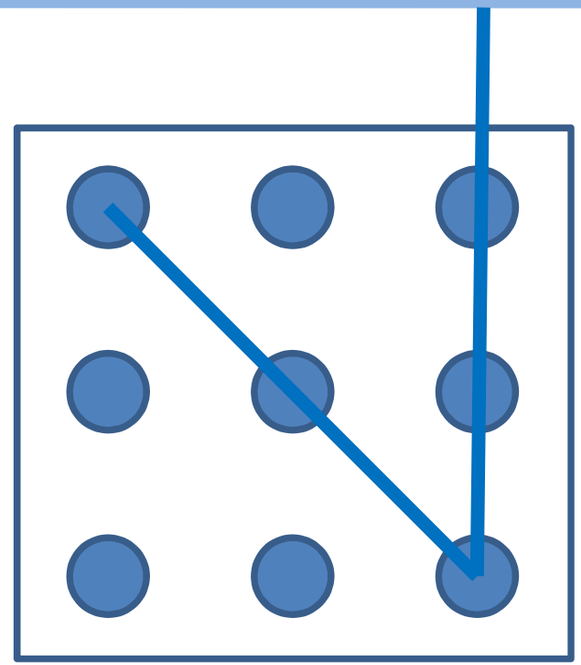
Draw four straight lines which go through the middle of all of the dots without taking your pen off the paper.

A Puzzle



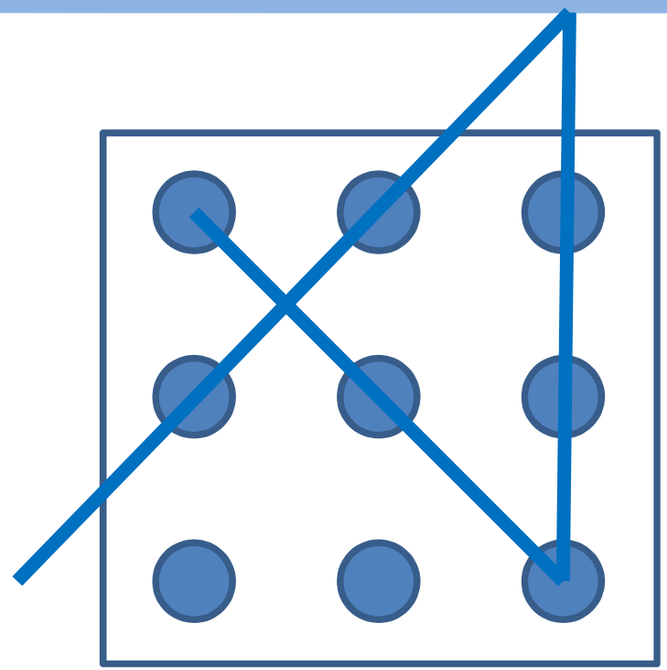
Draw four straight lines which go through the middle of all of the dots without taking your pen off the paper.

A Puzzle



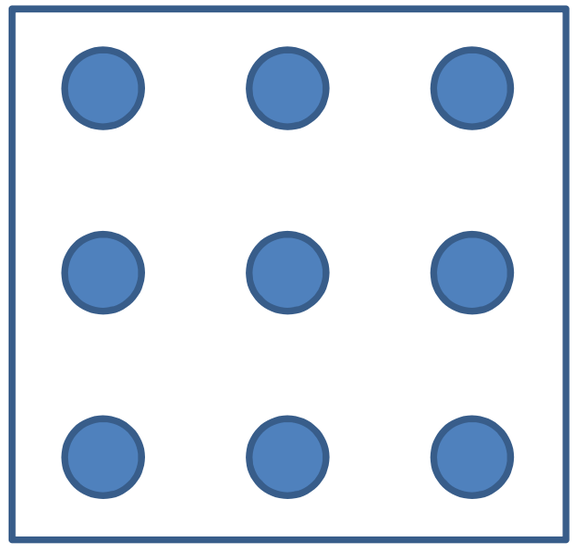
Think outside the box!

A puzzle



Think outside the box!

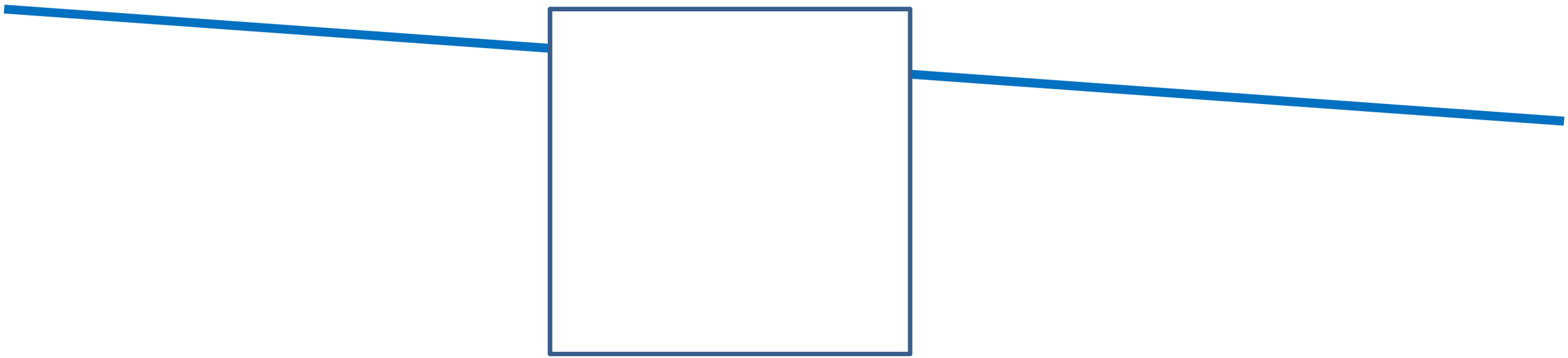
A Puzzle



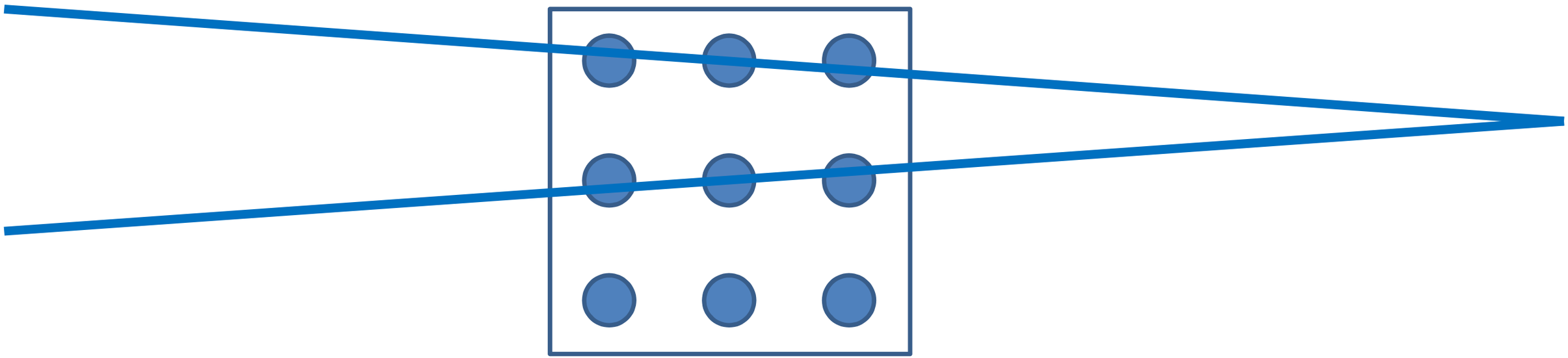
Can you draw over all 3 dots with three straight lines connected end-end?

Hint: Think even further outside the box

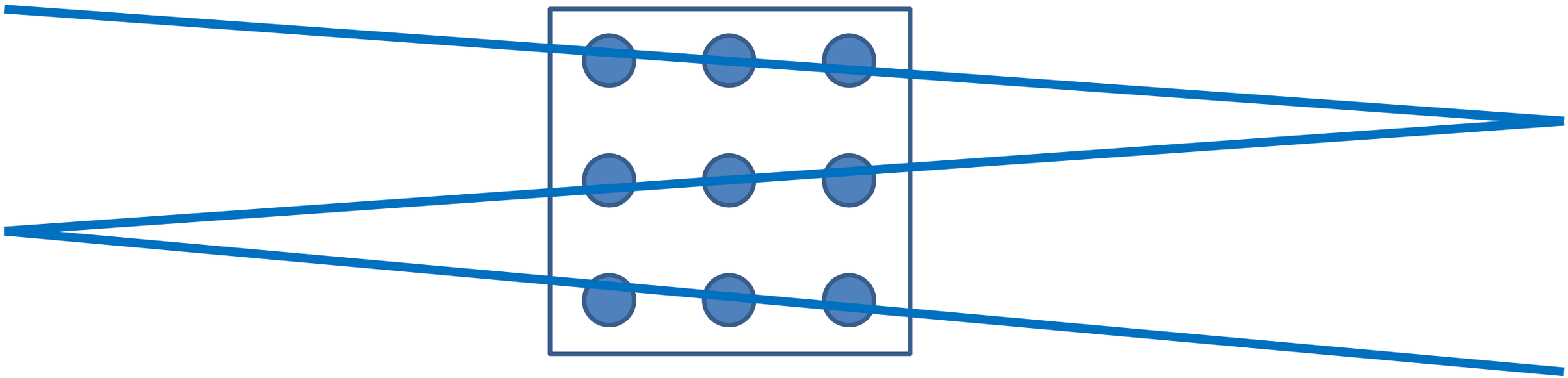
A Puzzle



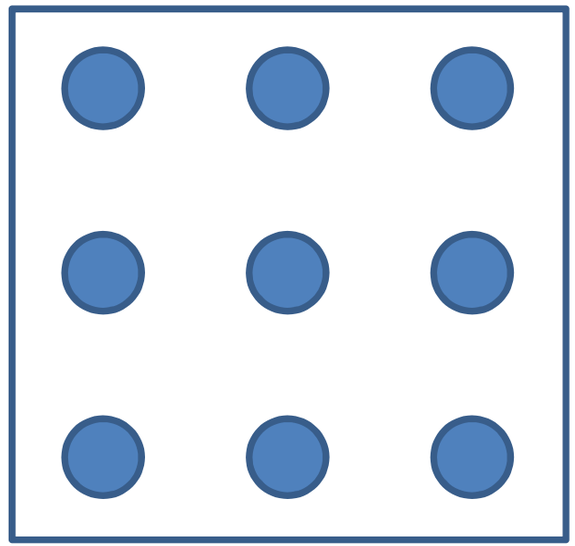
A Puzzle



A Puzzle

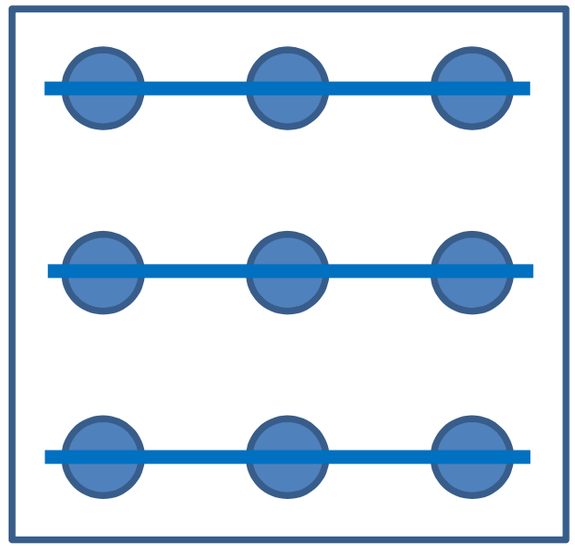


A Puzzle

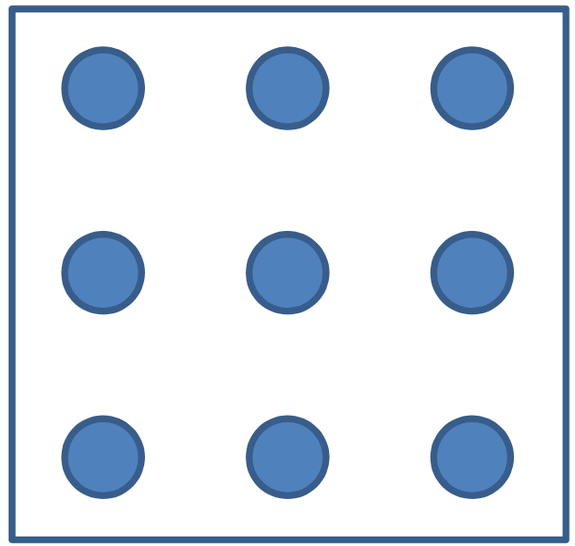


Now draw over all nine dots with three straight lines, but this time the lines cannot extend beyond the box boundaries

A Puzzle

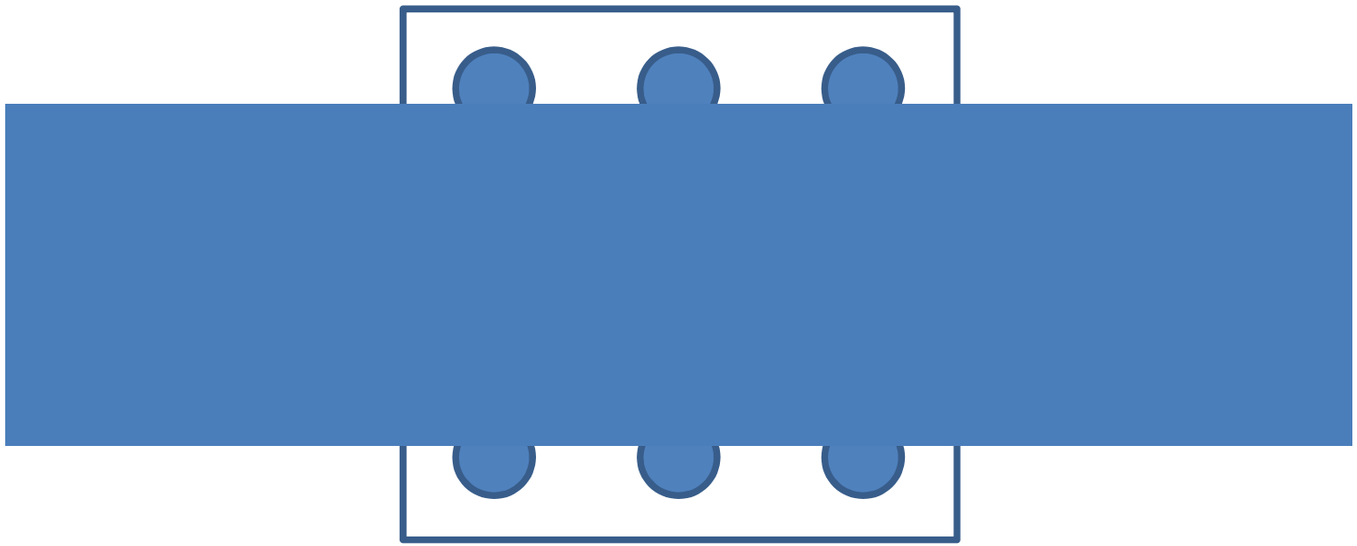


A Puzzle



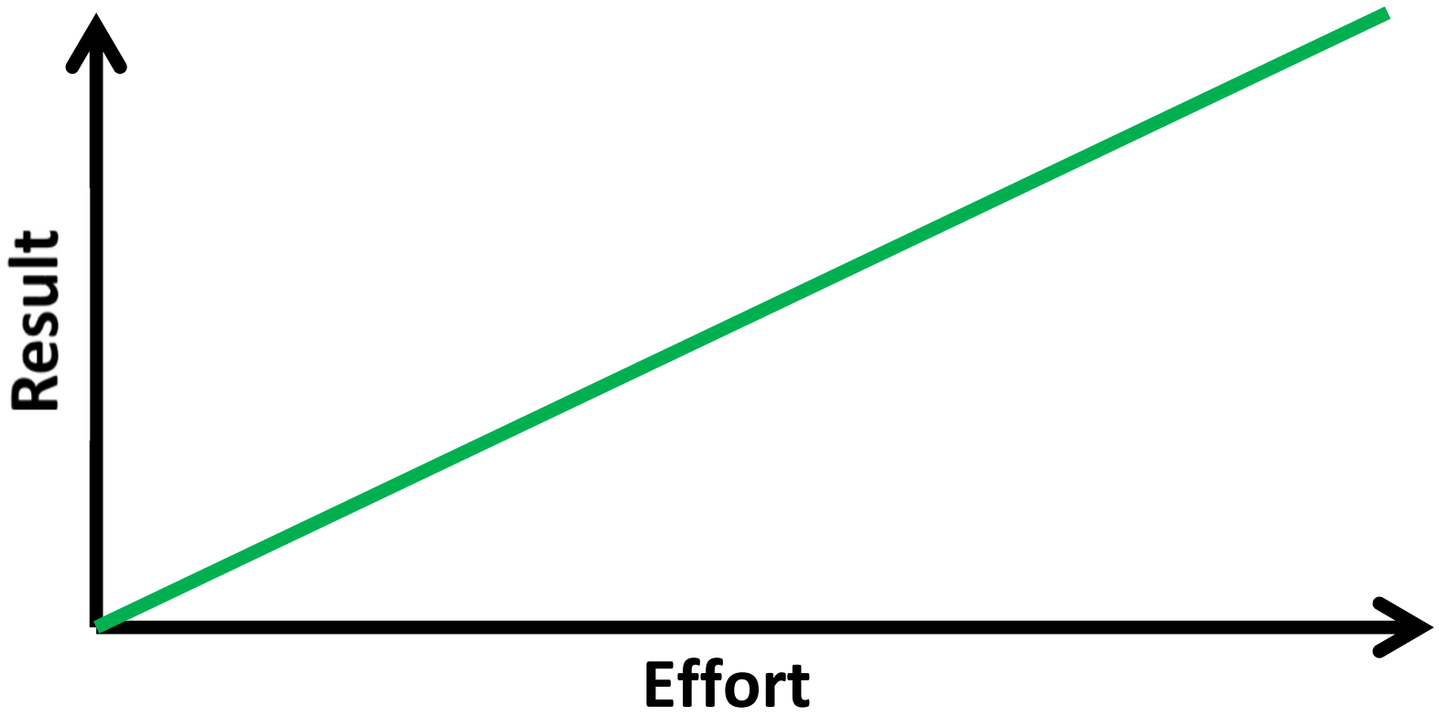
Now draw over all nine dots
with a single straight line

A Puzzle



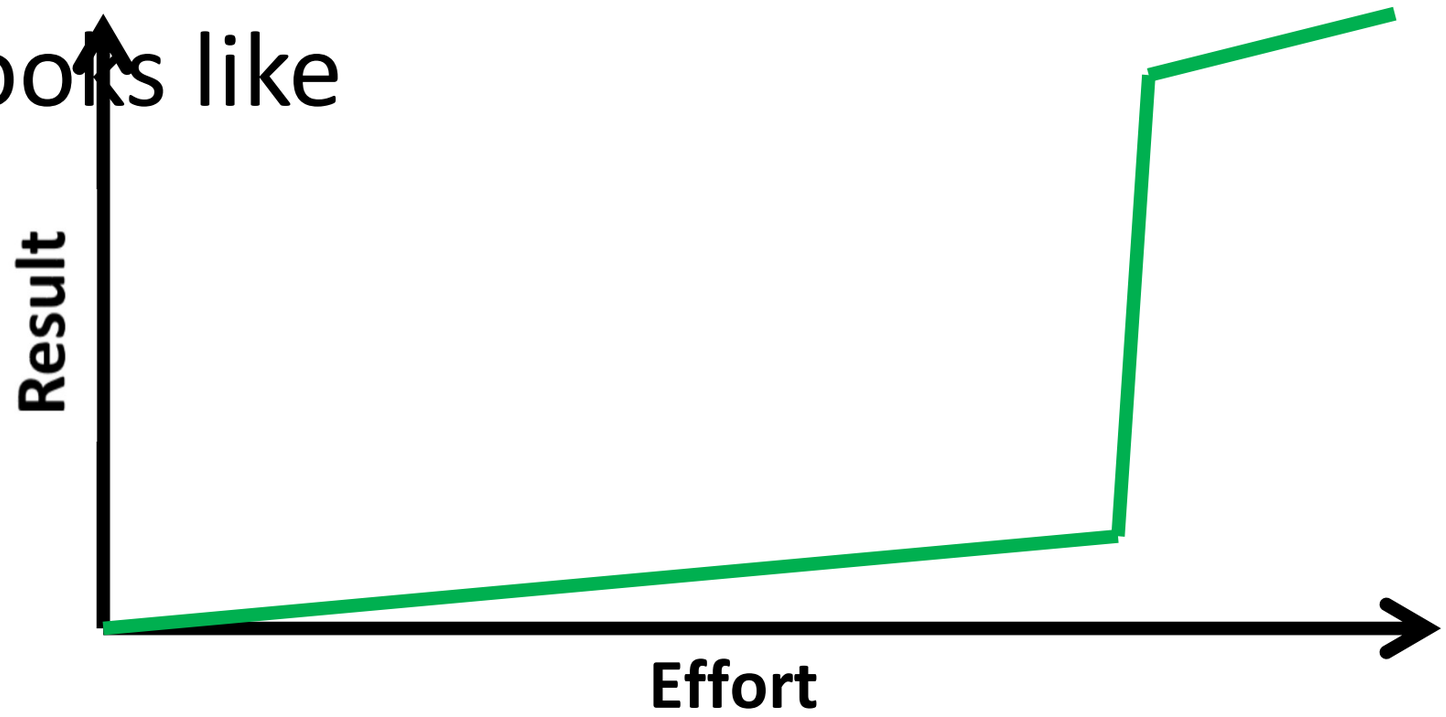
Innovation

What people think it looks like

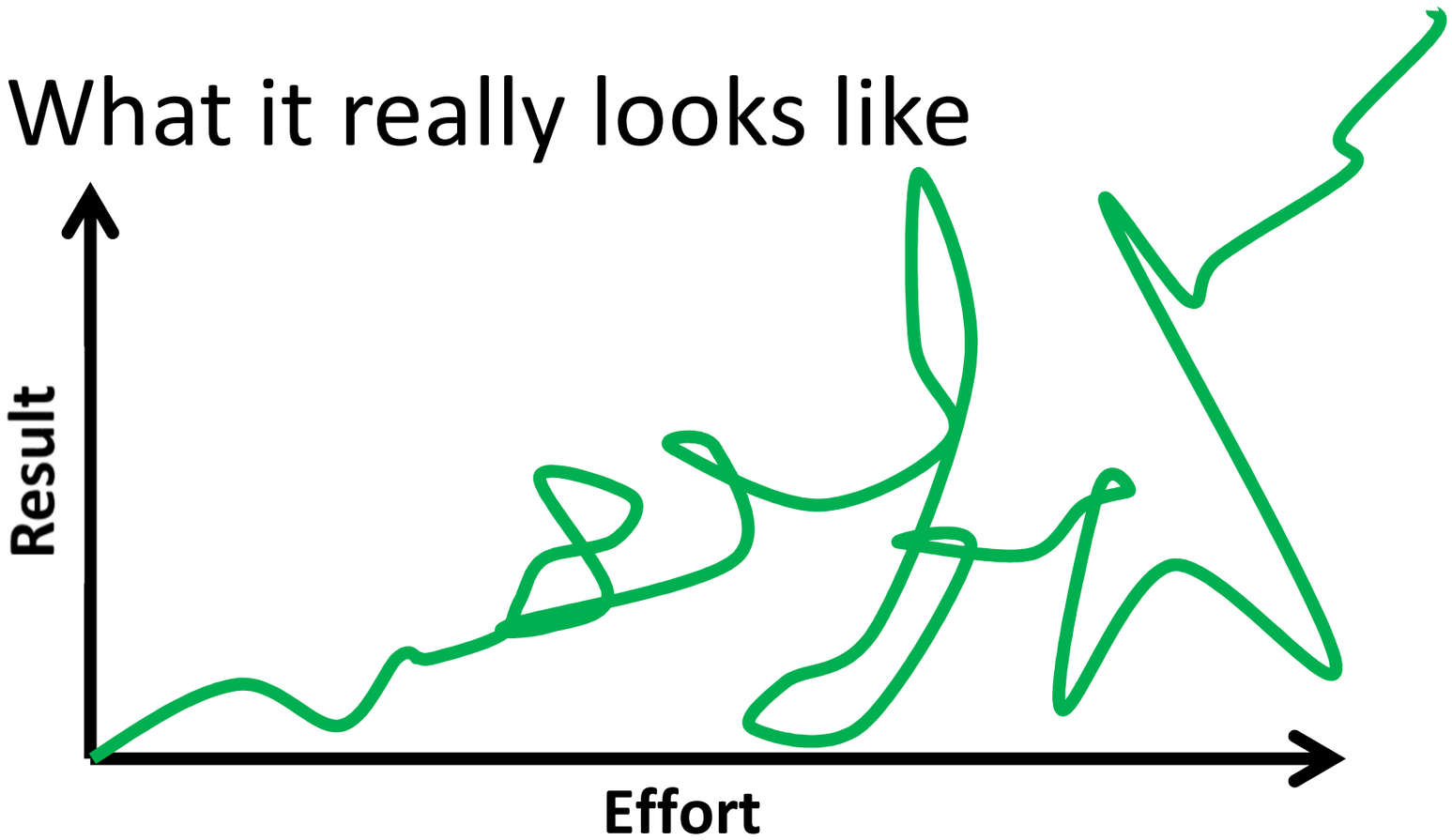


Innovation

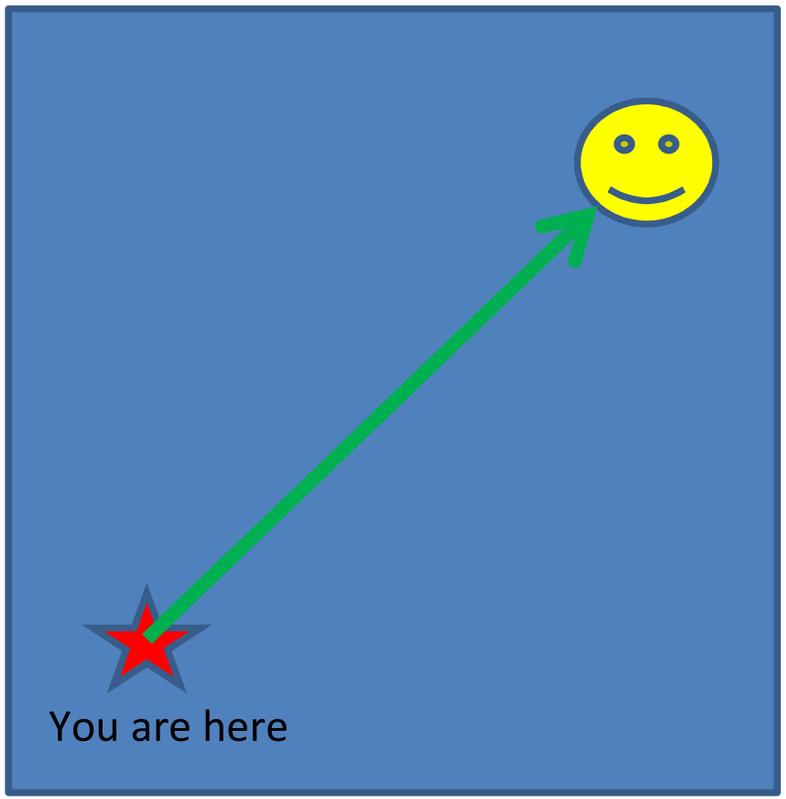
What enlightened people think it looks like



Innovation



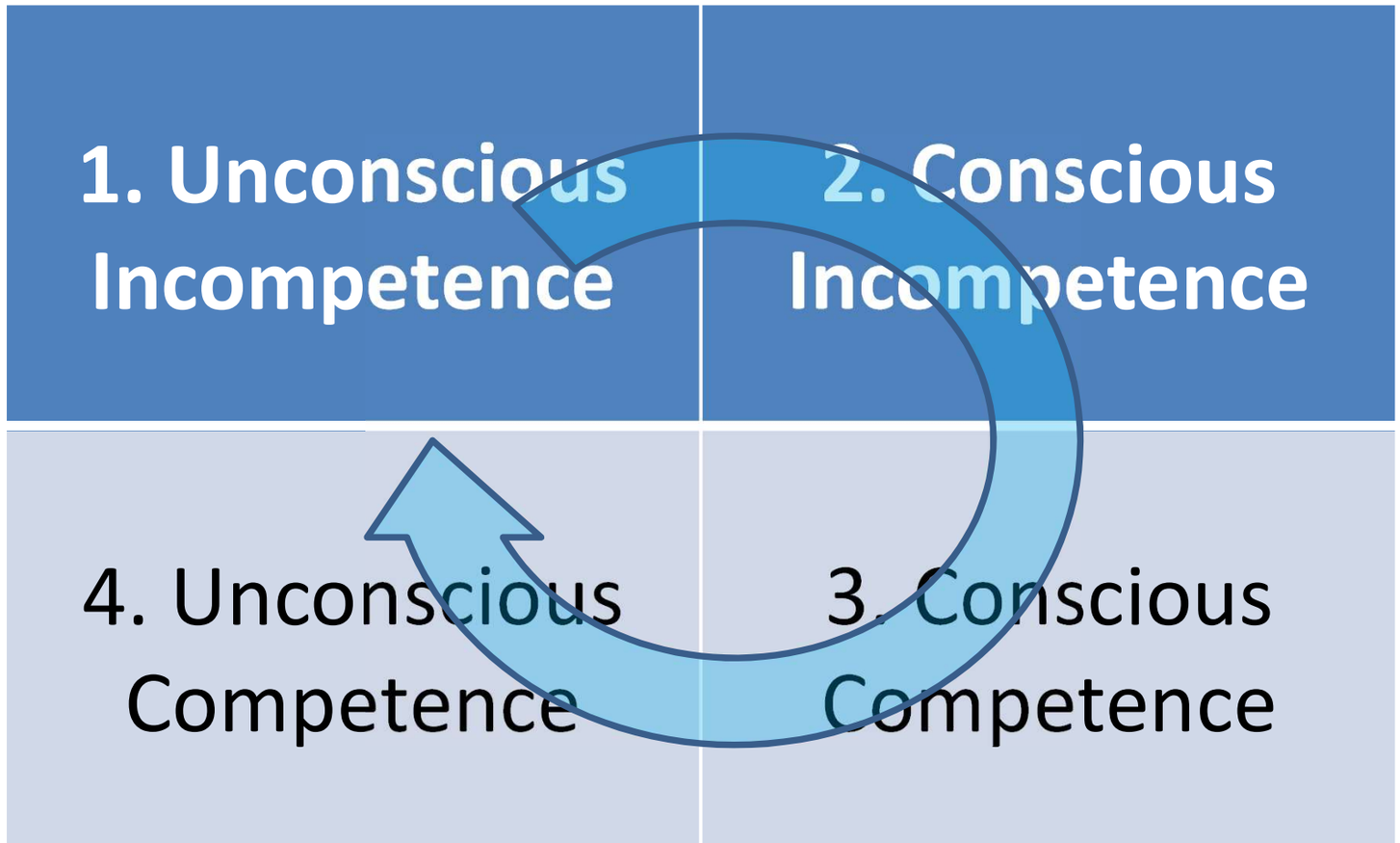
Two Methods



The Fantasy Method

The Zig-Zag Method

The 4 Levels of Competence



An Uncomfortable Exercise

How to Get Better at…

What is the secret of quality VR apps?

✓The secret is that there is no secret

Practice.

Practice.

Practice.

Your First Innovations

Will not be great!

✓In fact it may be painful

Sometimes you win, sometimes you learn. -*John Maxwell*

Becoming a Great VR Creator

Learning to create great VR is no different than anything else in life

There is a learning curve

Becoming great will not happen overnight

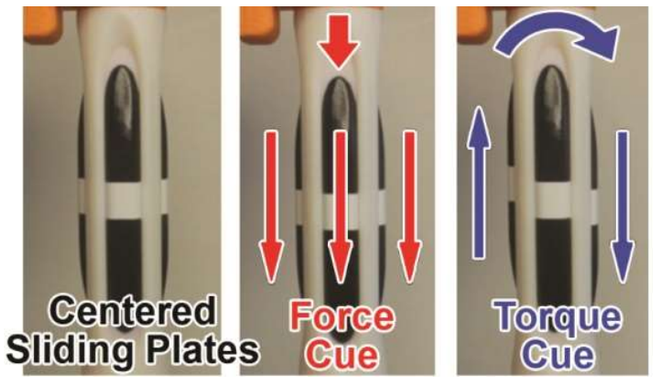
Summary

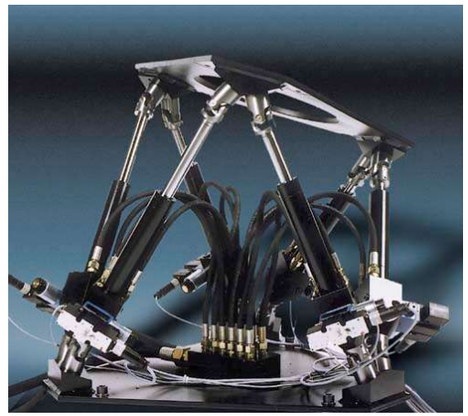
1. Persistence of action

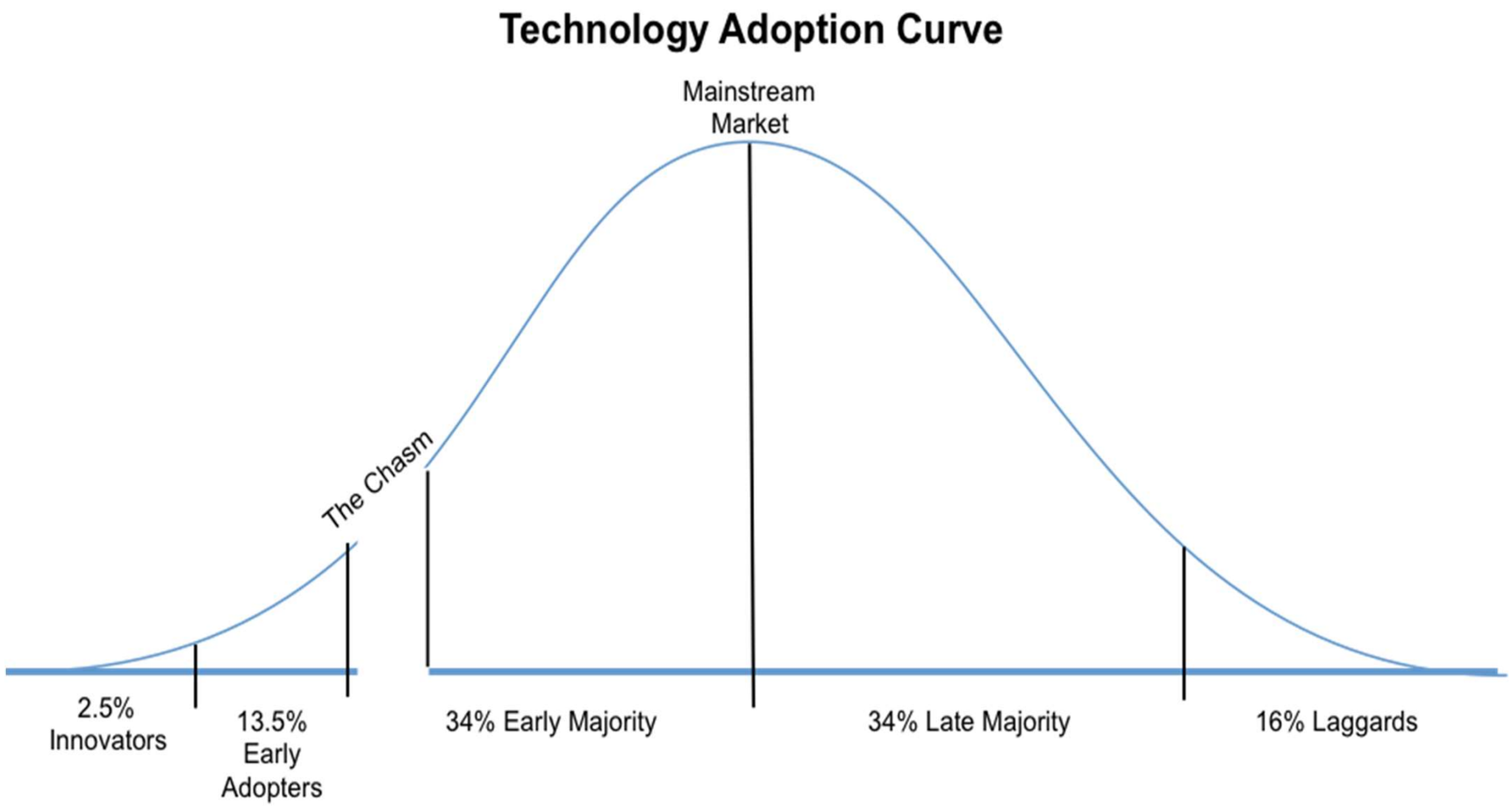
2. Open minded exploration

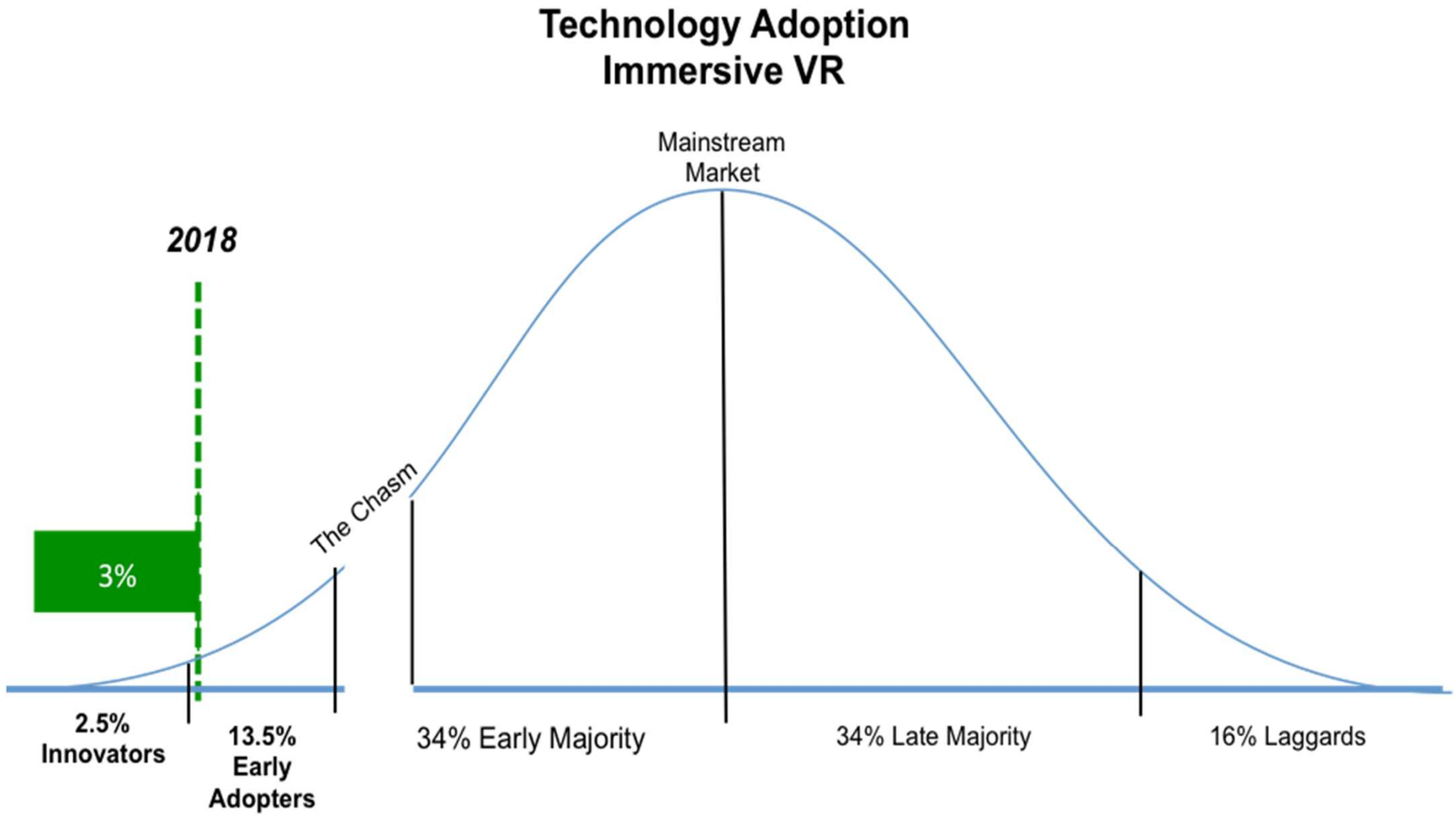
3. Vision is seeing that which does not yet exist

Haptics and Motion Devices






Technology Adoption Curve
Mainstream Market
The Chasm
2.5% Innovators
13.5% Early Adopters
34% Early Majority
34% Late Majority
16% Laggards


Technology Adoption
Immersive VR
Mainstream
Market
2018
The Chasm
3%
2.5%
Innovators
13.5%
Early
Adopters
34% Early Majority
34% Late Majority
16% Laggards

Segmenting Users

User Category	% Distribution	General Attributes
Innovator	2.5%	• Risk Takers • Not afraid of failure • Typically viewed as the “Techie” or “Tinkerer” • Access to afford costlier models • High tolerance to product bugs and often desires to be part of development
Early Adopter	13.5%	• More selective on technology usage • Considered Visionaries and often cited as the group to check in with for input before other peers proceed to buy • Product is more widely available
Early Majority	34%	• Takes time to adopt new technology • “Wait and see” but still willing to adopt when there is a clear fit in the user’s lifestyle • Product is widely available and has undergone several generations of enhancements
Late Majority	34%	• Skeptical and generally adopts new technologies in reaction to peer pressure or general social norms. • Product is overall mature with a clear stickiness in the marketplace
Laggard	16%	• Traditionalists that do not accept change easily • Typically do not have means or desire to spend money on new applications • Product has reached maturity and may be a necessity that prohibits non-adoption

VR Market: A Changing Paradigm

2012
55% of AR/VR-related systems are military based[1]

2017
75% of all AR/VR systems related to entertainment, infotainment, & edutainment[1]

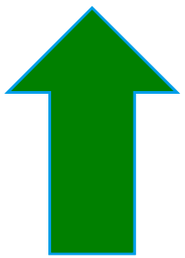
Key Drivers

- Lower cost
- Improved technology
- Mainstream media attention

A paradigm shift resulting in greater competition, innovation, and an educated market

1. Balanced Business Advisors & CyberEdge Information Services, Virtual & Augmented Reality: Nearing Consumer-Driven Inflection Point, 2012

Financial Implications



Revenue

- Visualize before you rent/buy
- Upsell opportunities
- Immersive marketing – no longer limited to showroom
- Increase sales training effectiveness

Expenses

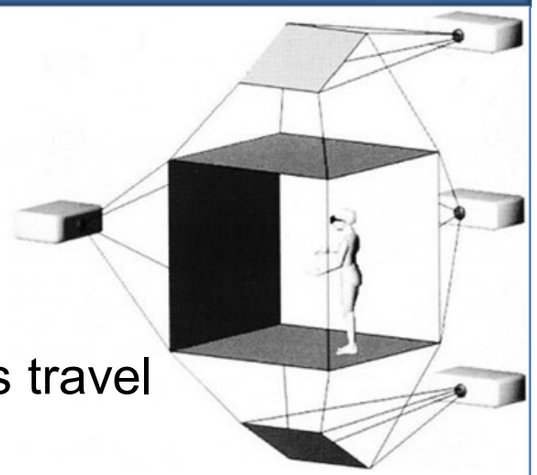
- Avoid costly manufacturing mistakes
- Limit travel
- Lower cost and greater accessibility outside of the lab
- Decrease overhead / inventory needs

Technical Challenges

Fixed-World Displays vs Head-Mounted Displays

Fixed-World Displays

$$$$$



Truck

Requires travel

Group settings

Less sim sickness

- Less swimming
- Real-world cues

Head-Mounted Displays

$

Suitcase

On the go

Isolating / fully immersive

More sim sickness

- Technical
- Perceptual

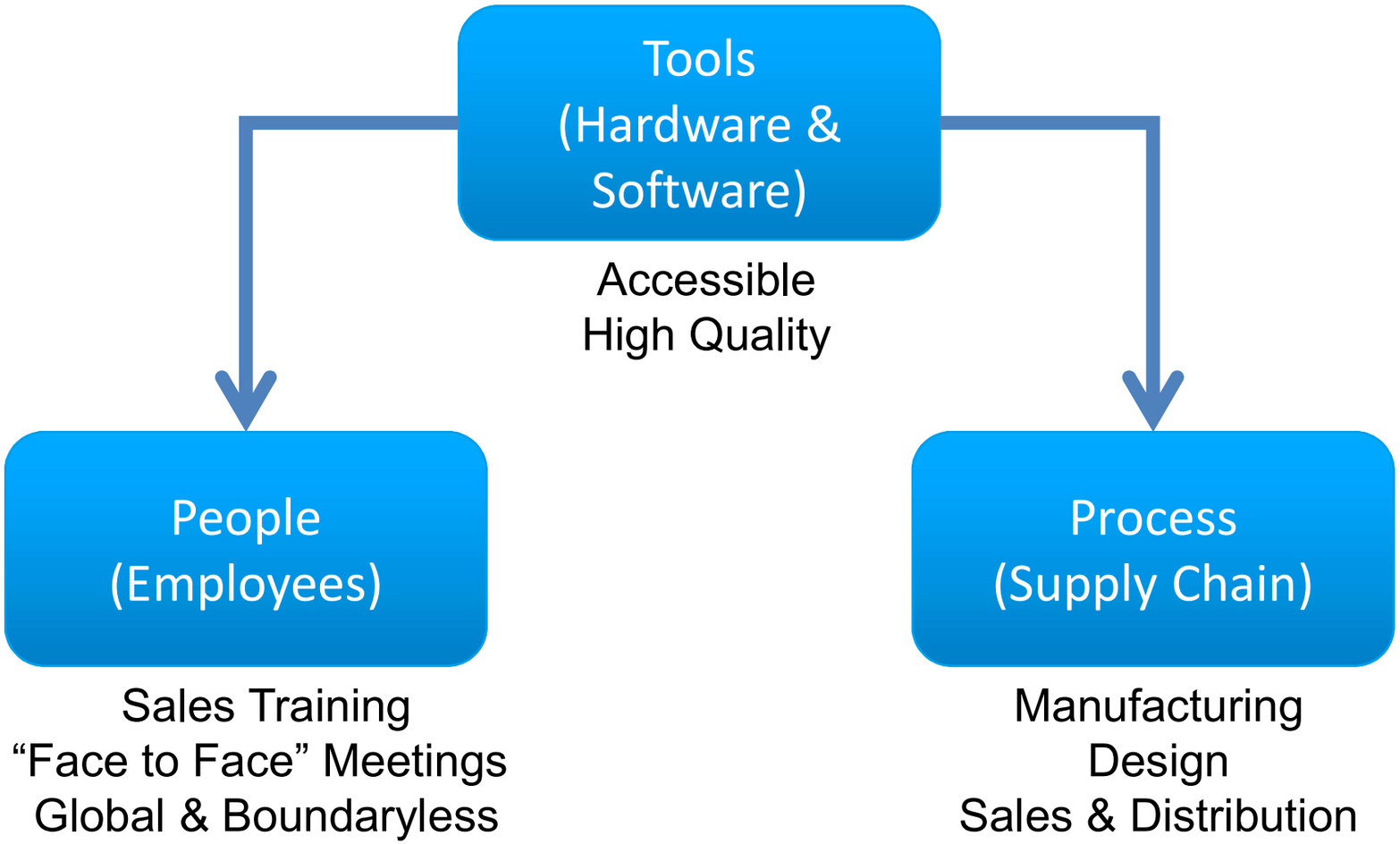
Content and Interaction

Content is largely independent of display
- Static data & models
- Animations, simulations, & behaviors

Interaction sometimes independent of display
- The display is not perceived in an HMD
- Interactions in display space are specific to the display

VR content quality is now expected to be high quality

Operational Implications



Conclusion

The AR/VR industry is dramatically changing

Accessible anywhere

Significant financial benefits

Enhanced operational capabilities

Competition will create innovation