VR Technology

Lecture 3

RVAU - Realidade Virtual e Aumentada - EIC0070

2019/2020 - 1S

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(adaptado de slides Rui Nóbrega, A. Augusto Sousa)

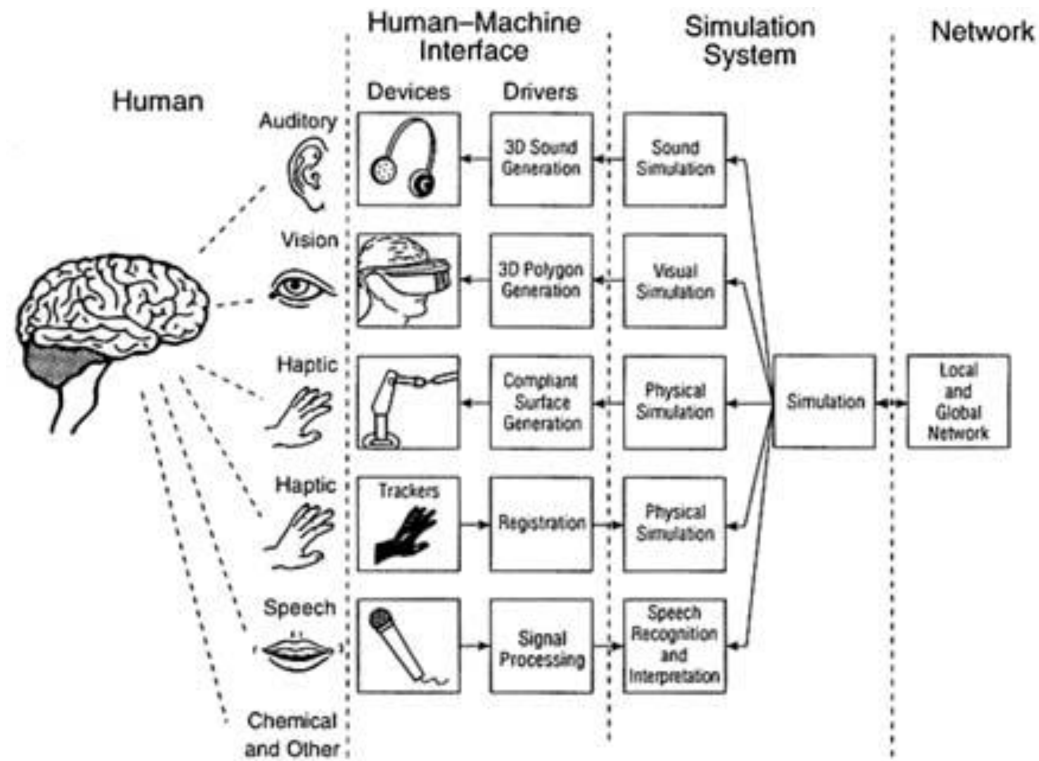
Overview

- VR Technology
- VR Interaction
- VR Rendering

VR Technology

Using Technology to Stimulate Senses

- Simulate output
  - E.g. simulate real scene
- Map output to devices
  - Graphics to HMD
- Use devices to stimulate the senses
  - HMD stimulates eyes



Example: Visual Simulation

Visual Simulation → **3D Graphics** → **HMD** → **Vision System** → **Brain**

$\underbrace{\text{HMD} \rightarrow \text{Vision System}}_{\text{Human-Machine Interface}}$

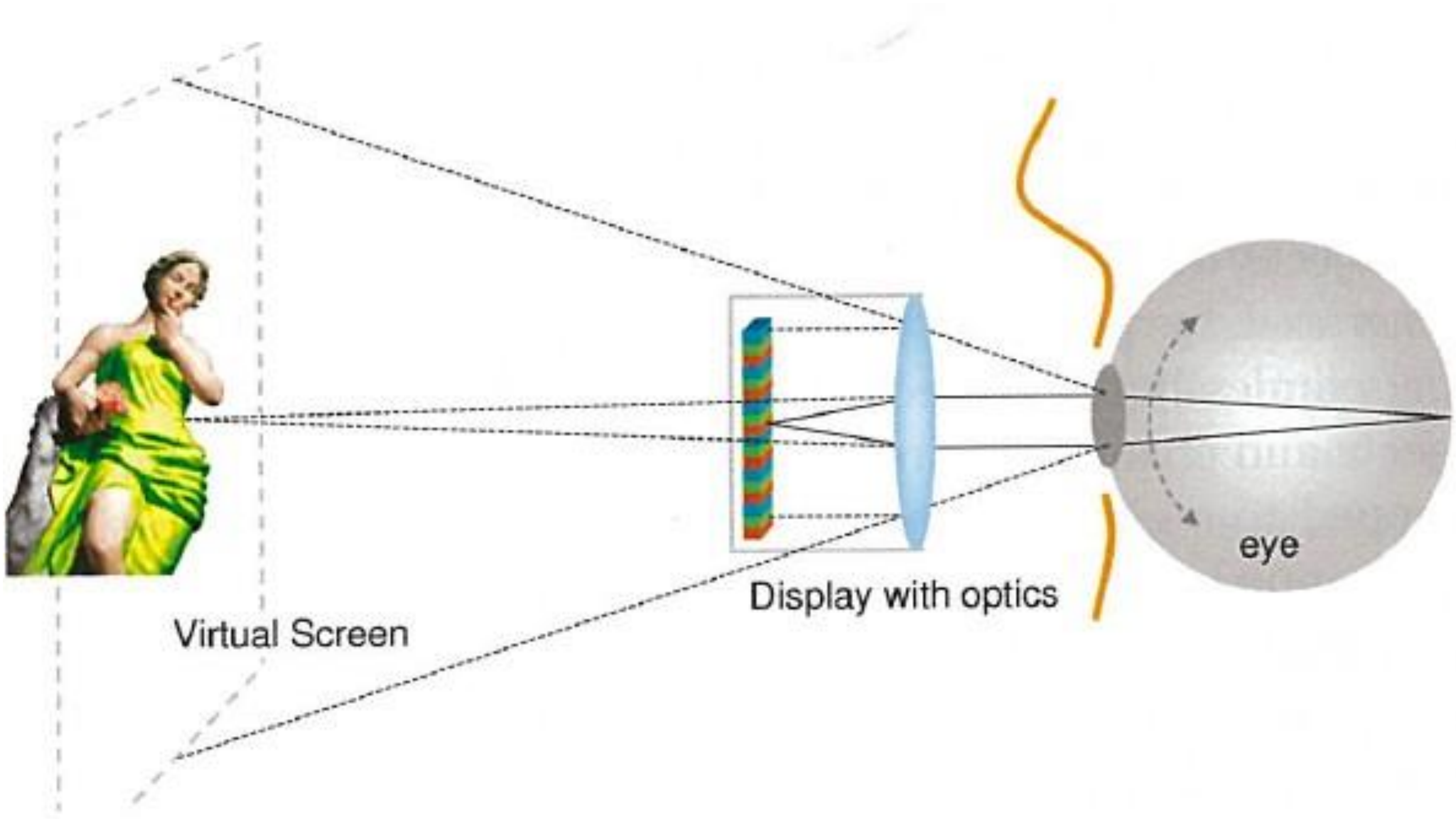
Key Technologies for VR System

- Visual Display
  - Stimulate visual sense
- Audio/Tactile Display
  - Stimulate hearing/touch
- Tracking
  - Changing viewpoint
  - User input
- Input Devices
  - Supporting user interaction

VISUAL DISPLAY

- Head Mounted Display
  - Immerse the eyes
- Projection/Large Screen
  - Immerse the head/body
- Future Technologies?
  - Neural implants
  - Contact lens displays
  - Etc…

HMD Basic Principles



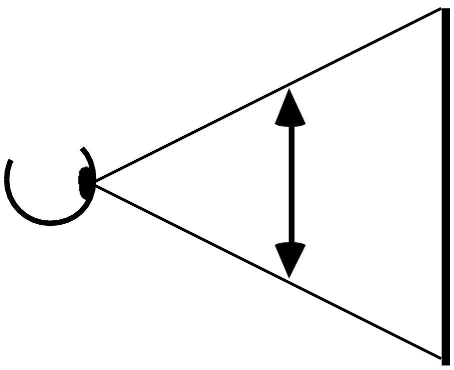
- Use display with optics to create illusion of virtual screen

Key Properties of HMDs

- Lens
  - Field of View
  - Ocularity (mono/stereo)
  - Interpupillary distance, Focal length
  - Eye relief, Eye box
- Display
  - Resolution, contrast
  - Brightness
  - Refresh rate
- Ergonomics
  - Size, weight
  - Wearability

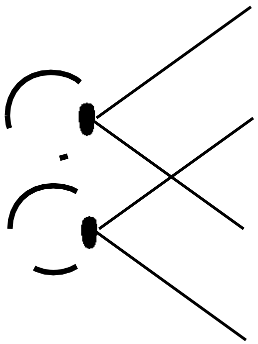
Field of View

Monocular FOV is the angular subtense (usually expressed in degrees) of the displayed image as measured from the pupil of one eye.



Total FOV is the total angular size of the displayed image visible to both eyes.

Binocular(or stereoscopic) FOV refers to the part of the displayed image visible to both eyes.

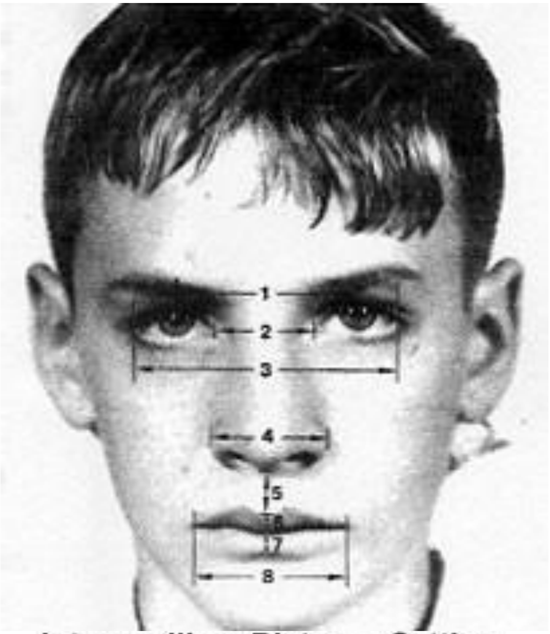


FOV may be measured horizontally, vertically or diagonally.

Ocularity

- **Monocular** - HMD image to only one eye.
- **Bioccular** - Same HMD image to both eyes.
- **Binocular (stereoscopic)** - Different but matched images to each eye.

Interpupillary Distance (IPD)



Interpupillary Distance Setting

Figure 5

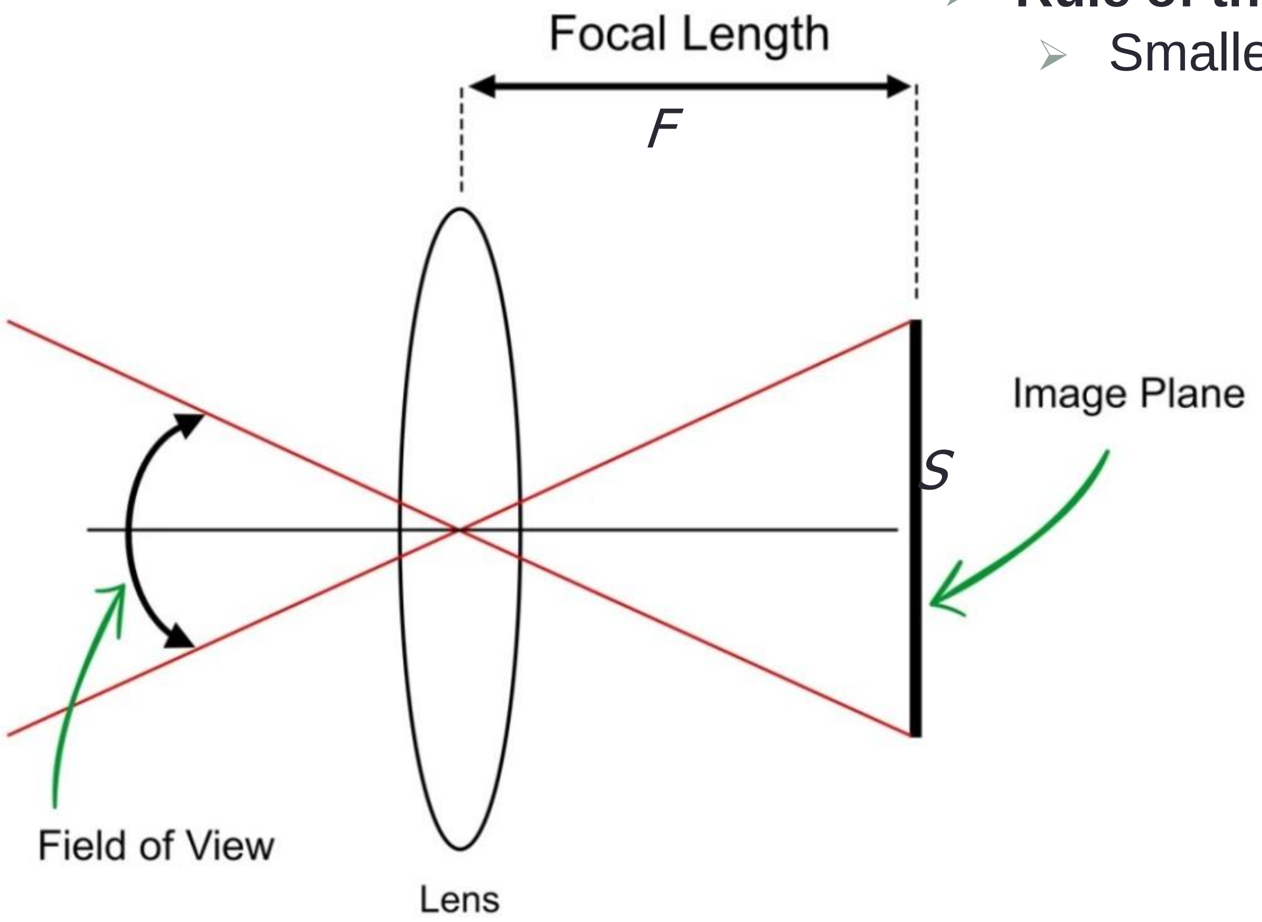
- IPD is the horizontal distance between a user's eyes.

- IPD is the distance between the two optical axes in a binocular view system.

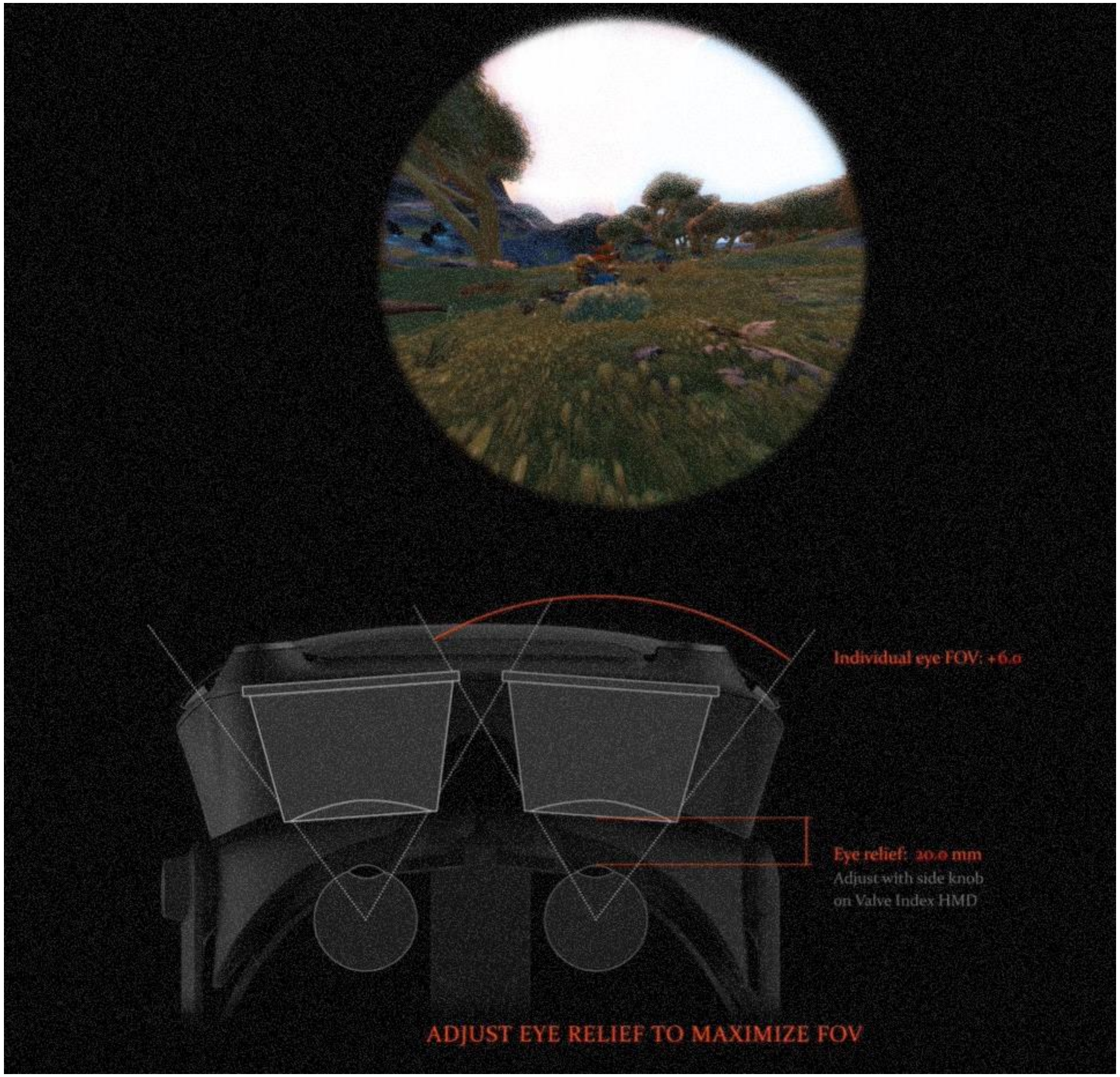
- **HMD is adjustable?**
  - Rift S IPD = 64mm

Focal Length

- FOV = *2*atan(S / (2*F))*
- **Rule of thumb:**
  - Smaller F = Bigger FOV



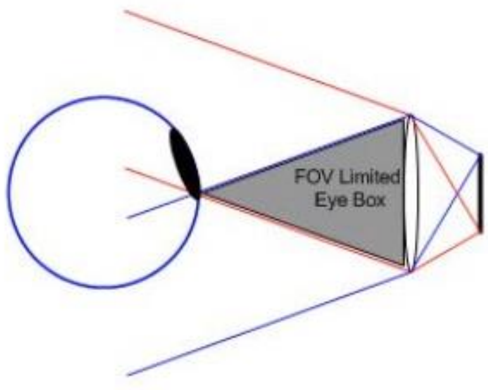
Eye Relief and FOV



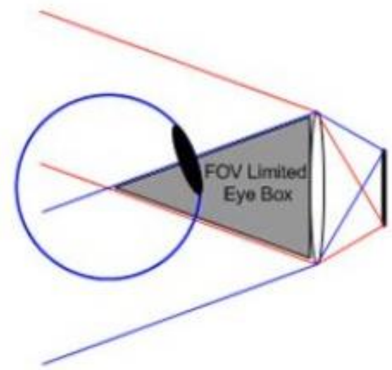
- Defines the **distance** at which the user can obtain **full viewing angles**.
- An **important consideration** especially for **people** who **wear corrective lenses** or glasses.

https://www.valvesoftware.com/en/index/deep-dive/fov

Eye Box and FOV

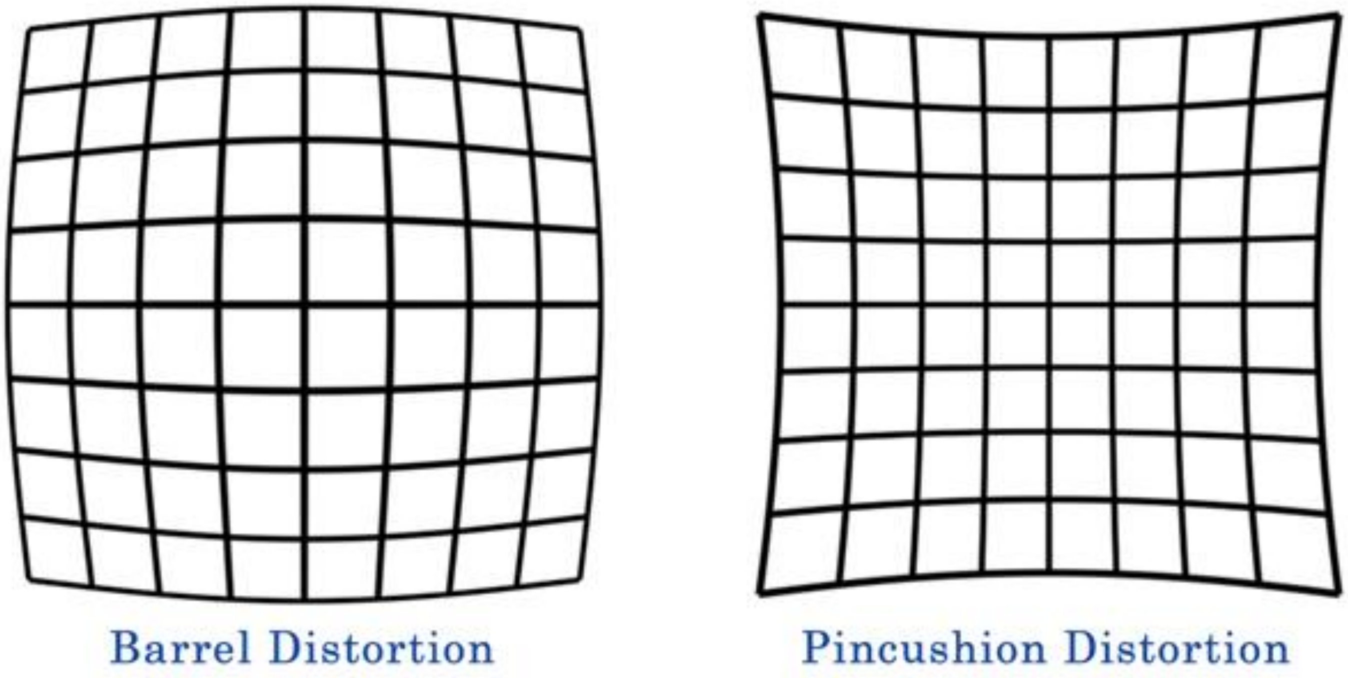


Pupil placed at ER resulting in vignetting of off axis field angles (lose FOV at edges)



Eye point of rotation placed at ER resulting in reduced clearance between user's eye and the HMD, but vignetting minimized

Distortion in Lens Optics

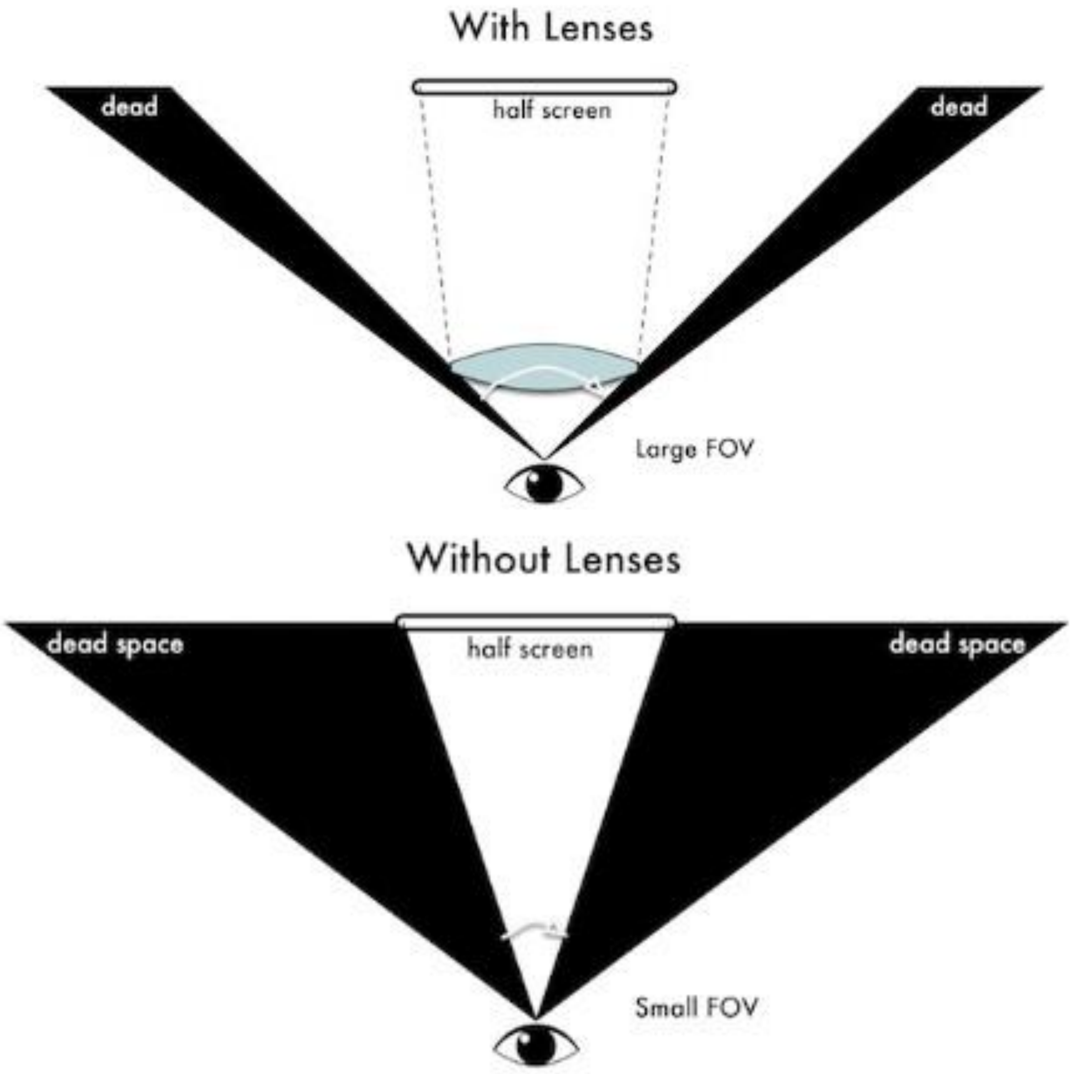


Why do we have these distortions?

Distortion in Lens Optics

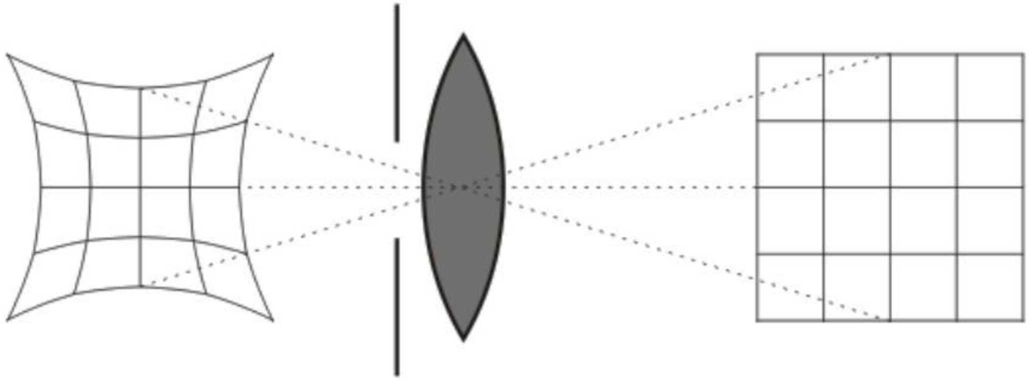
Why do we need lenses at all?

Distortion in Lens Optics

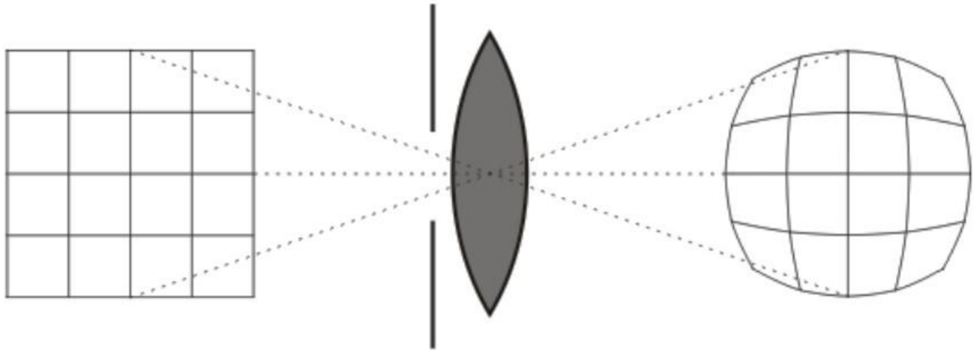


Example Distortion

Pincushion is caused by lenses:

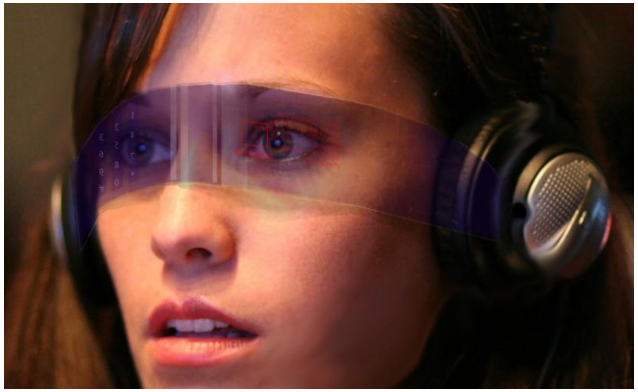


Barrel Distortion to counter lens distortion:



- Must pre-distort image
- This is a pixel-based distortion
- Use shader programming

HMD Design Trade-offs

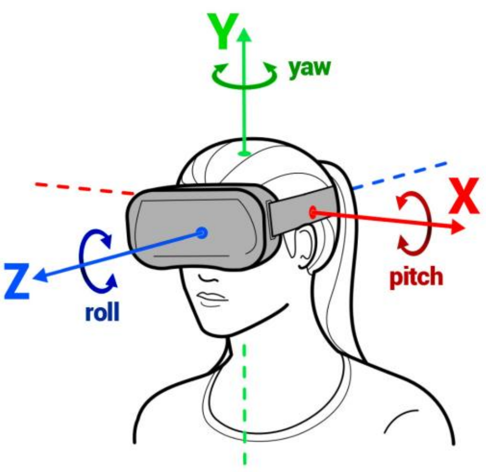


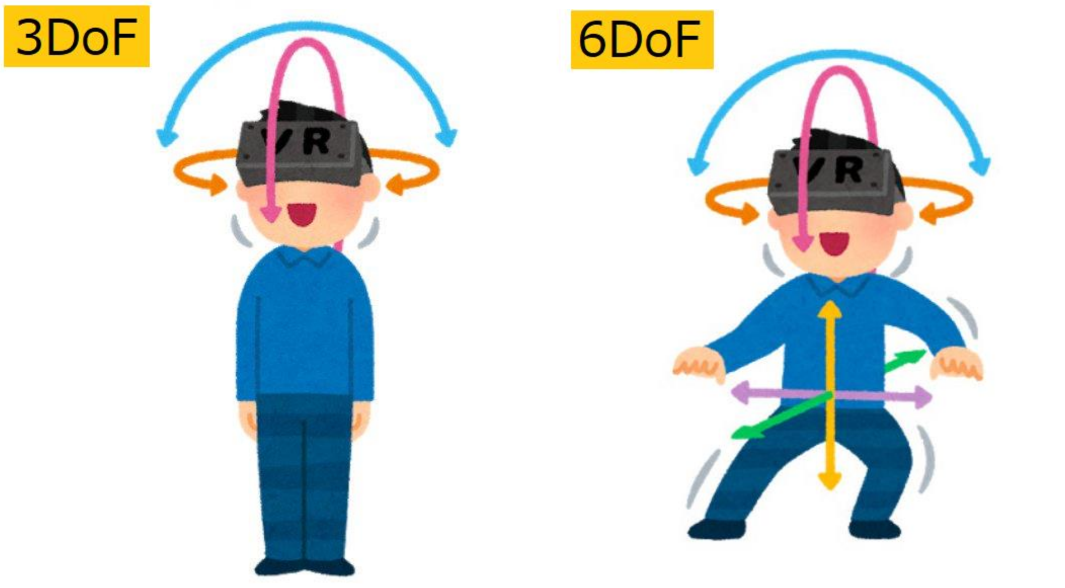
vs.

- Resolution vs. field of view
  - As FOV increases, resolution decreases for fixed pixels
- Eye box vs. field of view
  - Larger eye box limits field of view
- Size, Weight and Power vs. everything else

Oculus Rift CV1

- FOV: 110^{o} Horizontal
- Refresh rate: 90 Hz
- Resolution 1080x1200/eye
- 6 DoF tracking





Inside an Oculus Rift DK2

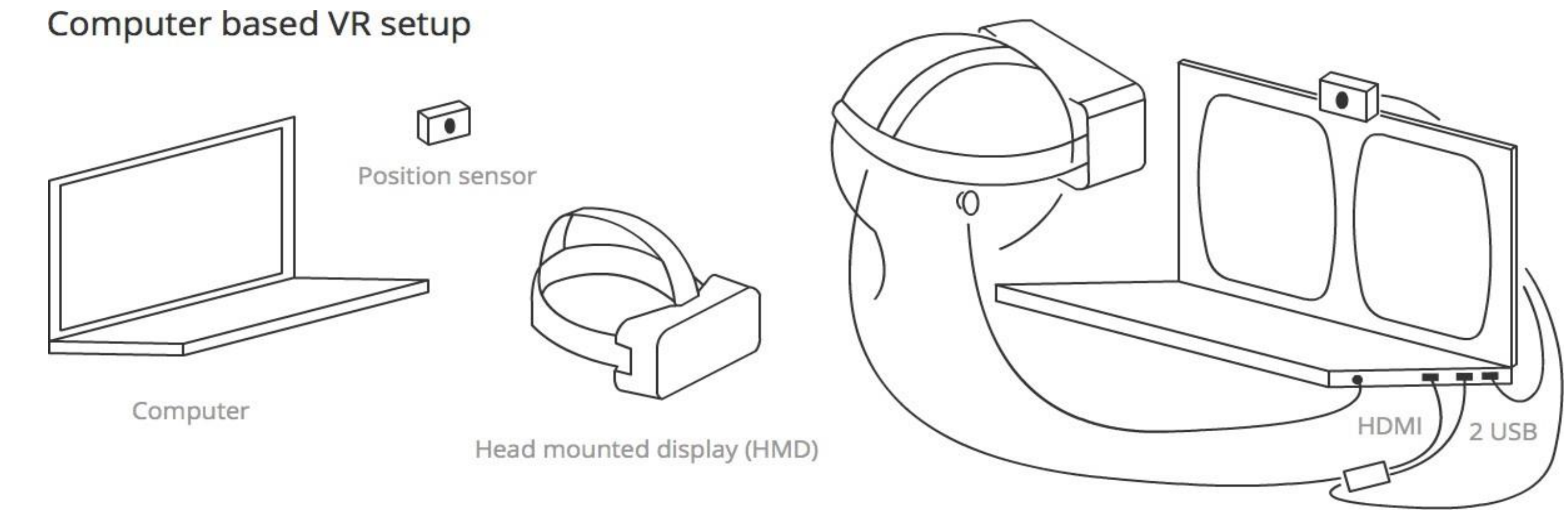
Oculus DK2 Teardown

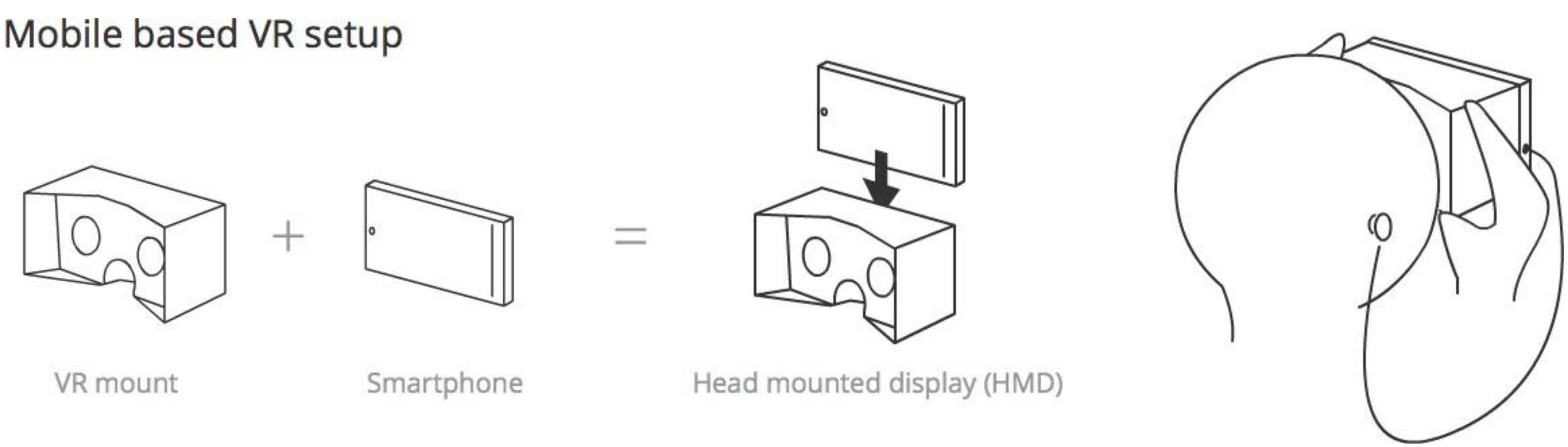
- Samsung 5.7" AMOLED: 1920x1080px, 75Hz
- 2 sets of lenses (for different prescriptions)
- InvenSense 6-axis IMU
- ARM Cortex-M3 MCU
- …

https://youtu.be/-HoHkFgslJc

https://www.ifixit.com/Teardown/Oculus+Rift+Development+Kit+2+Teardown/27613

Computer Based vs. Mobile VR Displays

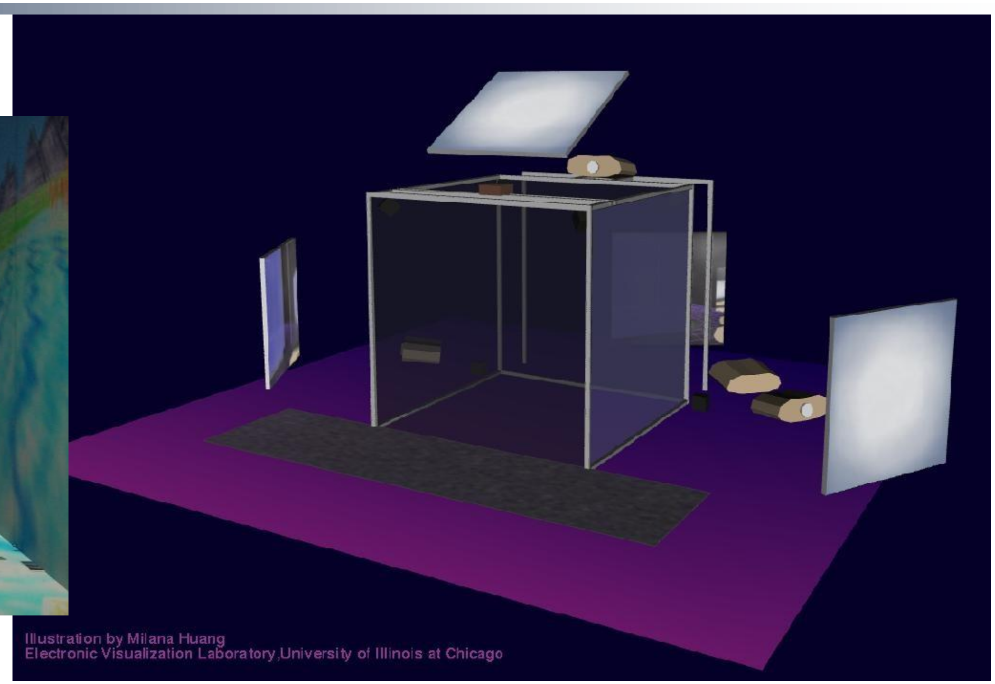




Projection/Large Display Technologies

- Room Scale Projection
  - CAVE, multi-wall environment
- Dome projection
  - Hemisphere/spherical display
  - Head/body inside
- Vehicle Simulator
  - Simulated visual display in windows

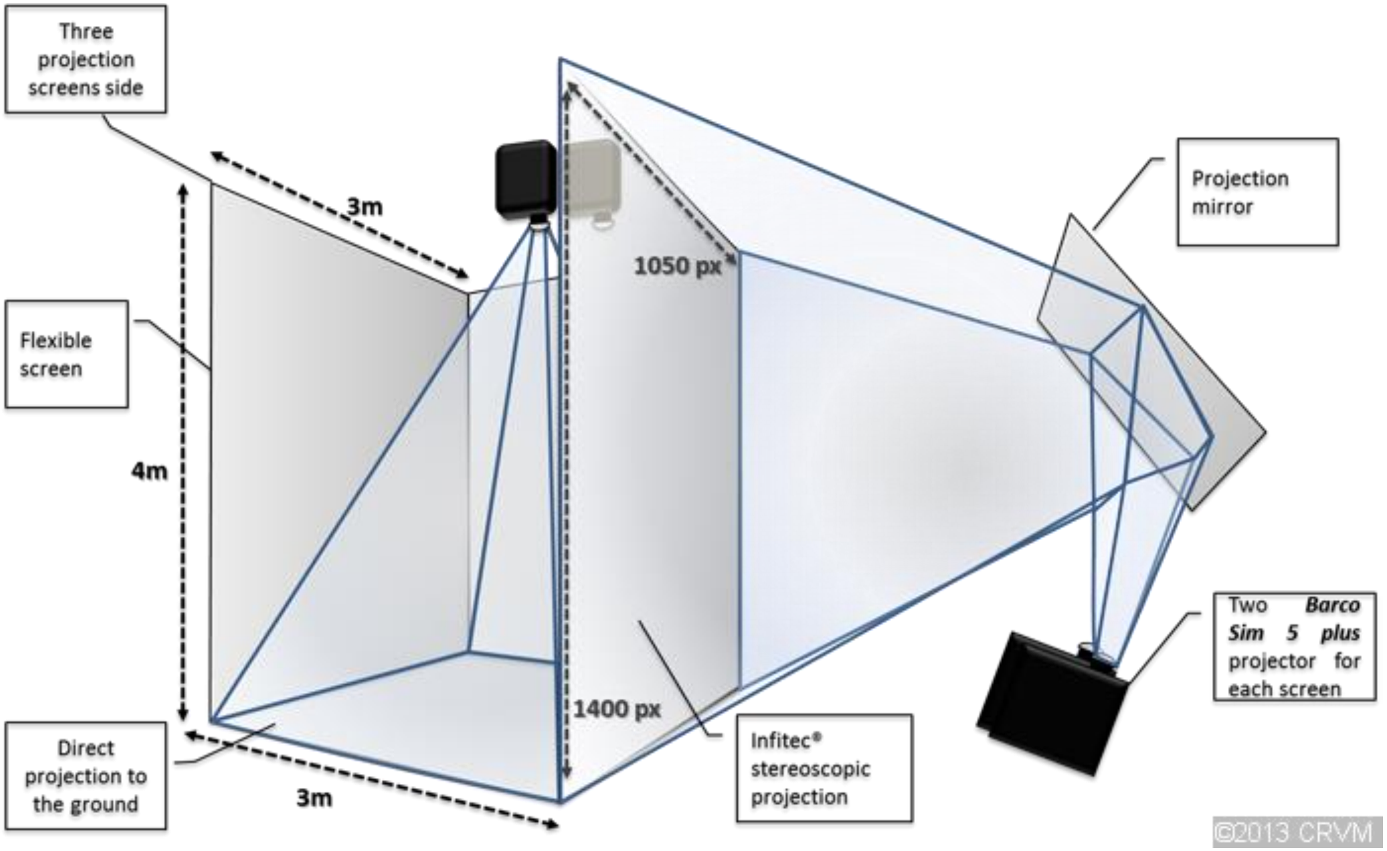
CAVE



- Developed in 1992, EVL University of Illinois Chicago
- Multi-walled stereo projection environment
  - Head tracked active stereo

Cruz-Neira, C., Sandin, D. J., DeFanti, T. A., Kenyon, R. V., & Hart, J. C. (1992). The CAVE: audio visual experience automatic virtual environment. *Communications of the ACM*, *35*(6), 64-73.

Typical CAVE Setup

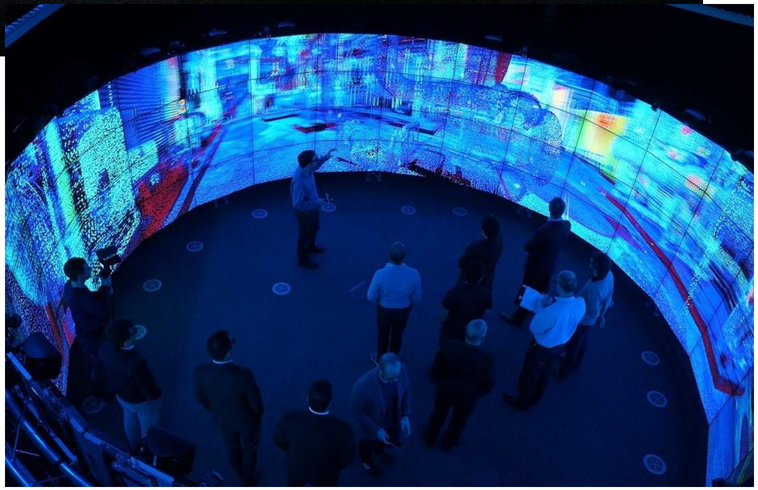


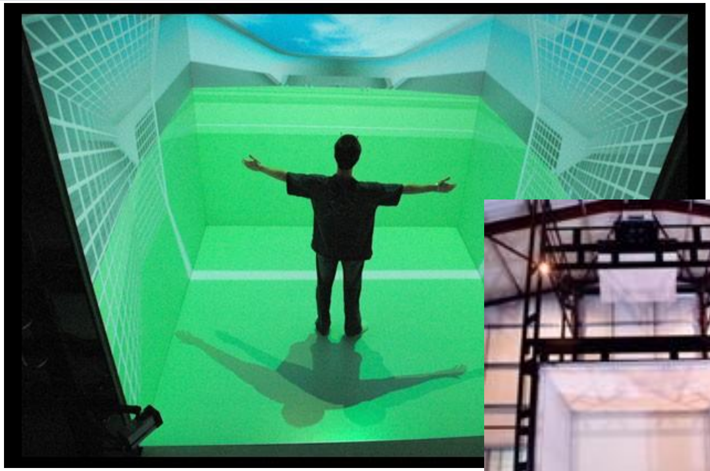
- 4 sides, rear projected stereo images

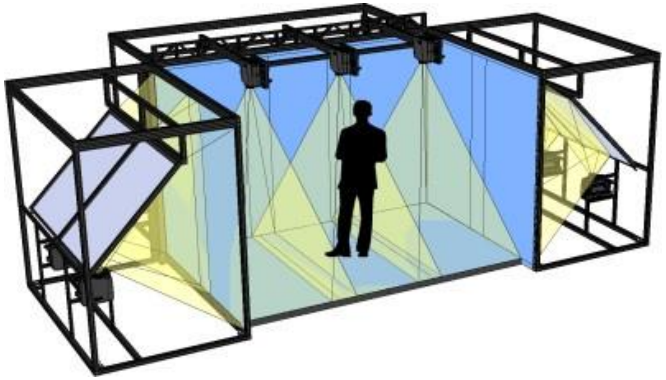
Demo Video –CAVE

- https://www.youtube.com/watch?v=mBs-OGDoPDY

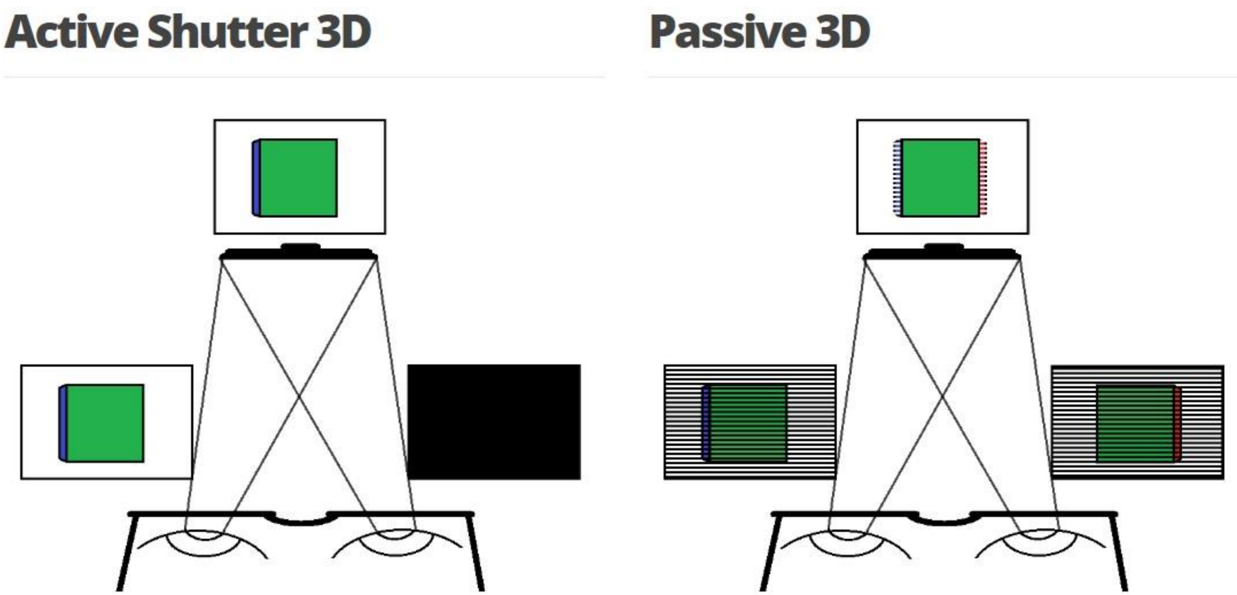
CAVE Variations







Stereo Projection



- Active Stereo
  - Active shutter glasses
  - Time synced signal
  - Brighter images
  - Higher resolution
  - Can cause flickering
  - More expensive
- Passive Stereo
  - Polarized images
  - Two projectors (one/eye)
  - Cheap glasses (powerless)
  - More comfortable?
  - Lower resolution/dimmer
  - Less expensive

https://www.youtube.com/watch?v=b3TeUb1q2MM&feature=youtu.be&t=9

Vehicle Simulators

- Combine VR displays with vehicle
  - Visual displays on windows
  - Motion base for haptic feedback
  - Audio feedback
- Physical vehicle controls
  - Steering wheel, flight stick, etc
- Full vehicle simulation
  - Emergencies, normal operation, etc
  - Weapon operation
  - Training scenarios

Demo: Boeing 787 Simulator

- https://www.youtube.com/watch?v=3iah-blsw_U

HAPTIC/TACTILE DISPLAYS

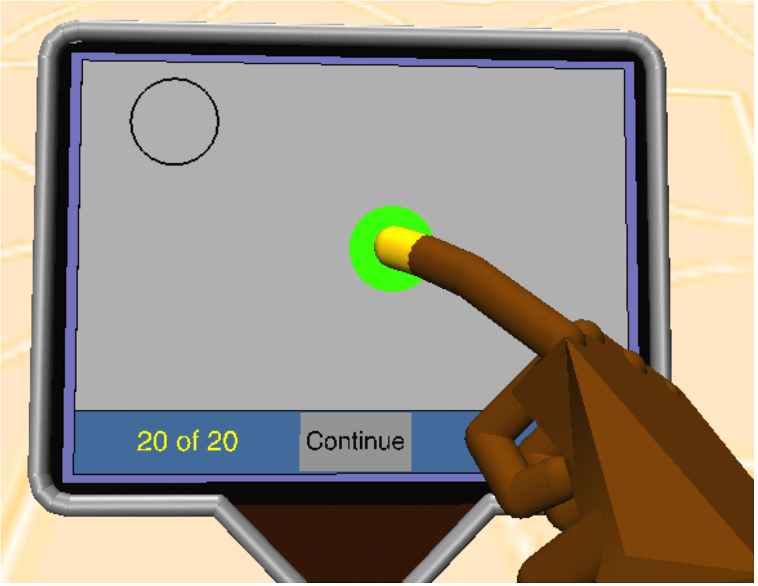
Haptic Feedback

- Greatly improves realism
- Hands are the most important recepts
  - High density of touch receptors
- Two kinds of feedback:
  - Touch Feedback
    - Information on texture, temperature, etc.
    - Does not resist user contact
  - Force Feedback
    - Information on weight, and inertia.
    - Actively resists contact motion

Passive Haptics

- Not controlled by system
  - Use real props
- Pros
  - Cheap
  - Large scale
  - Accurate
- Cons
  - Not dynamic
  - Limited use

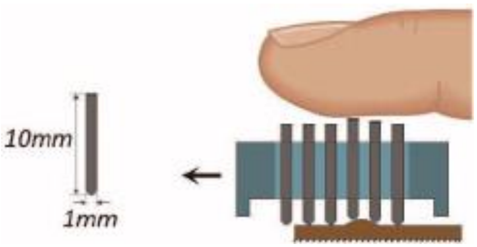
Passive Haptic Paddle



- Using physical props to provide haptic feedback

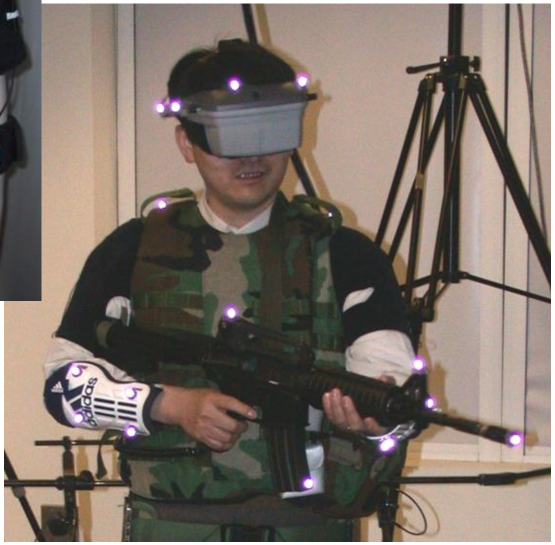
Tactile Feedback Interfaces

- Goal: Stimulate skin tactile receptors
- Using different technologies
  - Air bellows
  - Actuators (commercial)
  - Micro pin arrays
  - Neuromuscular electrical stimulation (research...)



Vibrotactile Feedback Projects

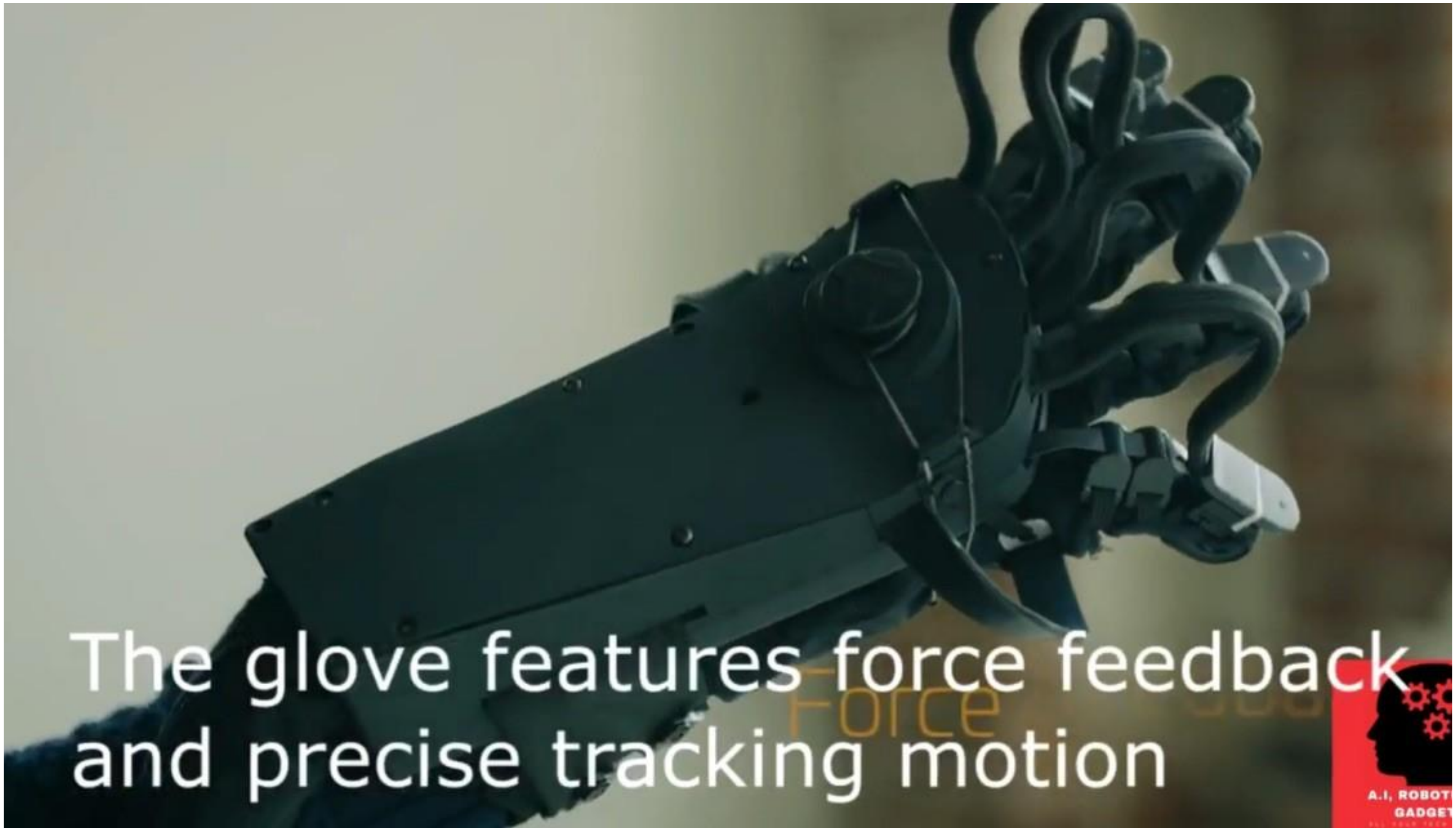
TactaBoard and
TactaVest



Navy TSAS
Project

<u>The most common tactile feedback</u>

Example: HaptX Glove



- https://www.youtube.com/watch?v=4K-MLVqD1_A

AUDIO DISPLAYS

Audio Displays

- Spatialization vs. Localization
- *Spatialization* is the processing of sound signals to make them emanate from a point in space
  - This is a *technical* topic
- *Localization* is the ability of people to identify the source position of a sound
  - This is a *human* topic, i.e., some people are better at it than others.

Audio Display Properties

Presentation Properties

- Number of channels
- Sound stage
    - Stage properties? Integration with channels?
- Localization
    - How the listener identifies the sound location?
- Masking
    - How a sound affects another?
- Amplification

Logistical Properties

- Noise pollution
- User mobility
- Interface with tracking
- Integration with the setup
- Portability
- Safety
- Cost

Audio Displays: Head-worn

Ear Buds

On Ear

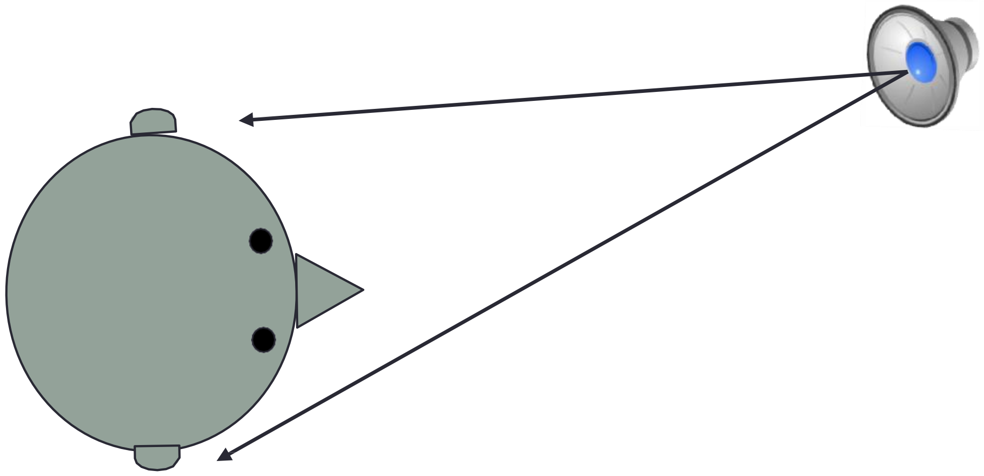
Open Back

Closed

Bone Conduction

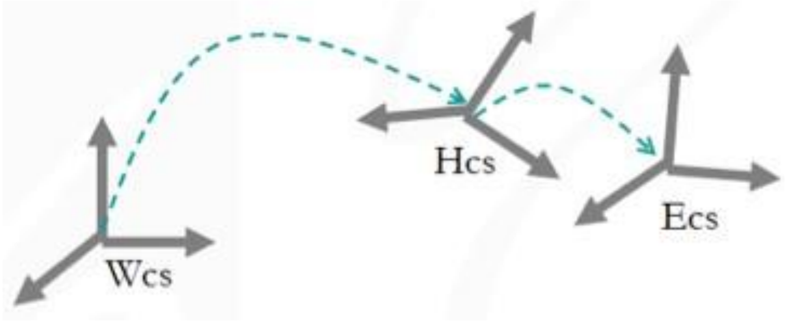
Head-Related Transfer Functions

- A.k.a. HRTFs
- A set of functions that model how sound from a source at a known location reaches the eardrum



TRACKING

Tracking in Virtual Reality



- Registration
  - Positioning virtual object with real/virtual objects
- Tracking
  - Continually locating the users viewpoint/input
    - Position (x,y,z), Orientation (r,p,y)

Mechanical Tracker

- Idea: mechanical arms with joint sensors

Microscribe

Sutherland

- ++: high accuracy, haptic feedback
- -- : cumbersome, expensive

Magnetic Tracker

- Idea: difference between a magnetic transmitter and a receiver

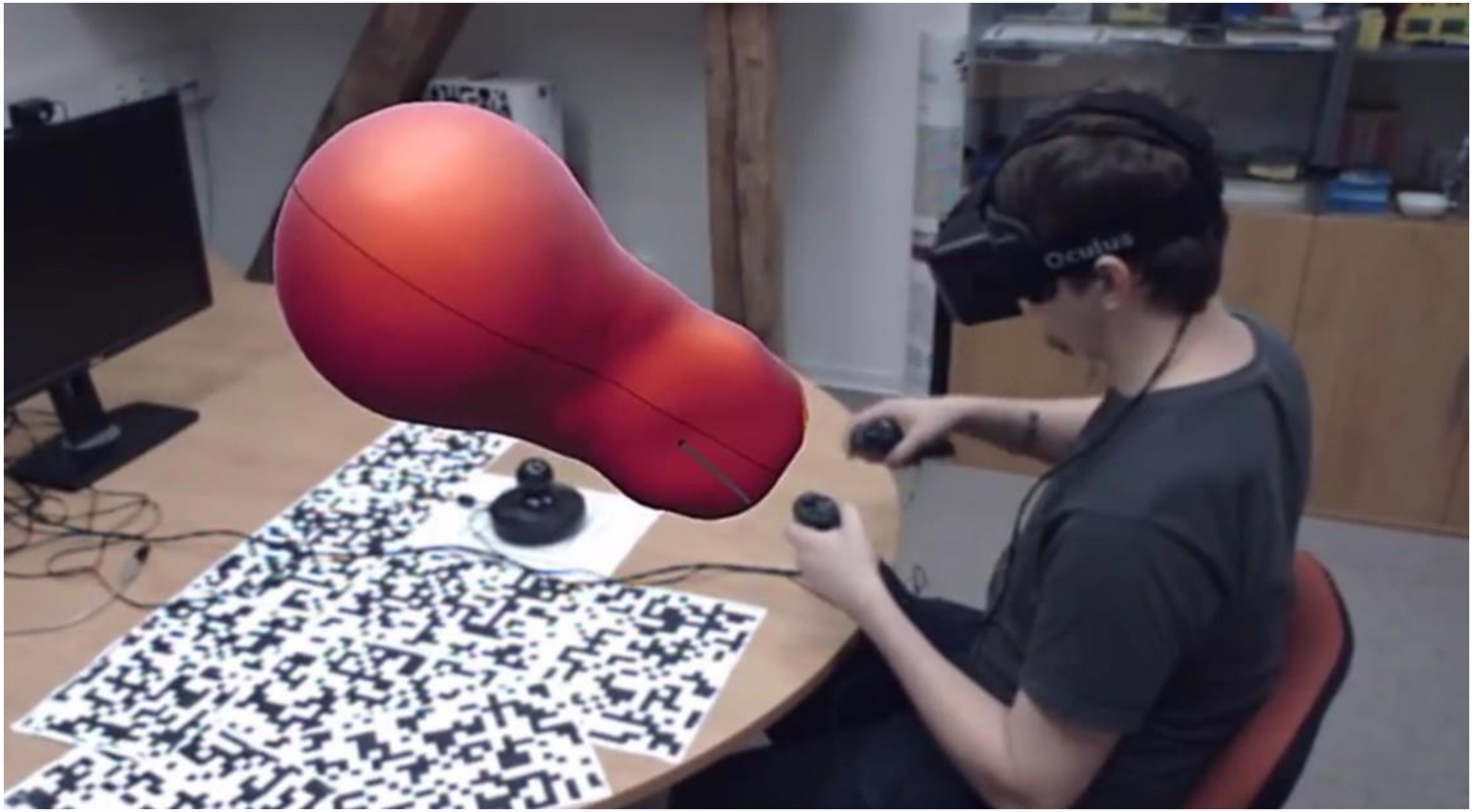
Flock of Birds (Ascension)

- ++: 6DoF, robust
- -- : wired, sensible to metal, noisy, expensive
- -- : error increases with distance

Example: Razer Hydra

- Developed by Sixense
- Magnetic source + 2 wired controllers
  - Short range (1-2 m)
  - Precision of 1mm and 1^{o}
- $600 USD

Razor Hydra Demo

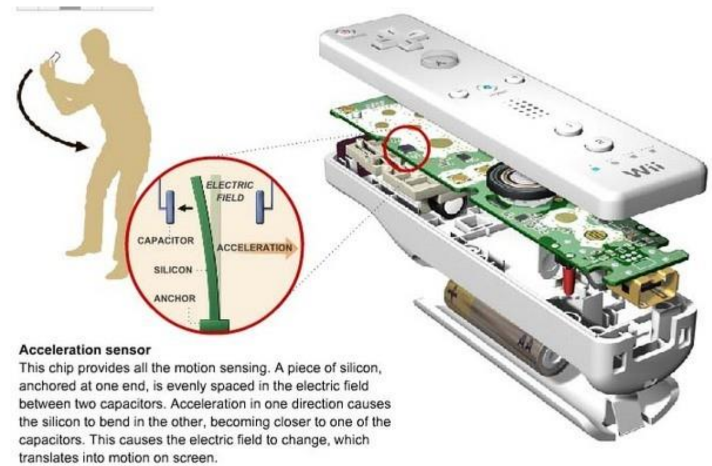


- https://youtu.be/jnqFdSa5p7w?t=34

Inertial Tracker

- Idea: measuring linear and angular orientation rates (accelerometer/gyroscope)

IS300 (Intersense)



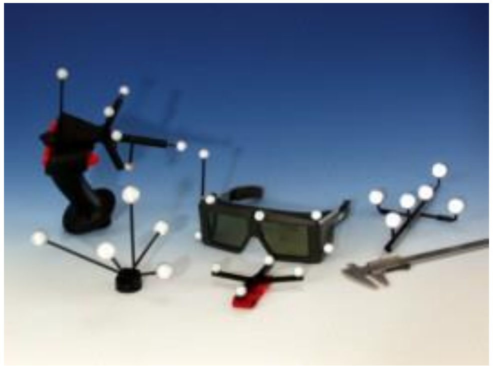
Wii Remote

- ++: no transmitter, cheap, small, high frequency, wireless
- -- : can drift, only 3DoF

Optical Tracker

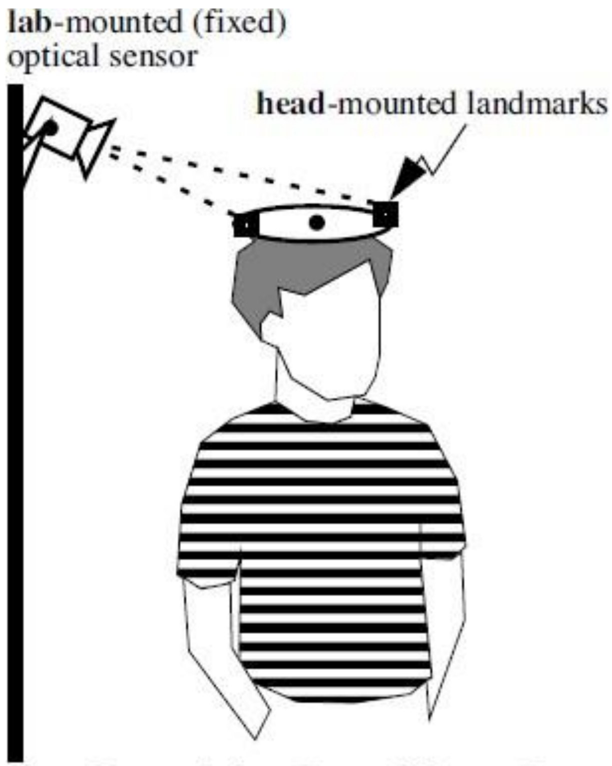
- Idea: Image Processing and Computer Vision
- Specialized: Infrared, Retro-Reflective components

ART

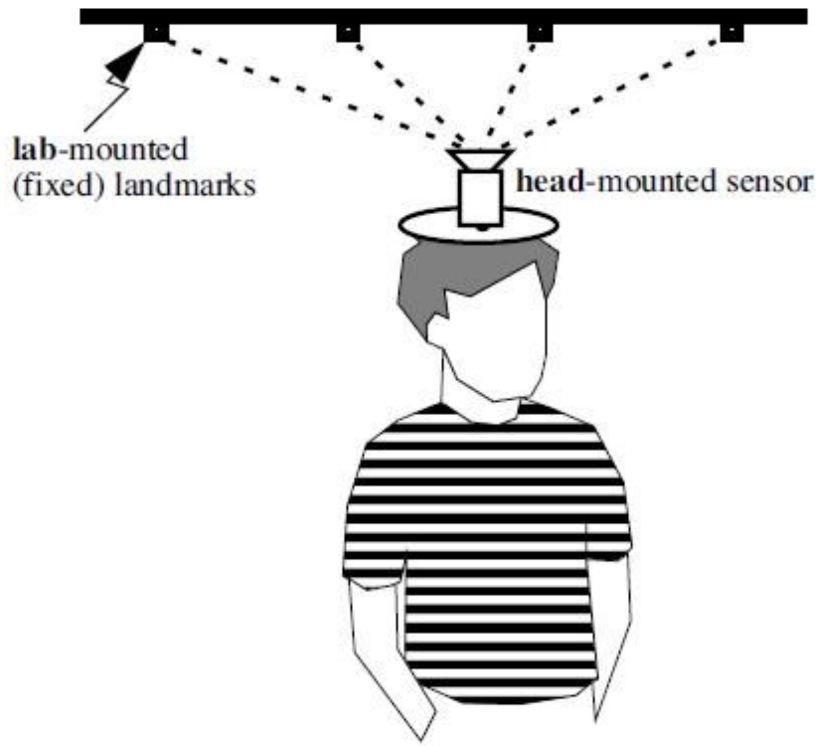


Hi-Ball

Outside-In vs. Inside-Out Tracking



Outside-Looking-In

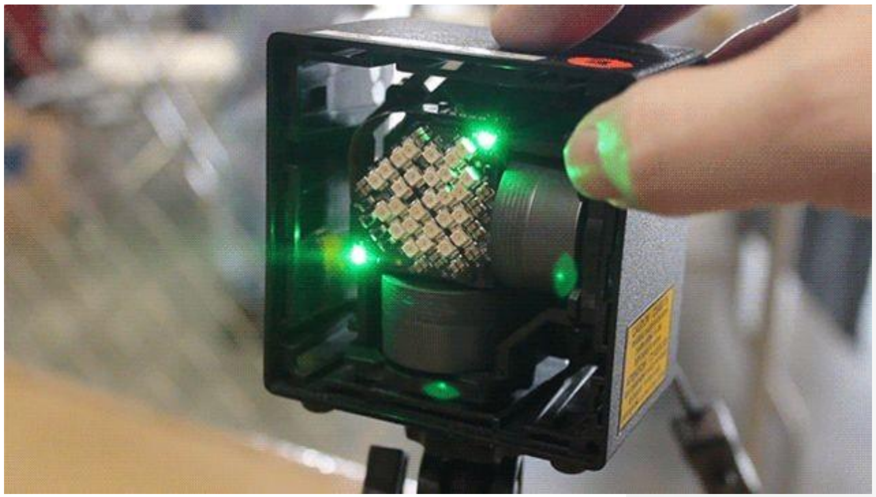


Inside-Looking-Out

- (HTC Vive)

- In the Microsoft Mixed Reality headsets the landmarks are image features

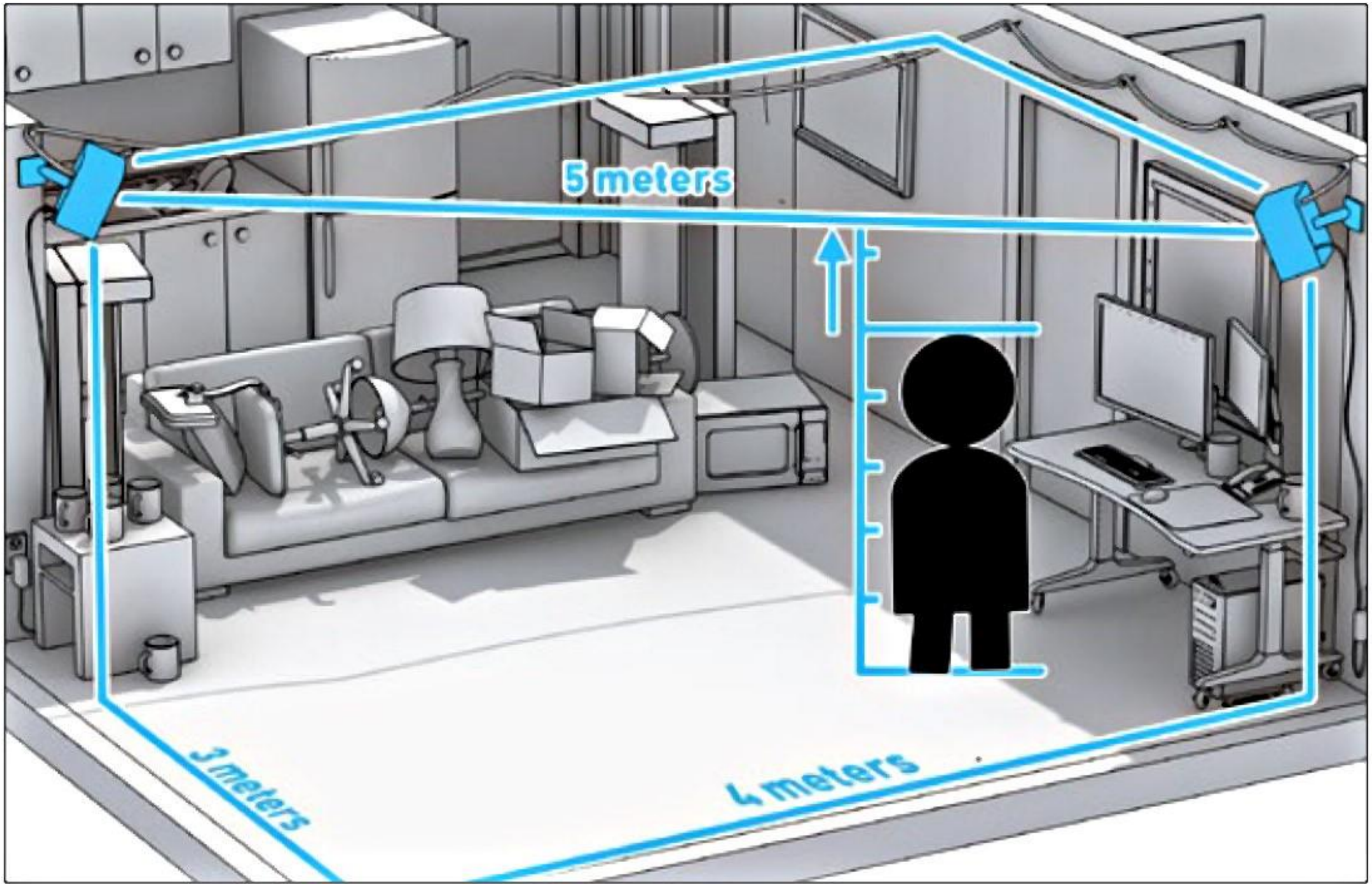
Vive Lighthouse Components



Base station
-IR LED array
-2 x scan lasers
-Sampling rate 250 Hz, 4 ms latency

Head Mounted Display
- 37 photo sensors
- 9 axis of inertial measurement

Lighthouse Setup



Lighthouse Tracking

Base station scanning

Room tracking

https://www.youtube.com/watch?v=avBt_P0wg_Y
https://www.youtube.com/watch?v=oqPaaMR4kY4

Example: Windows Mixed Reality

- Inside-out tracking
- Two cameras on HMD
  - Low res Black and White
  - Combined with Inertial Measurement data
- Uses environment mapping
  - Tracking from visual features

https://www.youtube.com/watch?v=67yLuiSfMWM

Example: Oculus Rift Quest

- Inside-out Positional Tracking
- Uses environment mapping
  - Tracking from visual features

https://www.youtube.com/watch?v=2jY3B_F3GZk

VR Interaction

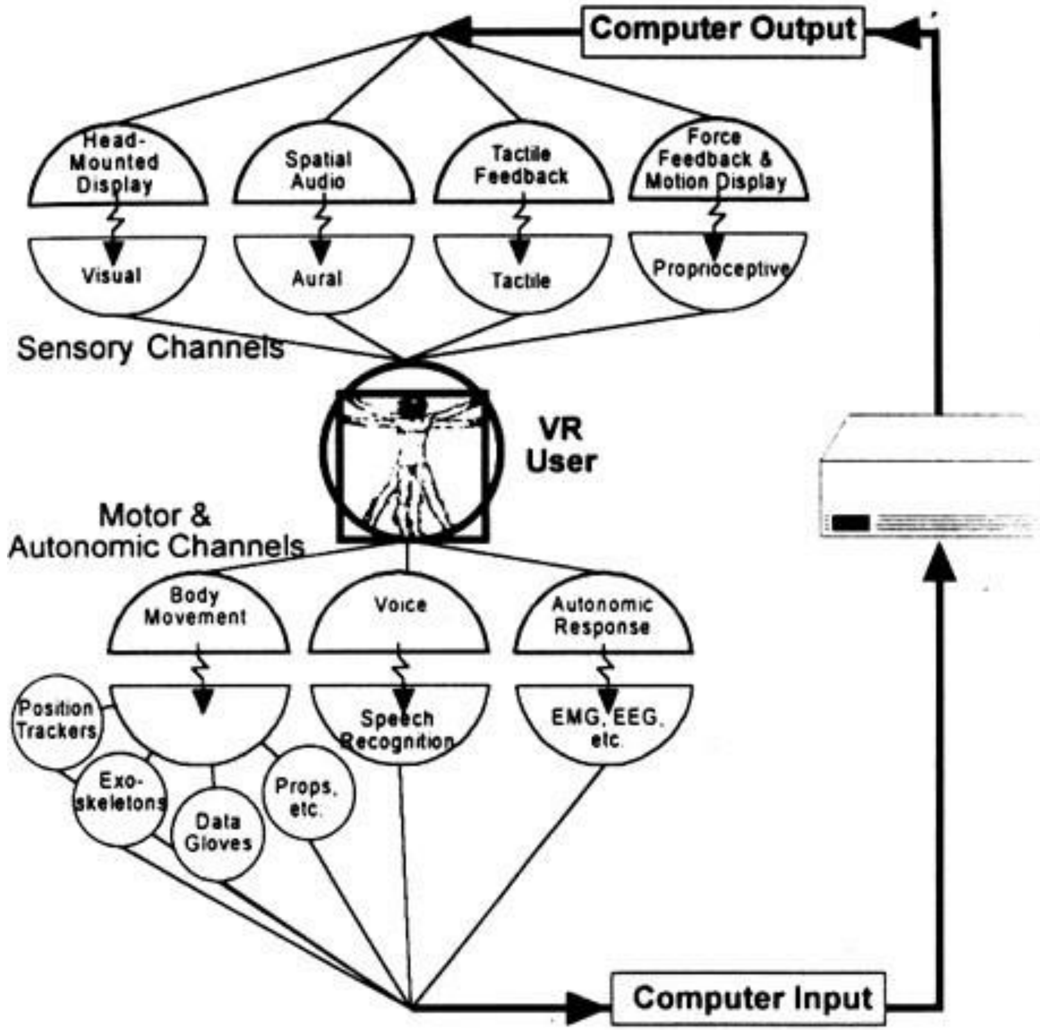
VR Input Devices

- Physical devices that convey information into the application and support interaction in the Virtual Environment

Mapping Between Input and Output

Input

Output



Motivation

vs.

- Mouse and keyboard are good for desktop UI tasks
  - Text entry, selection, drag and drop, scrolling, rubber banding, …
  - 2D mouse for 2D windows
- What devices are best for 3D input in VR?
  - Use multiple 2D input devices?
  - Use new types of devices?

Input Device Characteristics

- Size and shape, encumbrance
- Degrees of Freedom
- Direct (NUI) vs. Indirect manipulation
- Relative vs. Absolute input
  - Relative: measure difference between current and last input (mouse)
  - Absolute: measure input relative to a constant point of reference (tablet)
- Isometric vs. Isotonic
  - Isometric: measure pressure or force **with no** actual **movement**
  - Isotonic: measure deflection from a center point – **position sensing** (e.g. mouse)

Hand Input Devices

- Devices that integrate hand input into VR
- World-Grounded input devices
  - Devices fixed in real world (e.g. joystick)
- Non-Tracked handheld controllers
  - Devices held in hand, but not tracked in 3D (e.g. xbox controller)
- Tracked handheld controllers
  - Physical device with 6 DoF tracking inside (e.g. Vive controllers)
- Hand-Worn Devices
  - Gloves, EMG bands, rings, or devices worn on hand/arm
- Bare Hand Input
  - Using technology to recognize natural hand input

World Grounded Devices

Disney Aladdin Magic Carpet VR Ride

- Devices constrained or fixed in real world
- Not ideal for VR
  - Constrains user motion
- Good for VR vehicle metaphor
  - Used in location based entertainment (e.g. Disney Aladdin ride)

Non-Tracked Handheld Controllers

- Devices held in hand
  - Buttons, joysticks, game controllers, etc.
- Traditional video game controllers
  - Xbox controller

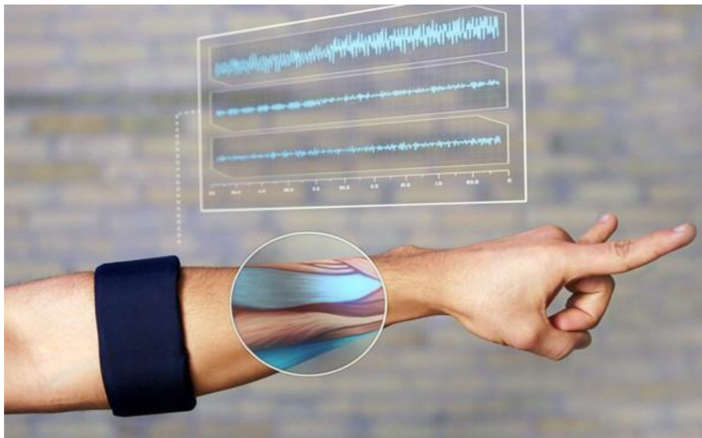
Tracked Handheld Controllers

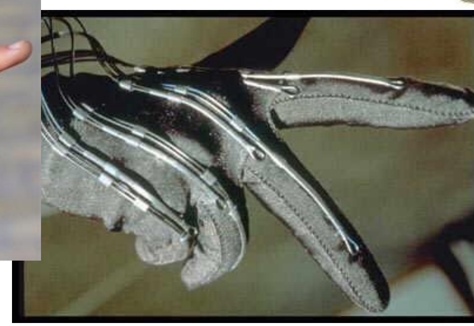
HTC Vive Controllers

Oculus Touch Controllers

- Handheld controller with 6 DoF tracking
  - Combines button/joystick input plus tracking
- One of the best options for VR applications
  - Physical prop enhancing VR presence
  - Providing *kinaesthesia*, passive haptic touch cues
  - Direct mapping to real hand motion

Hand Worn Devices





- Devices worn on hands/arms
  - Glove, EMG sensors, rings, etc...
- Advantages
  - Natural input with potentially rich gesture interaction
  - Hands can be held in comfortable positions – no line of sight issues
  - Hands and fingers can fully interact with real objects

Myo Arm Band

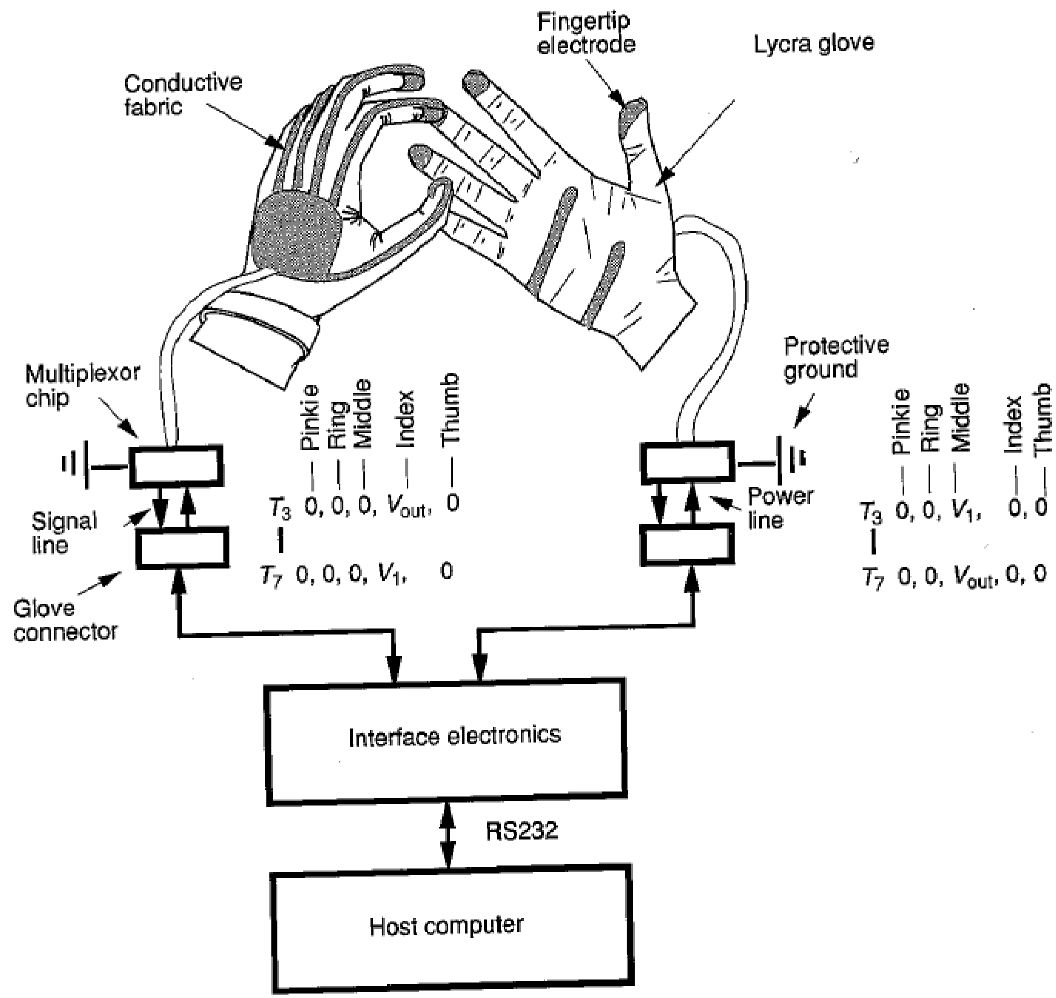
- https://www.youtube.com/watch?v=1f_bAXHckUY

Data Gloves

- Bend sensing gloves
  - Passive input device
  - Detecting hand posture and gestures
  - Continuous raw data from bend sensors
    - Fiber optic, resistive ink, strain-gauge
  - Natural hand output
- Pinch gloves
  - Conductive material at fingertips
  - Determine if fingertips touching
  - Used for discrete input
    - Object selection, mode switching, etc.

How Pinch Gloves Work

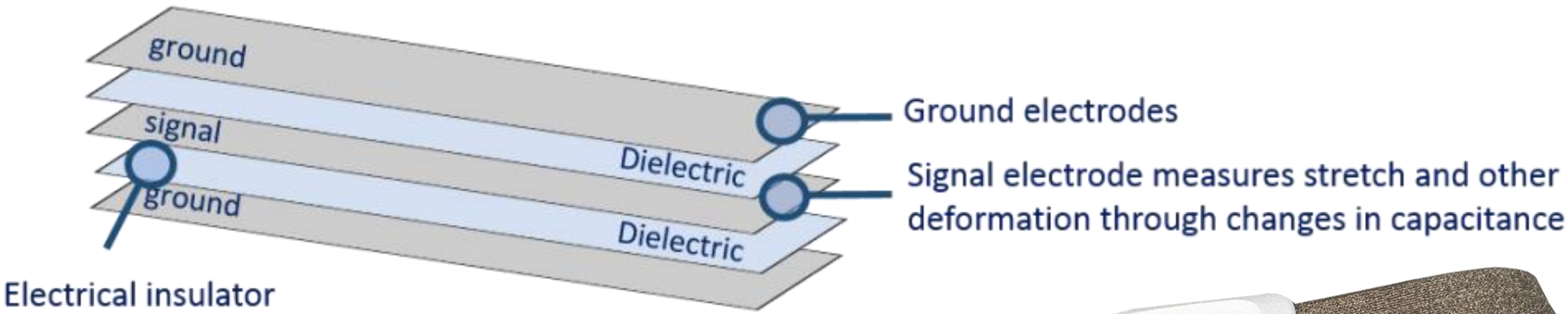
- Contact between conductive fabric completes circuit
- Each finger receives voltage in turn ($T_3 – T_7$)
- Look for output voltage at different times



Data Gloves: Demo Video

- https://www.youtube.com/watch?v=IUNx4FgQmas

StretchSense



- Wearable motion capture sensors
  - Capacitive sensors
  - Measure stretch, pressure, bend, shear
- Many applications
  - Garments, gloves, etc.
- http://stretchsense.com/

Bare Hands

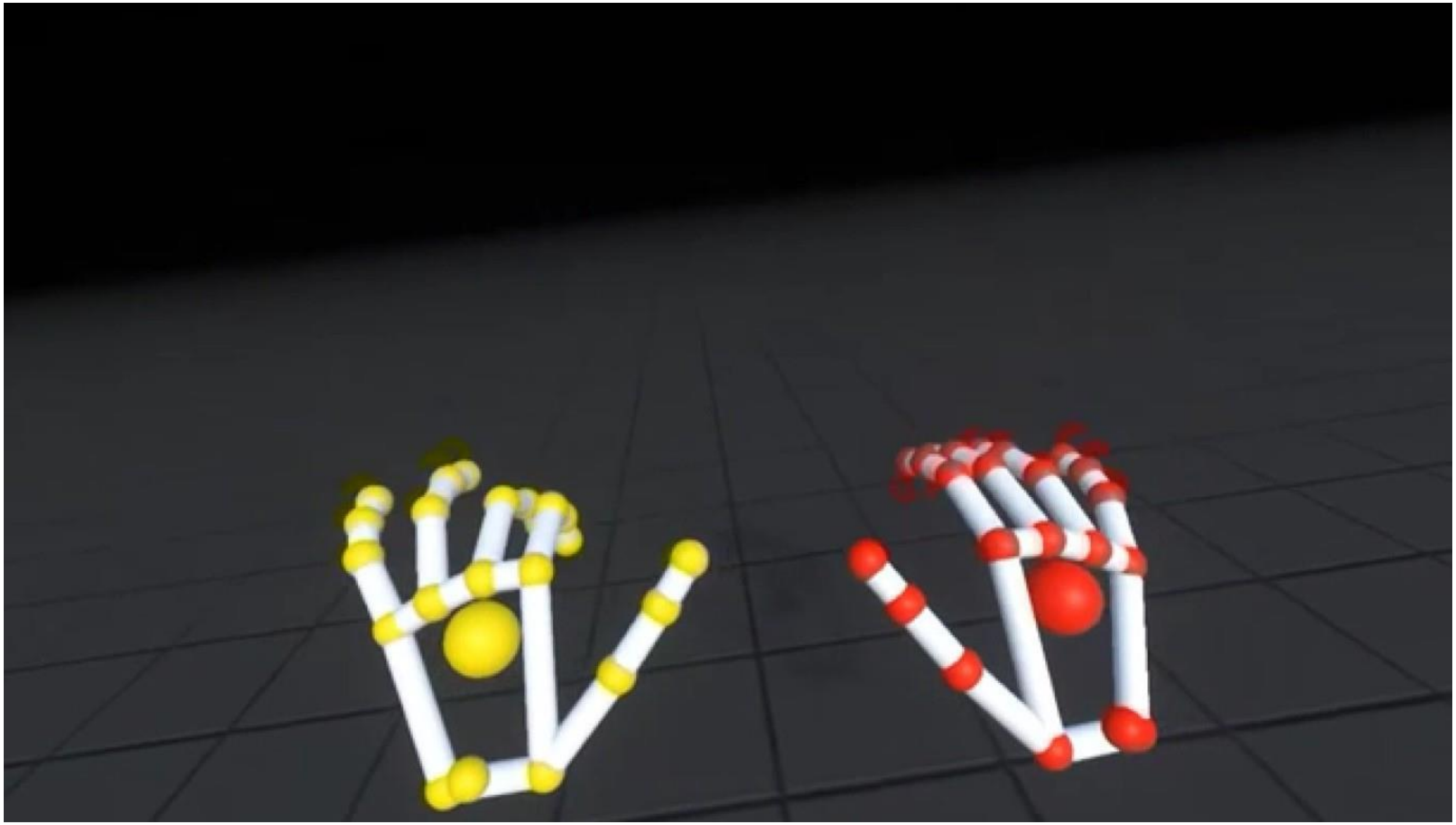
- Using computer vision to track bare hand input
- Creates compelling sense of Presence, natural interaction
- Challenges need to be solved
  - Not having sense of touch
  - Line of sight required to sensor
  - Fatigue from holding hands in front of sensor

Leap Motion

- IR based sensor for hand tracking ($50 USD)
  - HMD + Leap Motion = Hand input in VR
- Technology
  - 3 IR LEDS and 2 wide angle cameras
  - The LEDS generate patternless IR light
  - IR reflections picked up by cameras
  - Software performs hand tracking
- Performance
  - 1m range, 0.7 mm accuracy, 200Hz

- https://www.leapmotion.com/

Example: Leap Motion



- https://www.youtube.com/watch?v=QD4qQBL0X80

Non-Hand Input Devices

- Capturing input from other parts of the body
- Head Tracking
  - Use head motion for input
- Eye Tracking
  - Largely unexplored for VR...
- Microphones
  - Audio input, speech
- Full-Body tracking
  - Motion capture, body movement

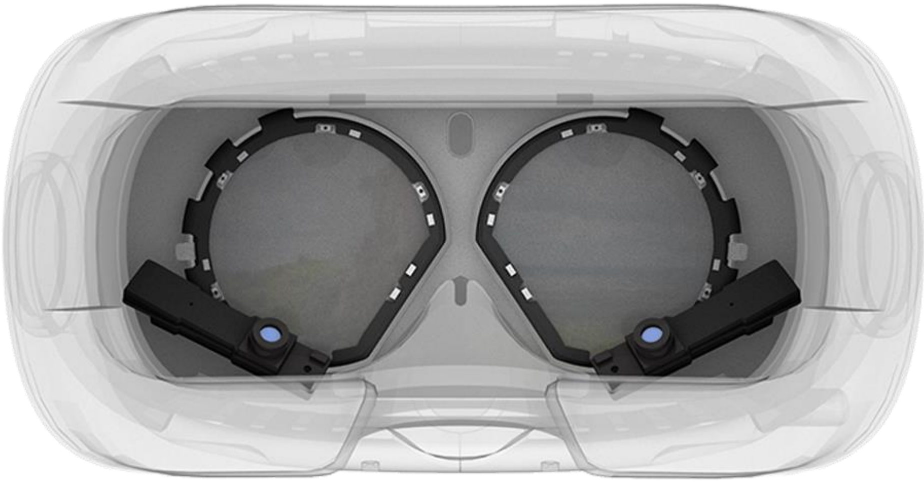
Eye Tracking

- Technology
  - Shine IR light into eye and look for reflections
- Advantages
  - Provides natural hands-free input
  - Gaze provides cues as to user attention
  - Can be combined with other input technologies

Example: FOVE VR Headset

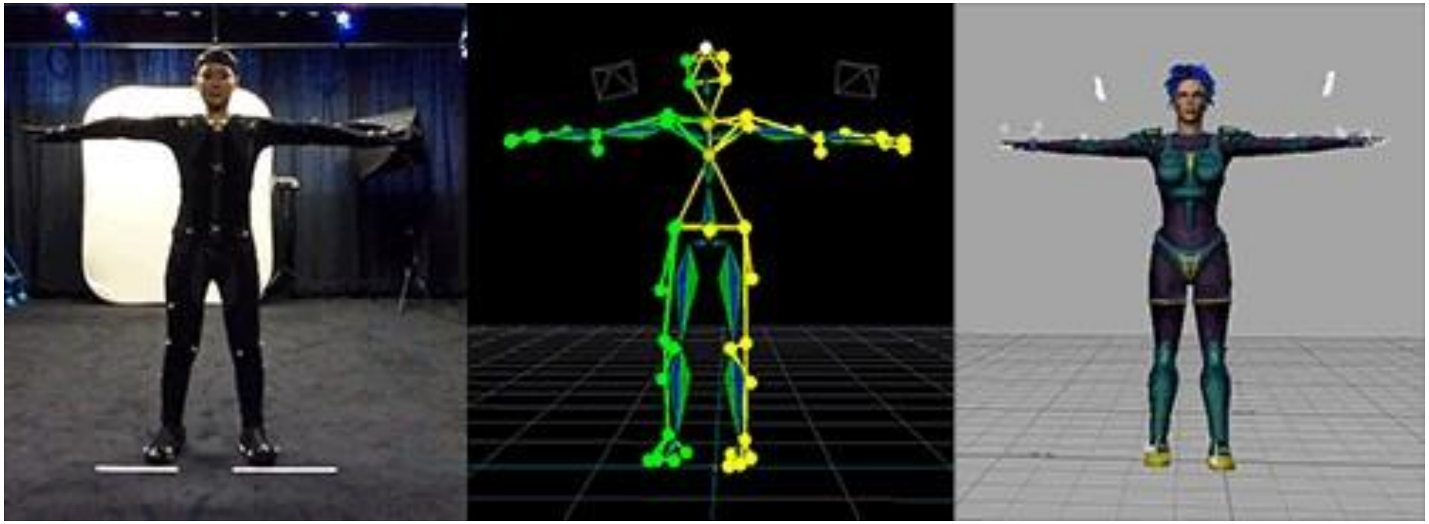
- Eye tracker integrated into VR HMD
- Gaze driven user interface, foveated rendering
- https://www.youtube.com/watch?v=8dwdzPaqsDY

Pupil Labs VIVE/Oculus Add-ons



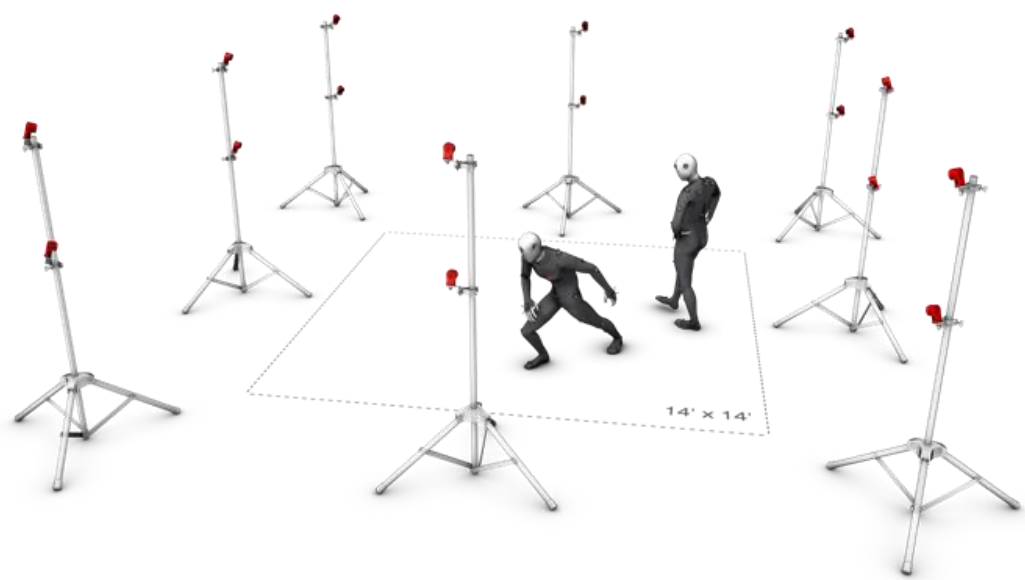
- Adds eye-tracking to HTC Vive/Oculus Rift HMDs
  - Mono or stereo eye-tracking
  - 120 Hz eye tracking, gaze accuracy of 0.6° with precision of 0.08°
  - Open source software for eye-tracking
- https://pupil-labs.com/pupil/

Full Body Tracking



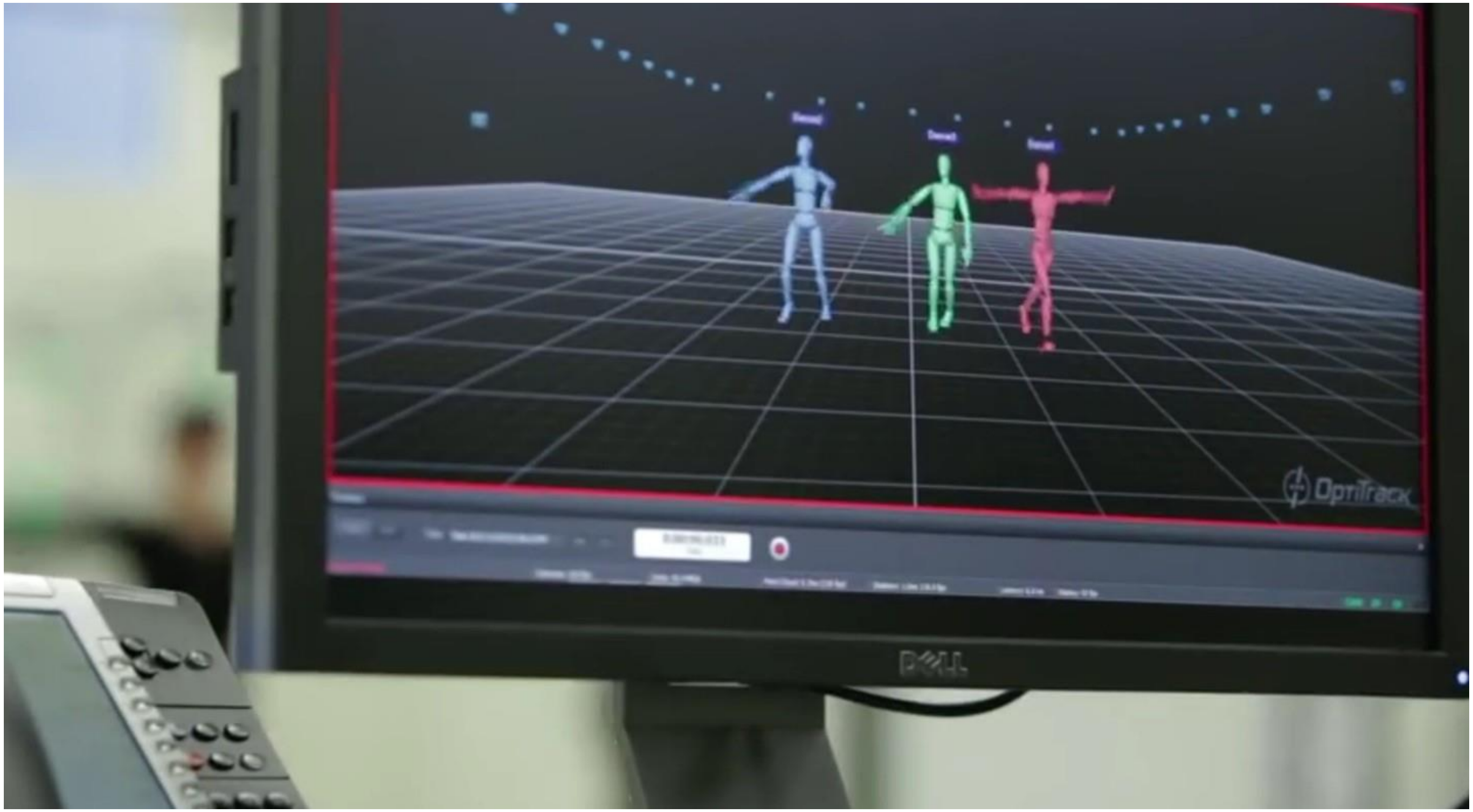
- Adding full-body input into VR
  - Creates illusion of self-embodiment
  - Significantly enhances sense of Presence
- Technologies
  - Motion capture suit and camera based systems
  - Can track large number of significant feature points

Camera Based Motion Capture



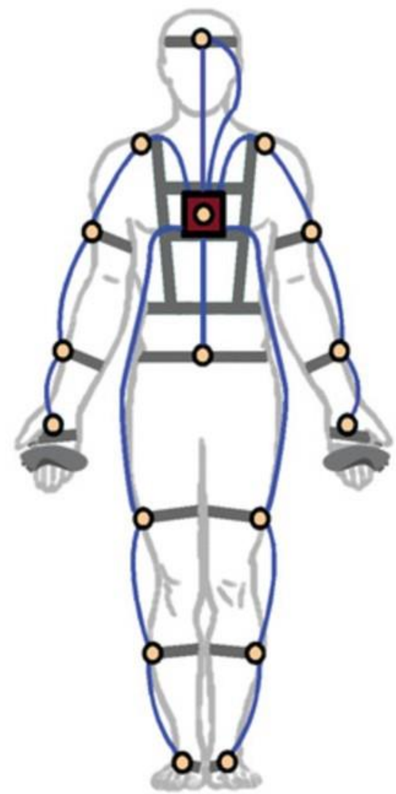
- Use multiple cameras
- Reflective markers on body
- Eg – Opitrack (www.optitrack.com)
  - 120 – 360 fps, < 10ms latency, < 1mm accuracy

Optitrack Demo



- https://www.youtube.com/watch?v=tBAvjU0ScuI

Wearable Motion Capture: PrioVR



- Wearable motion capture system
  - 8 – 17 inertial sensors + wireless data transmission
  - 30 – 40m range, 7.5 ms latency, 0.09° precision
  - Supports full range of motion, no occlusion
- www.priovr.com

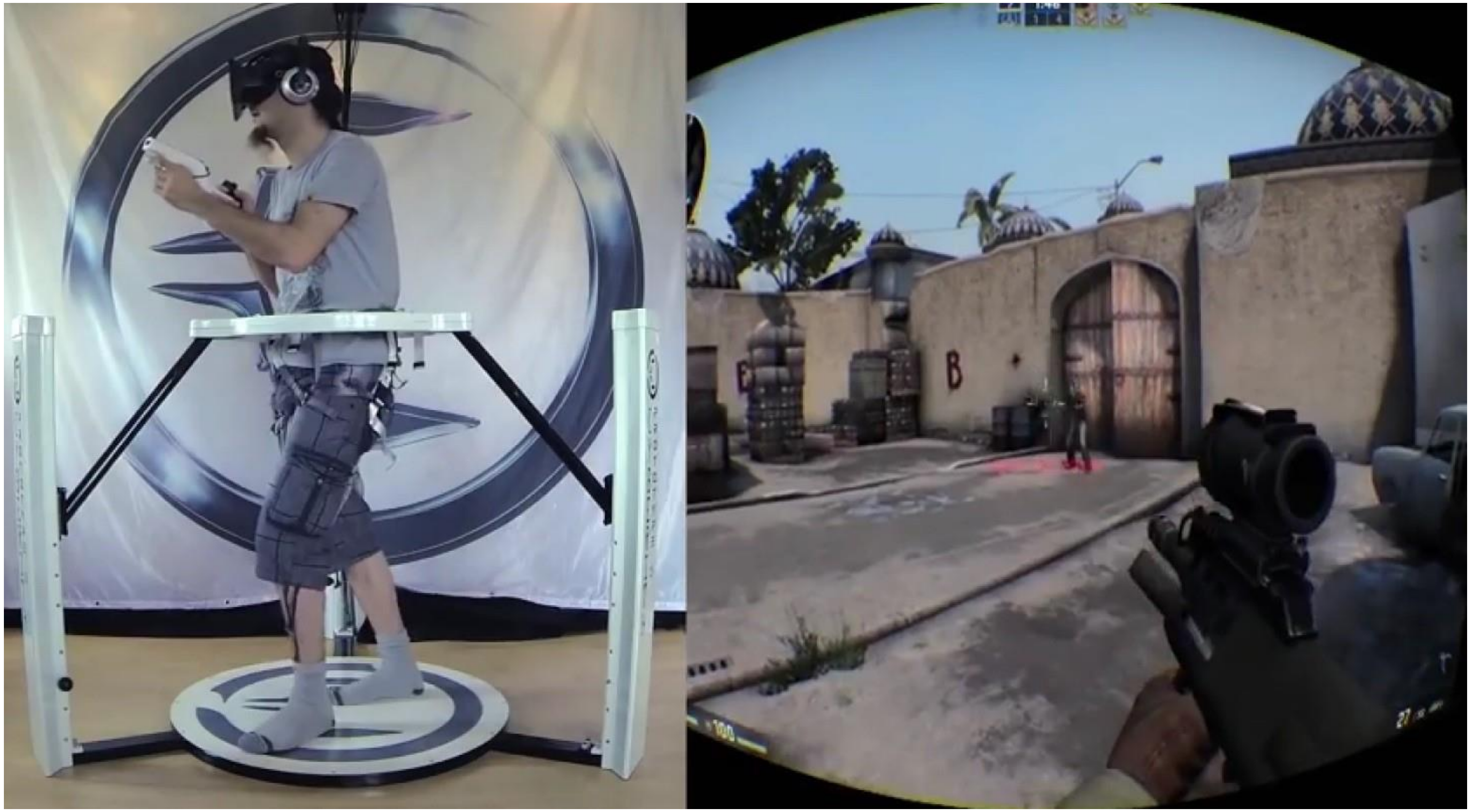
PrioVR Demo

- https://www.youtube.com/watch?v=q72iErtvhNc

Pedestrian Devices

- Pedestrian input in VR
  - Walking/running in VR
- Virtuix Omni
  - Special shoes
  - http://www.virtuix.com
- Cyberith Virtualizer
  - Socks + slippery surface
  - http://cyberith.com

Cyberith Virtualizer Demo

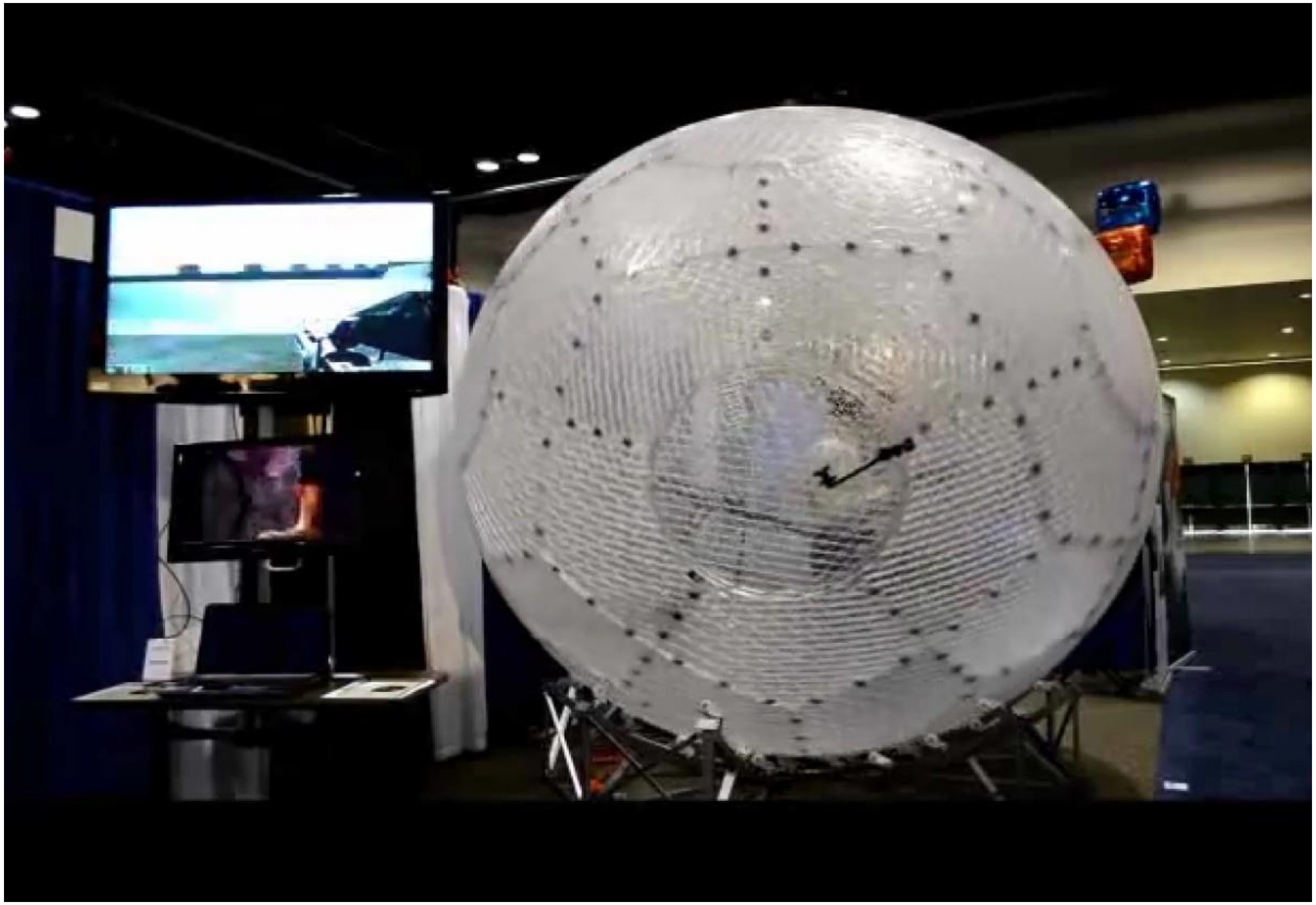


- https://www.youtube.com/watch?v=R8lmf3OFrms

Virtusphere

- Fully immersive sphere
  - Support walking, running in VR
  - Person inside trackball
- http://www.virtusphere.com

Virtusphere Demo

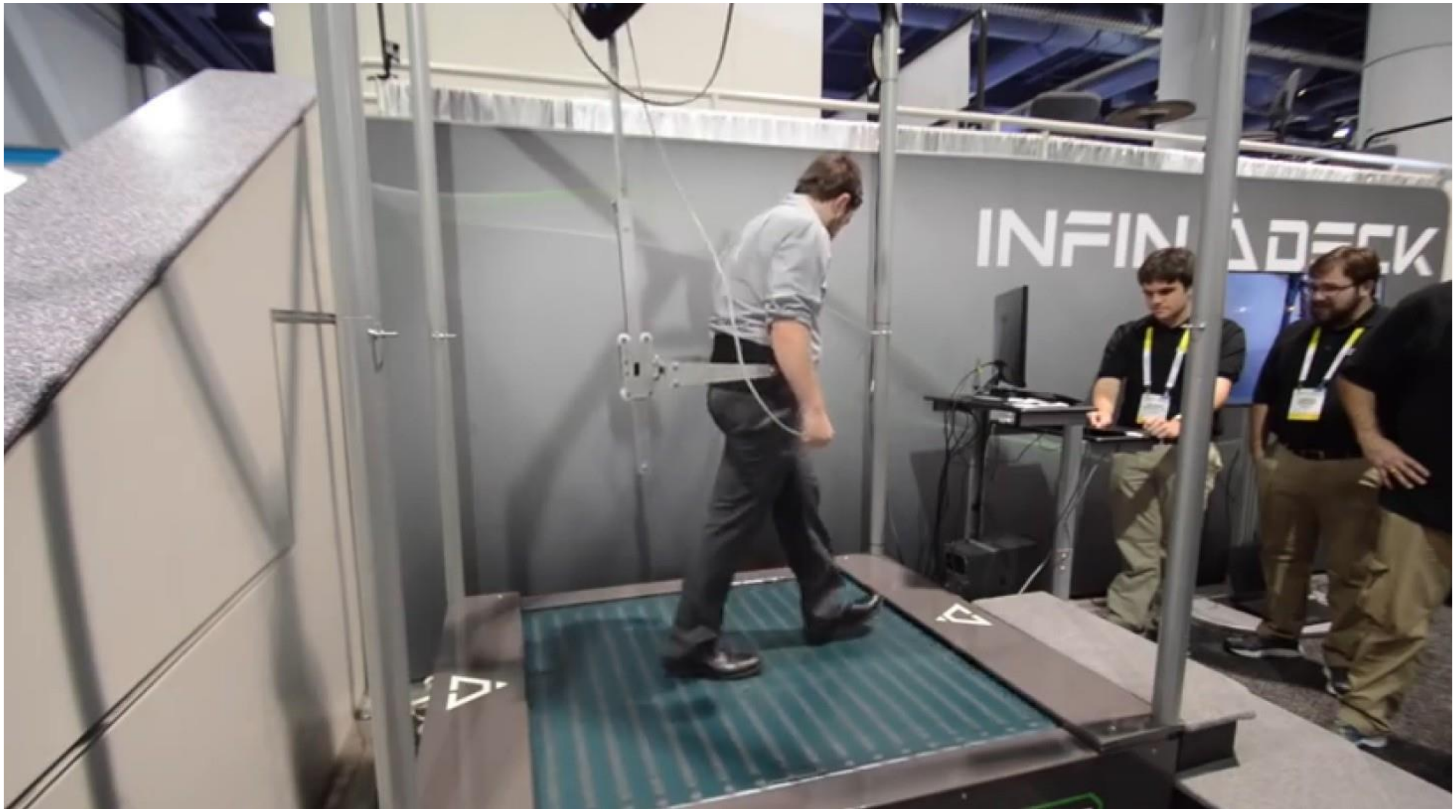


- https://youtu.be/5PSFCnrk0GI?t=53

Omnidirectional Treadmills

- Infinadeck
  - 2 axis treadmill, flexible material
  - Tracks user to keep them in centre
  - Limitless walking input in VR
- www.infinadeck.com

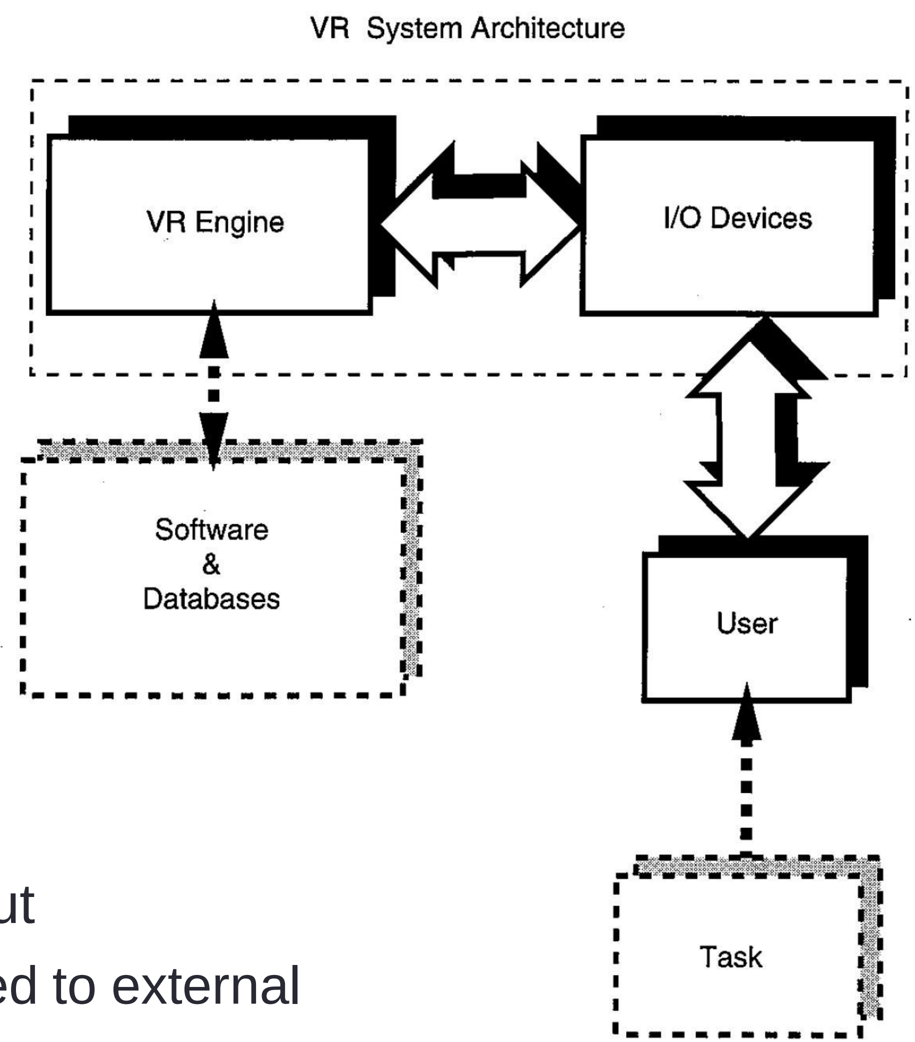
Infinadeck Demo



- https://www.youtube.com/watch?v=seML5CQBzP8

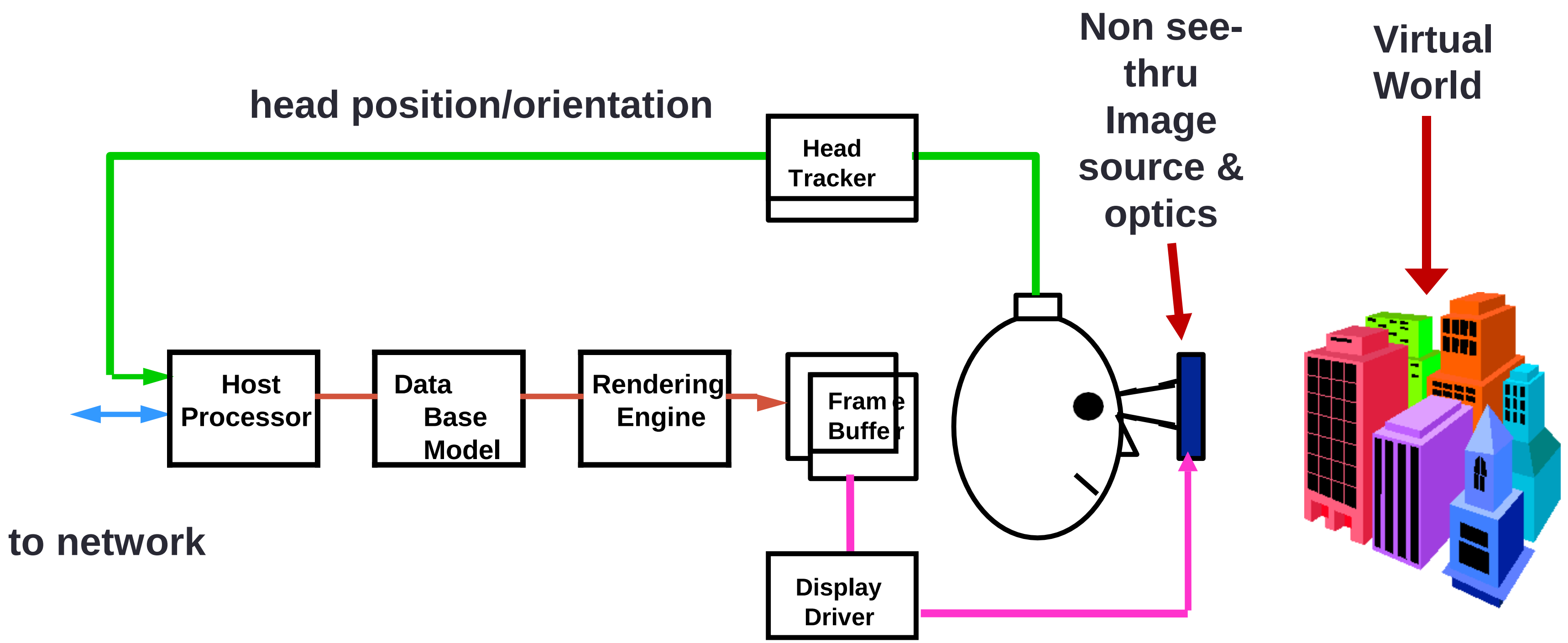
VR Rendering

Basic VR System

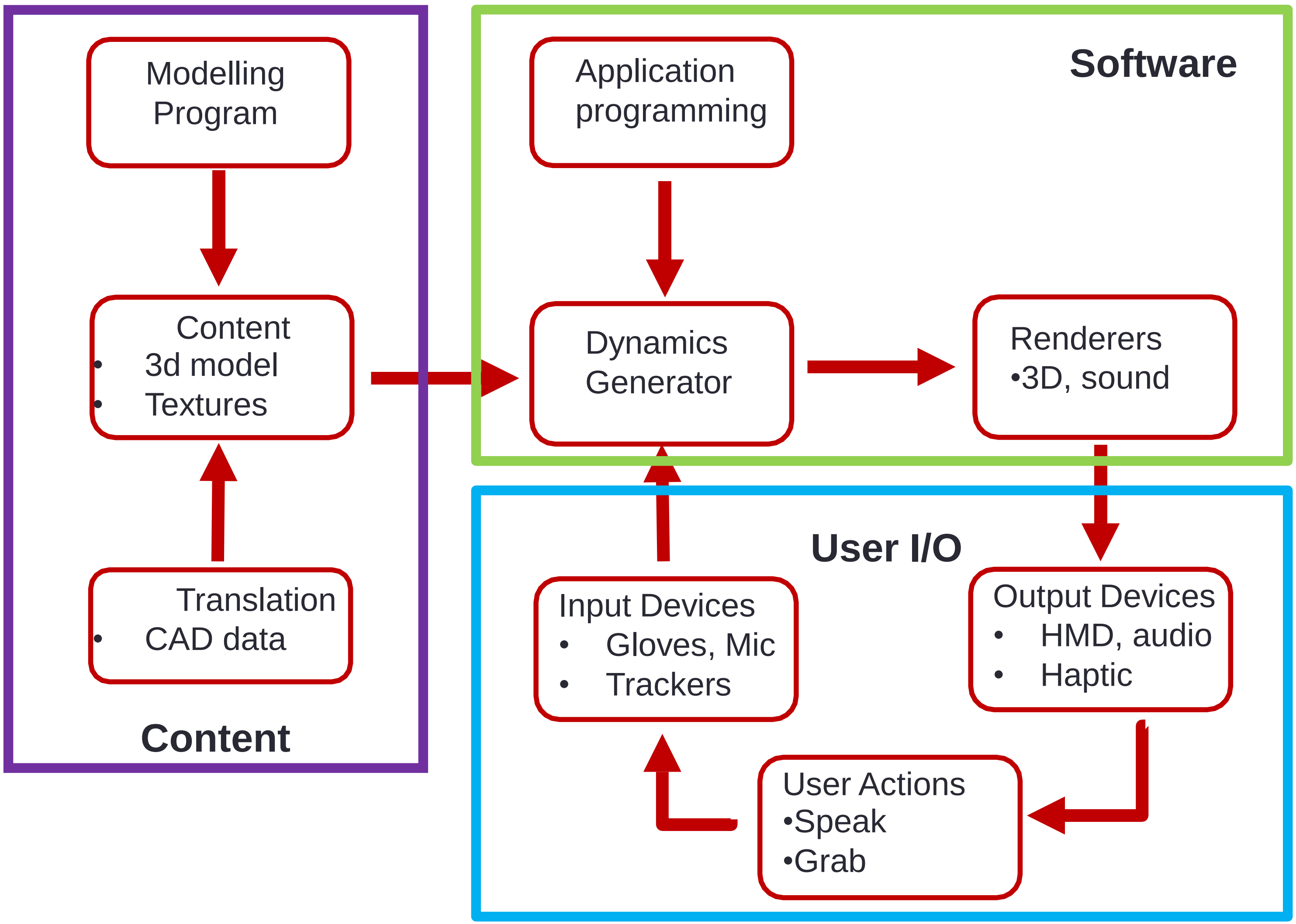


- High level overview
  - User engaged in task
  - User provides input
  - VR engine provides output
    - VR engine connected to external databases

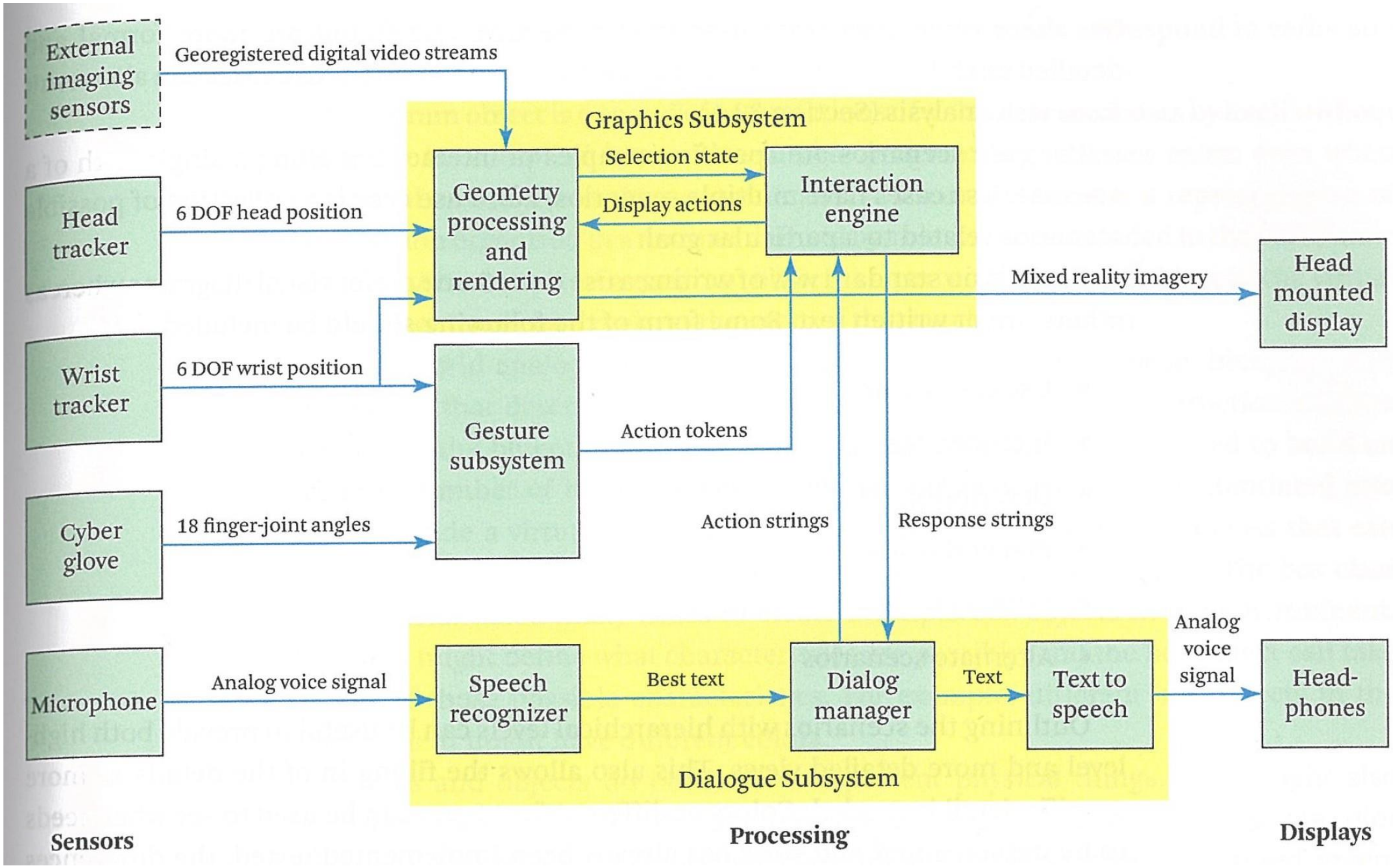
Simple System Architecture



From Content to User



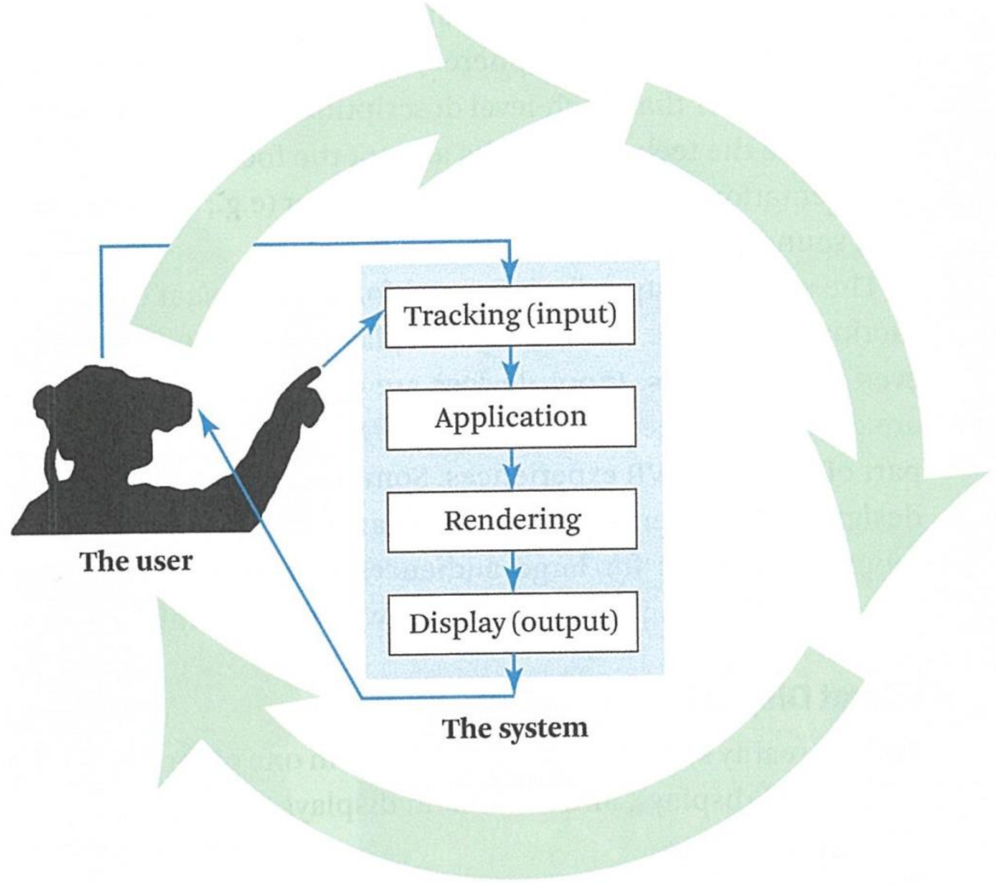
System Diagram



VR Graphics Architecture

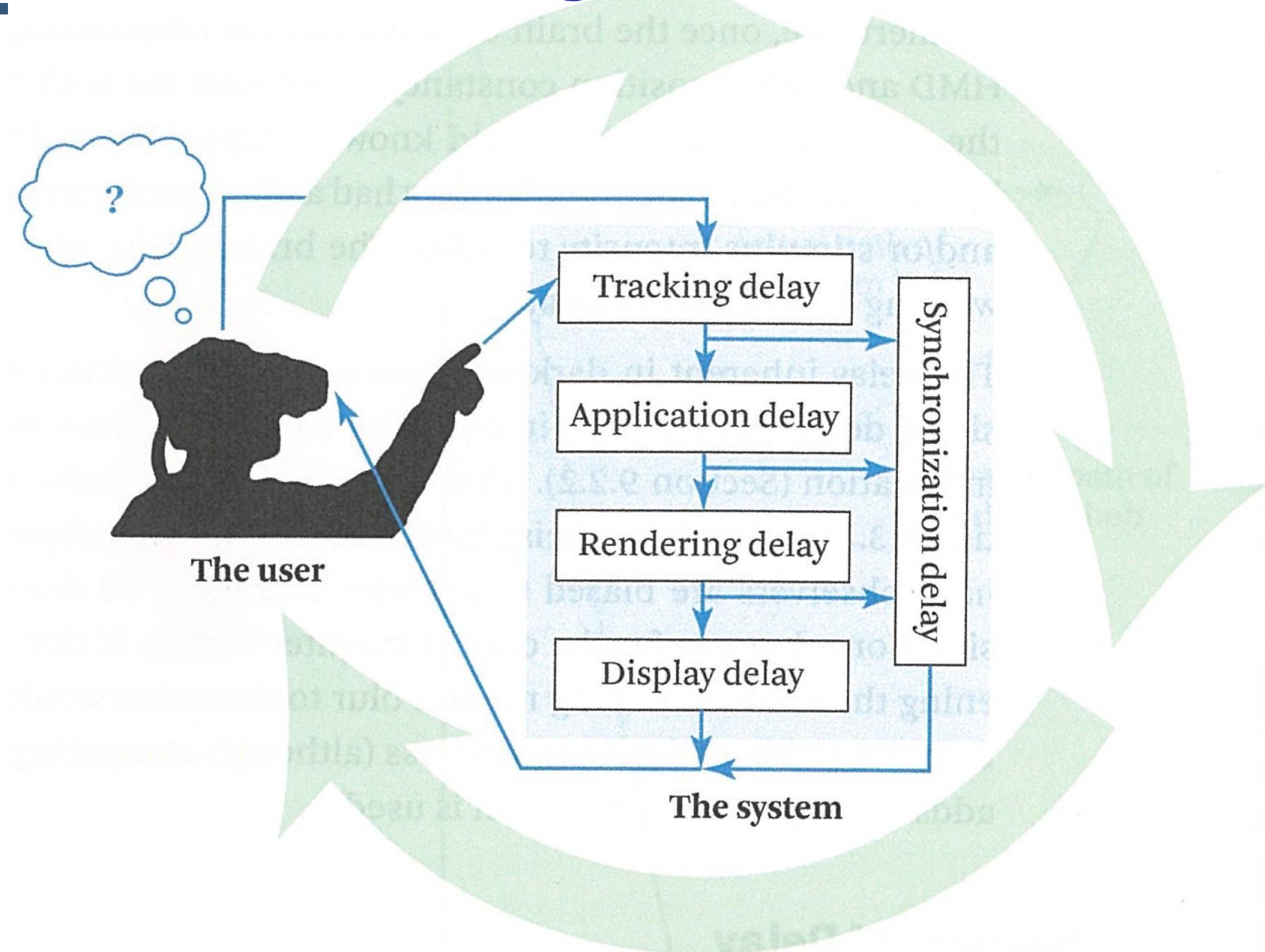
- Application Layer
  - User interface libraries
  - Simulation/behaviour code
  - User interaction specification
- Graphics Layer (CPU acceleration)
  - Scene graph specification
  - Object physics engine
  - Defining graphics objects
- Rendering Layer (GPU acceleration)
  - Low level graphics code
  - Rendering pixels/polygons
  - Interface with graphics card/frame buffer

Typical VR Simulation Loop...



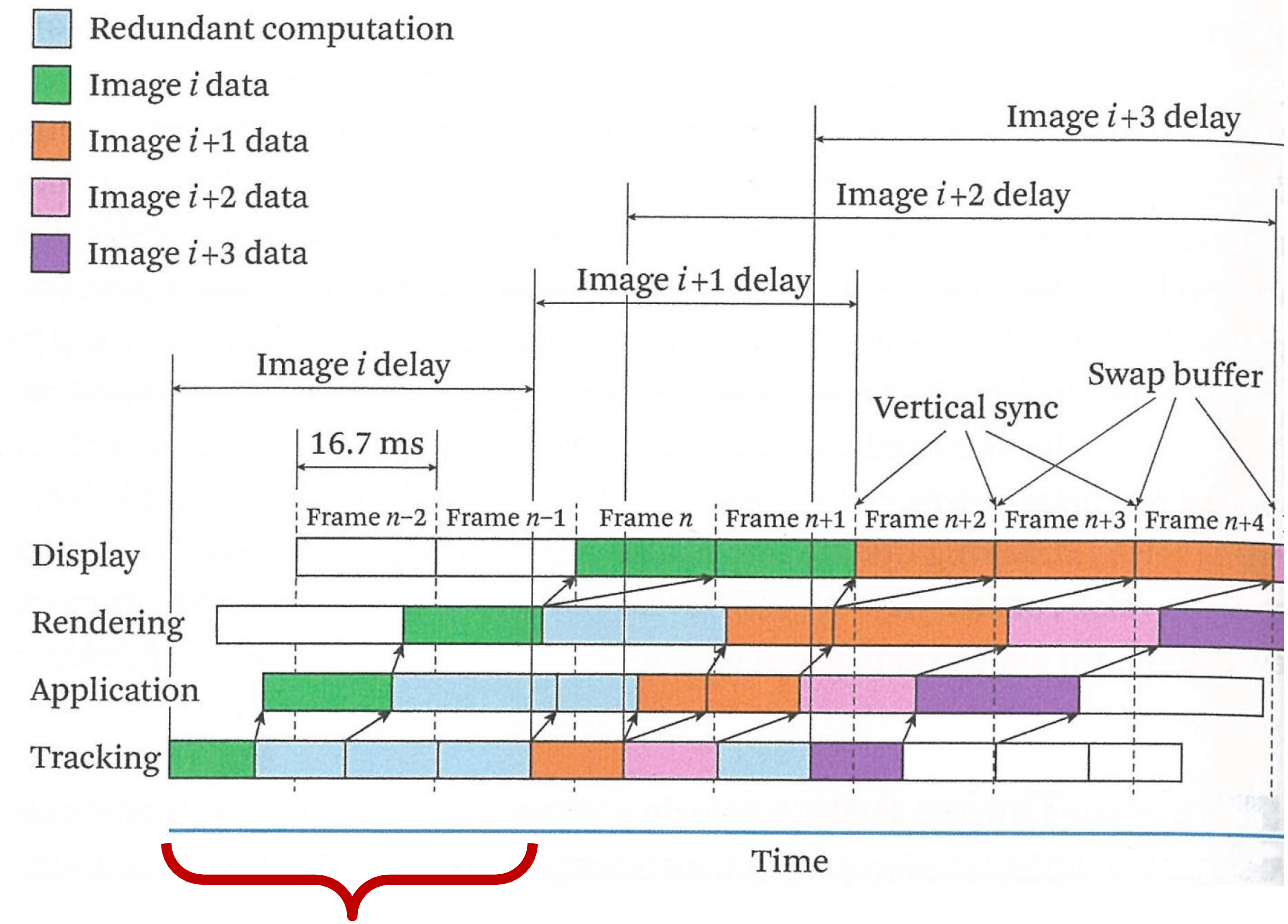
- User moves head, scene updates, displayed graphics change

System Delays



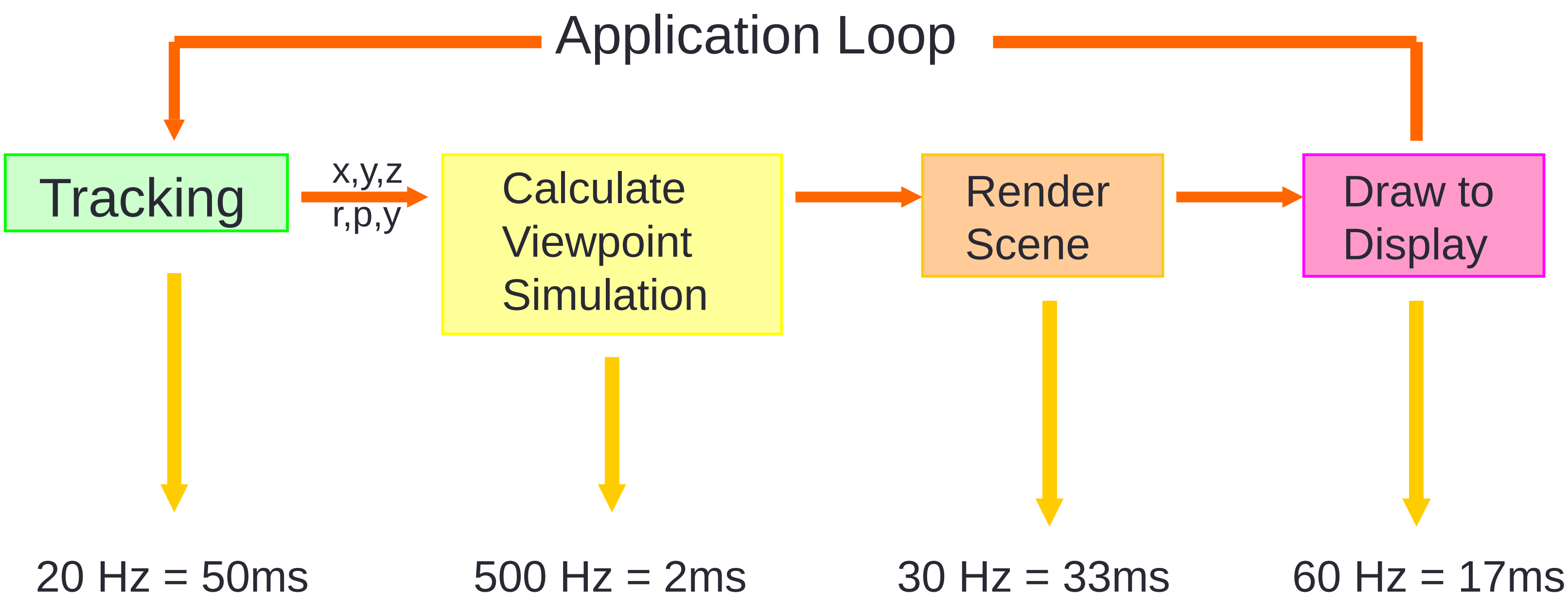
- Need to synchronize system to reduce delays

Typical Delay from Tracking to Rendering



System Delay

Typical System Delays



- Total Delay = 50 + 2 + 33 + 17 = 102 ms
  - **1 ms delay** = **1/3 mm error** for **object drawn** at **arms length**
  - So we have a **total of 33mm error** from when **user begins moving to when object drawn**

Living with High Latency (1/3 sec – 3 sec)

- https://www.youtube.com/watch?v=_fNp37zFn9Q

Effects of System Latency

- Degraded Visual Acuity/Sharpness
  - **Scene still moving when head stops = motion blur**
- Degraded Performance
  - As latency increases it’s difficult to select objects etc.
  - If latency > 120 ms, training doesn’t improve performance
- Breaks-in-Presence
  - If system delay high user doesn’t believe they are in VR
- Negative Training Effects
  - User train to operative in world with delay
- Simulator Sickness
  - Latency is greatest cause of simulator sickness