LECTURE 3: VR INPUT AND SYSTEMS

COMP 4026 – Advanced HCI

Semester 5 - 2017

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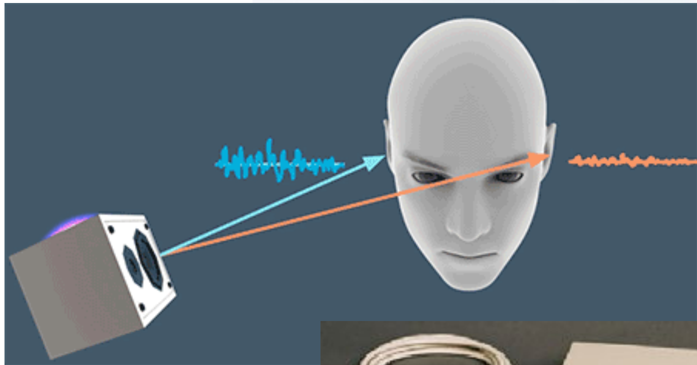
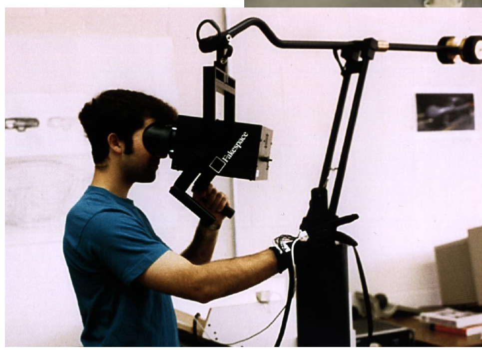
University of South Australia

Recap – Last Week

- Audio Displays
  - Synthesizing audio
    - Sound mixing
  - Spatial Audio Display
    - HRTF, Google VR Spatial Audio SDK
- VR Tracking
  - Performance criteria
    - Latency, accuracy, update, drift, etc.
  - Tracking technologies
    - Mechanical, electromagnetic, visual, etc
  - Example Vive Lighthouse Tracking





VR INPUT DEVICES

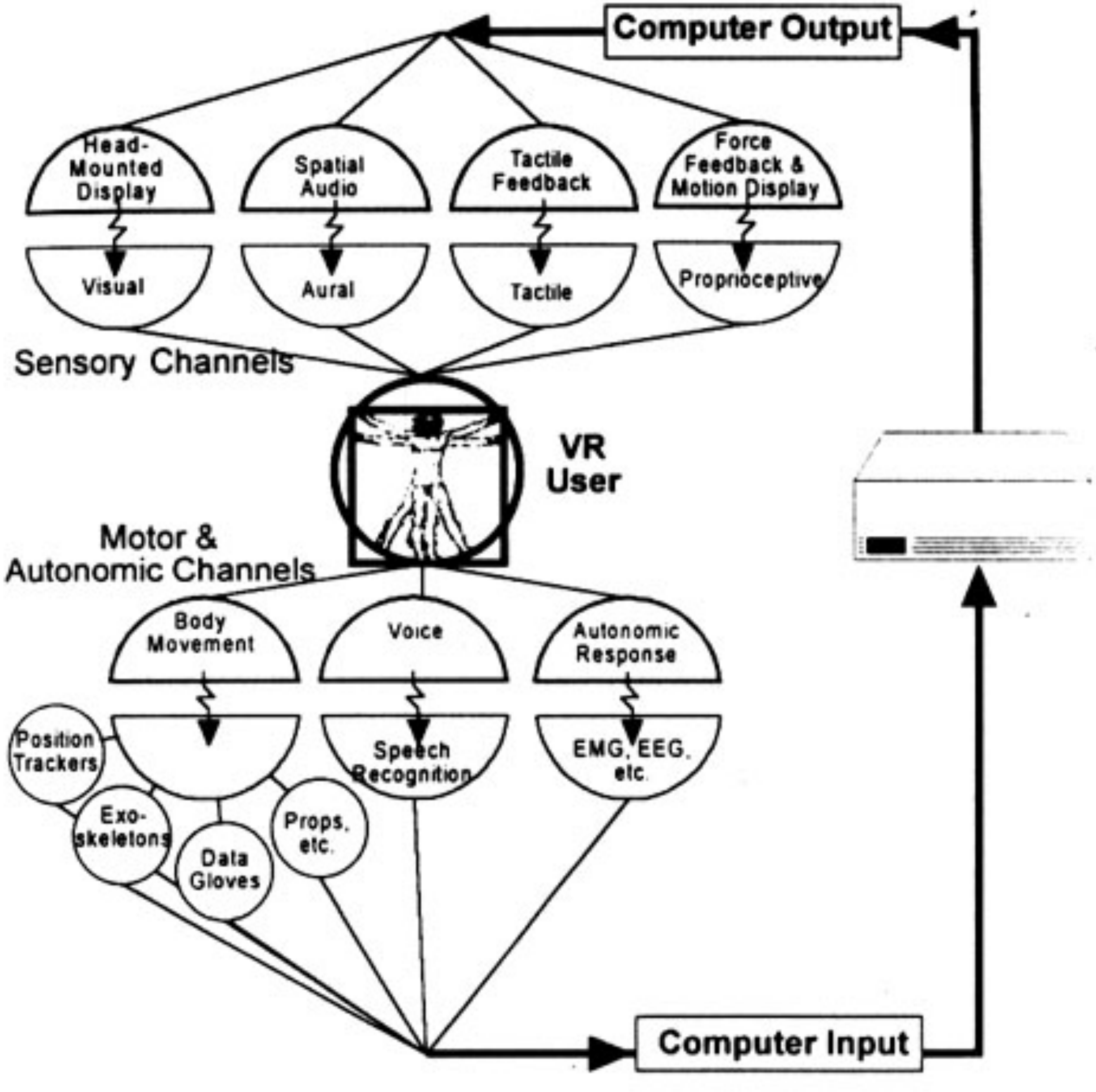
VR Input Devices

- 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
  - Integrated (mouse) vs. separable (Etch-a-sketch)
- Direct 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)
- Rate control vs. position control
- Isometric vs. Isotonic
  - Isometric: measure pressure or force with no actual movement
  - Isotonic: measure deflection from a center point (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 proprioceptive, passive haptic touch cues
  - Direct mapping to real hand motion

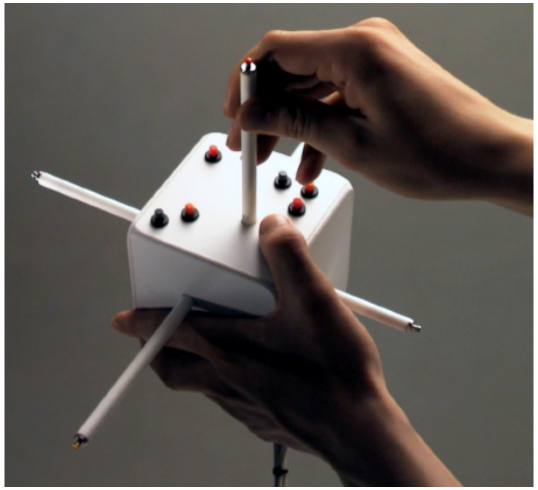
Example: Sixense STEM

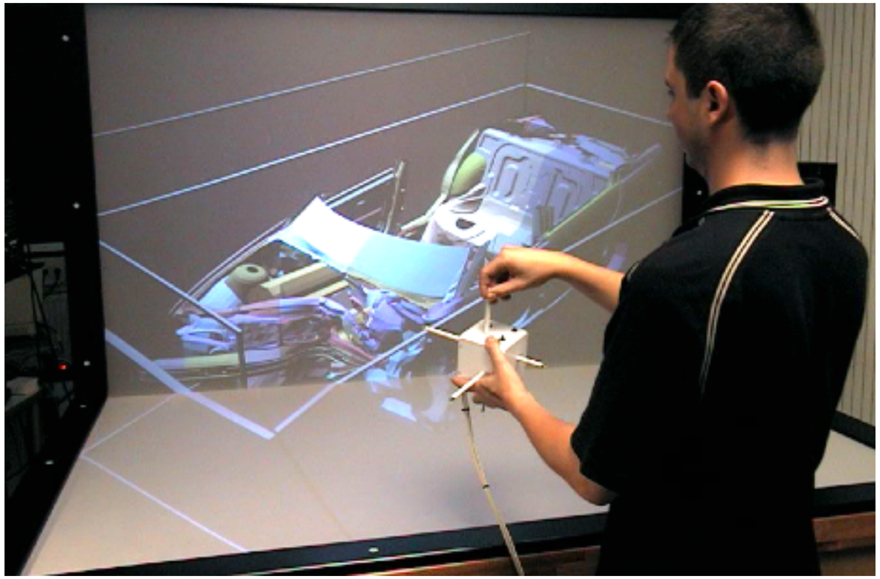
- Wireless motion tracking + button input
  - Electromagnetic tracking, 8 foot range, 5 tracked receivers
- http://sixense.com/wireless

Sixense Demo Video

- https://www.youtube.com/watch?v=2lY3XI0zDWw

Cubic Mouse

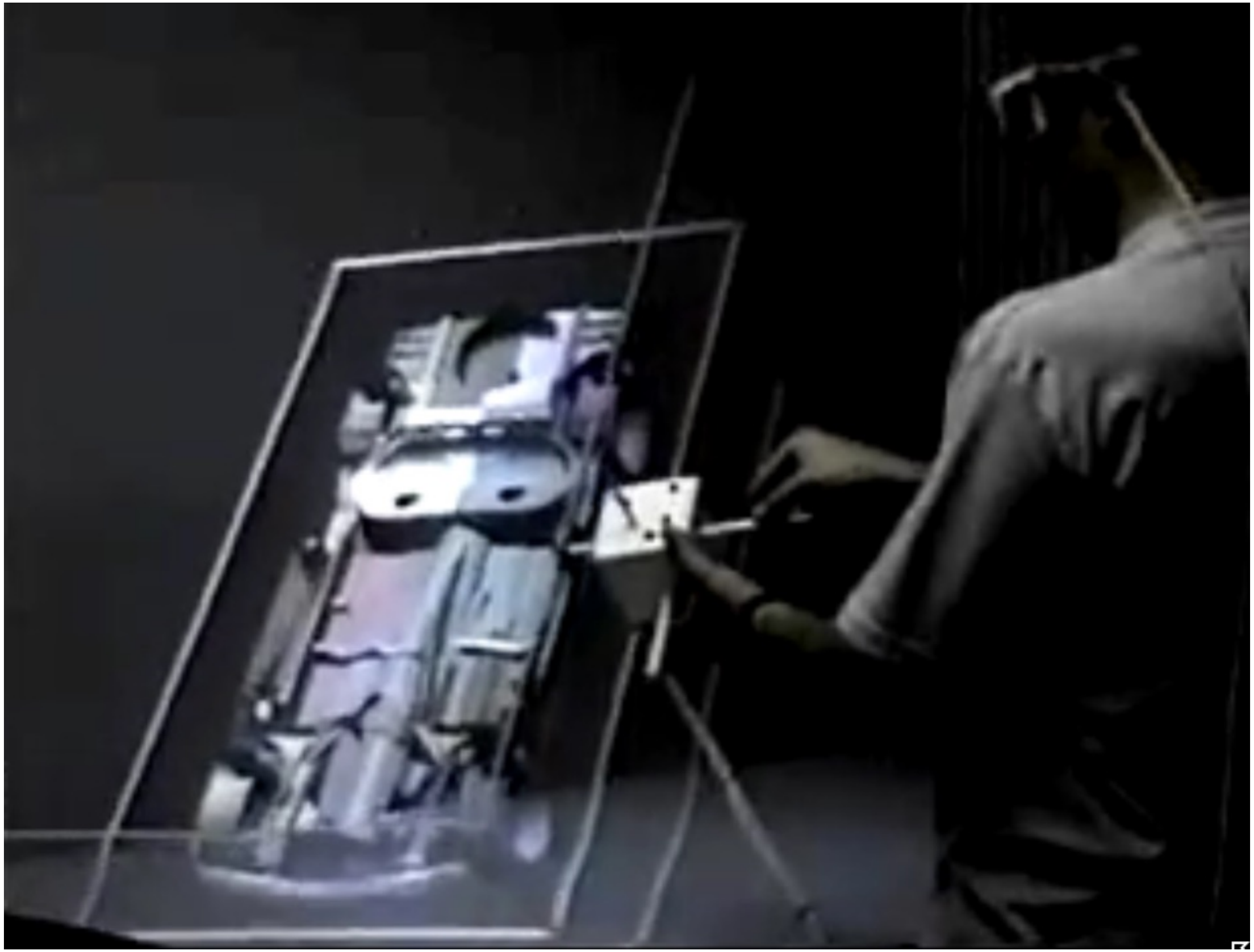




- Plastic box
  - Polhemus Fastrack inside (magnetic 6 DOF tracking)
  - 3 translating rods, 6 buttons
- Two handed interface
  - Supports object rotation, zooming, cutting plane, etc.

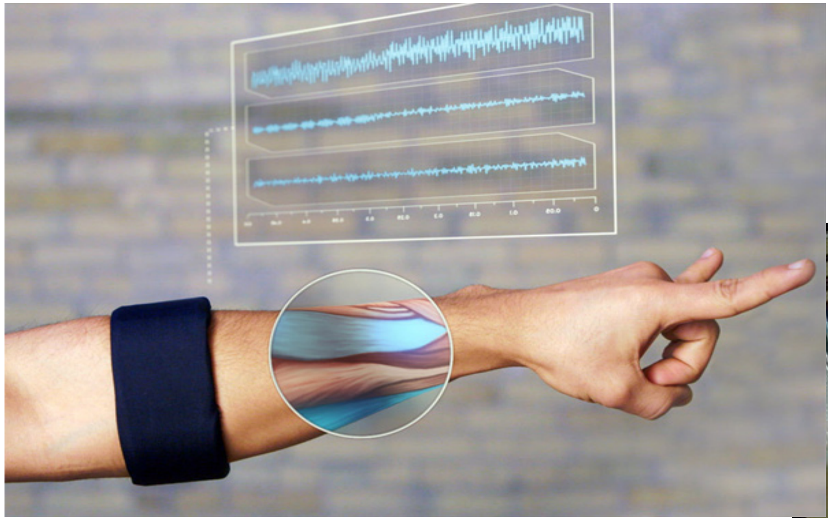
Fröhlich, B., & Plate, J. (2000). The cubic mouse: a new device for three-dimensional input. In *Proceedings of the SIGCHI conference on Human Factors in Computing Systems* (pp. 526-531). ACM.

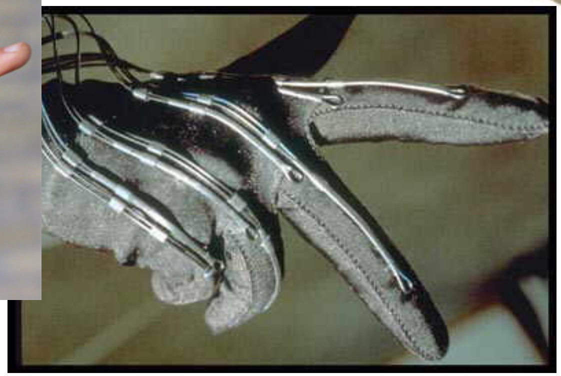
Cubic Mouse Video



- https://www.youtube.com/watch?v=1WuH7ezv_Gs

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

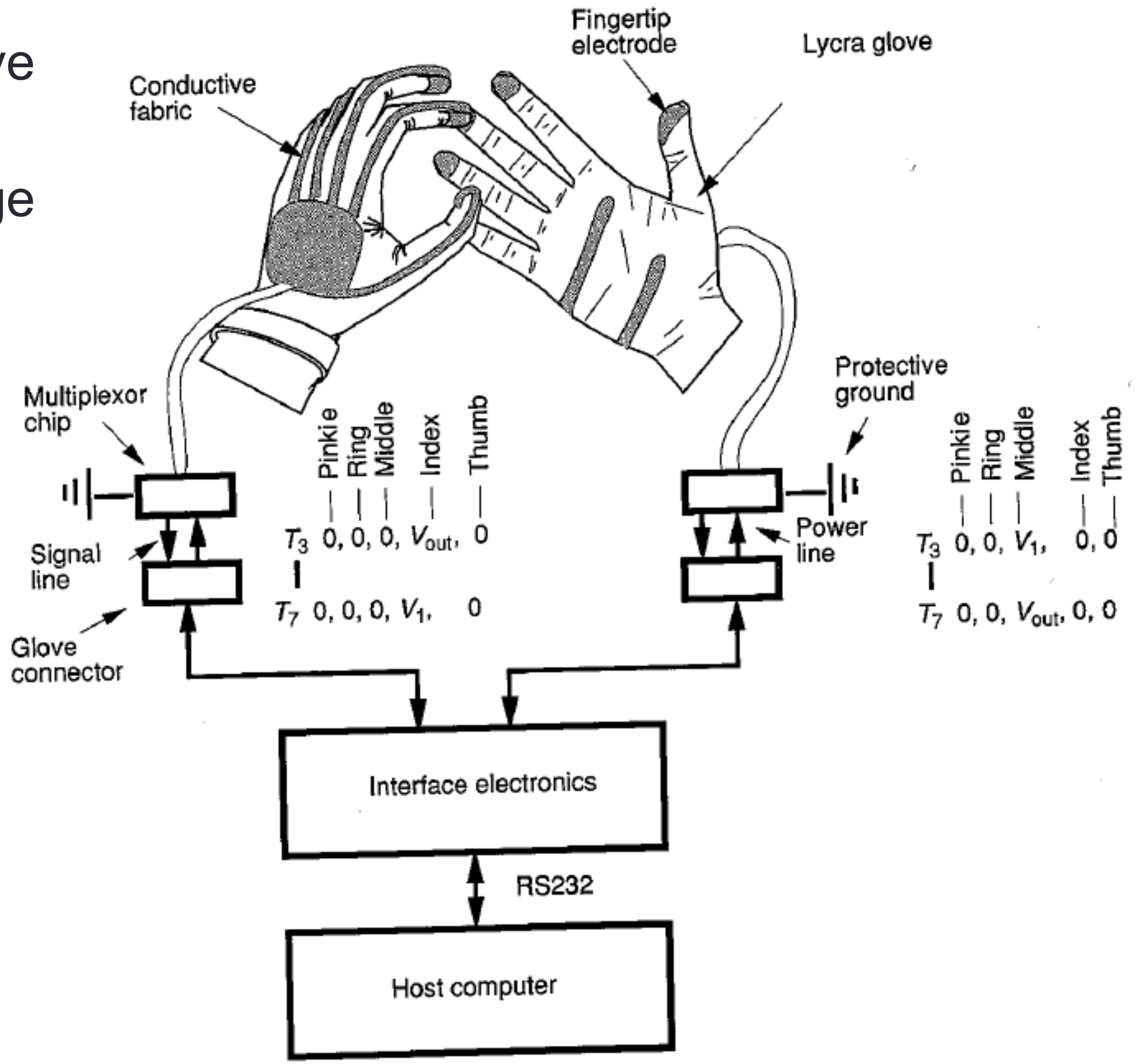
- https://www.youtube.com/watch?v=1f_bAXHckUY

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
  - Large DOF output, 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

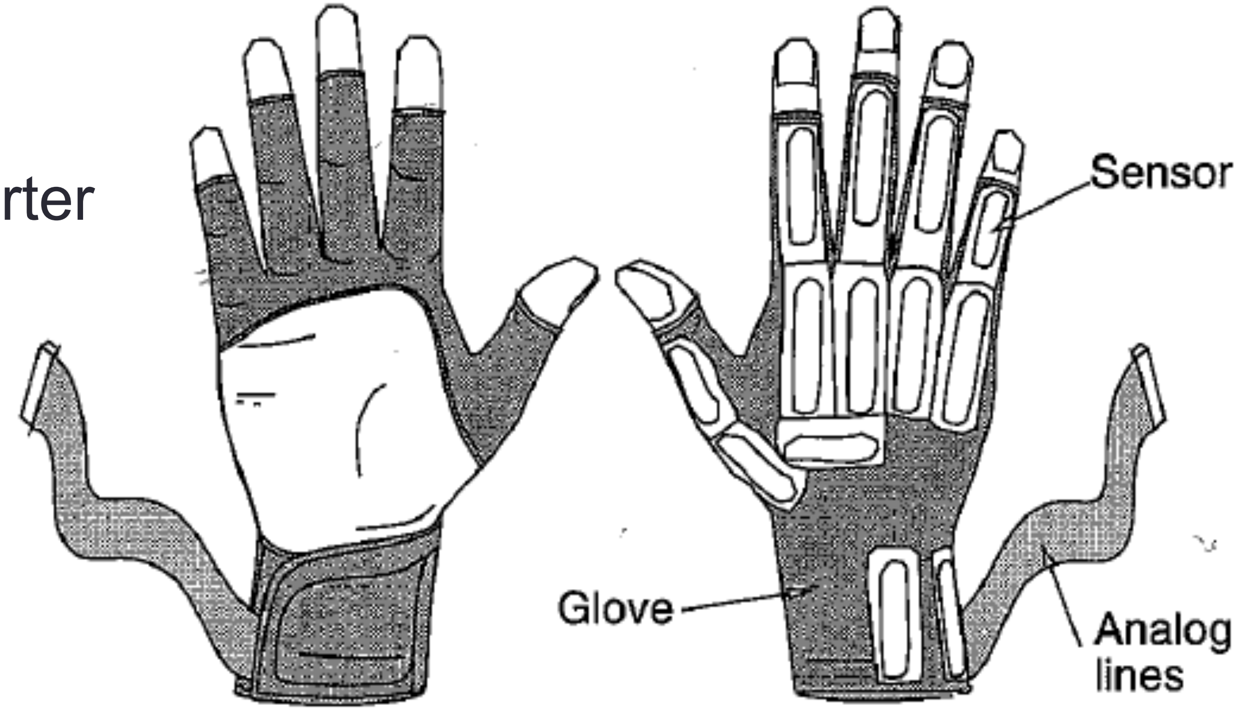


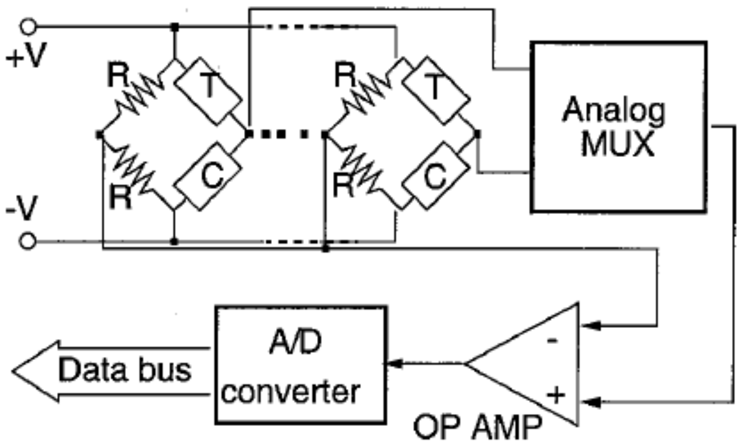
Example: Cyberglove

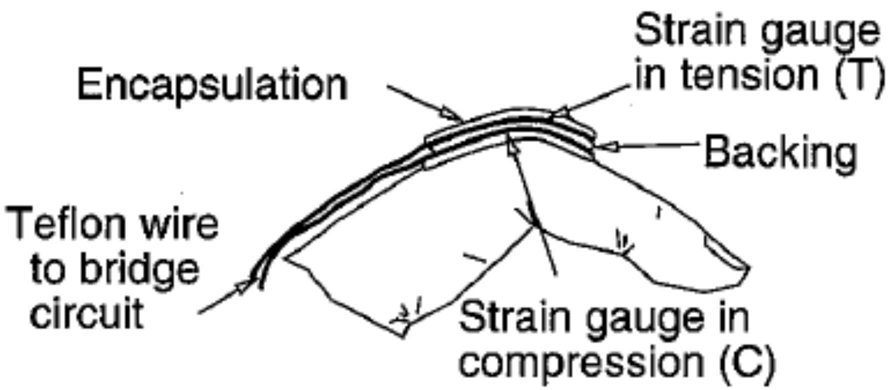
- Invented to support sign language
- Technology
  - Thin electrical strain gauges over fingers
  - Bending sensors changes resistence
  - 18-22 sensors per glove, 120 Hz samples
  - Sensor resolution 0.5^{o}
- Very expensive
  - >$10,000/glove
- http://www.cyberglovesystems.com

How CyberGlove Works

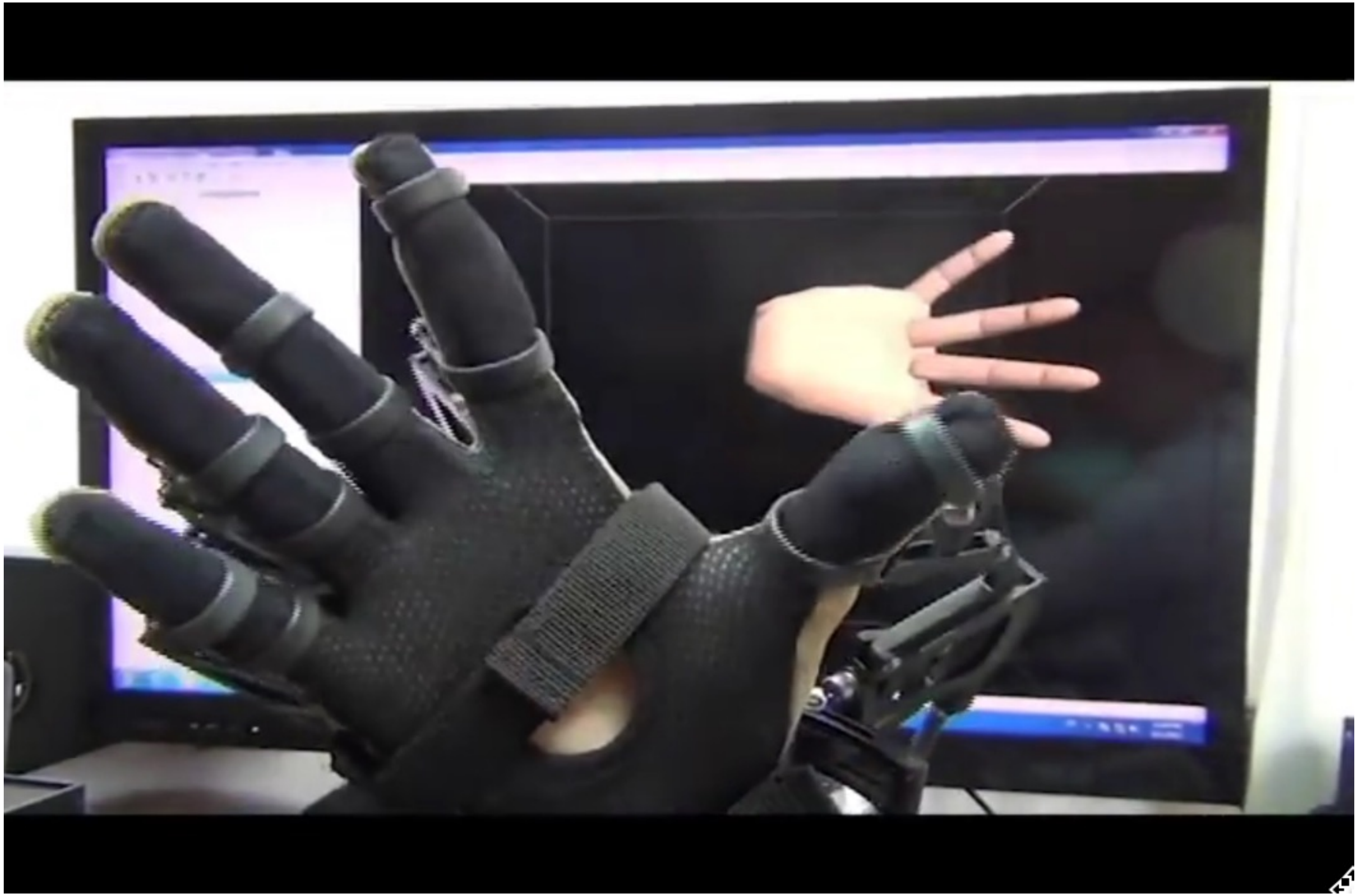
- Strain gauge at joints
- Connected to A/D converter





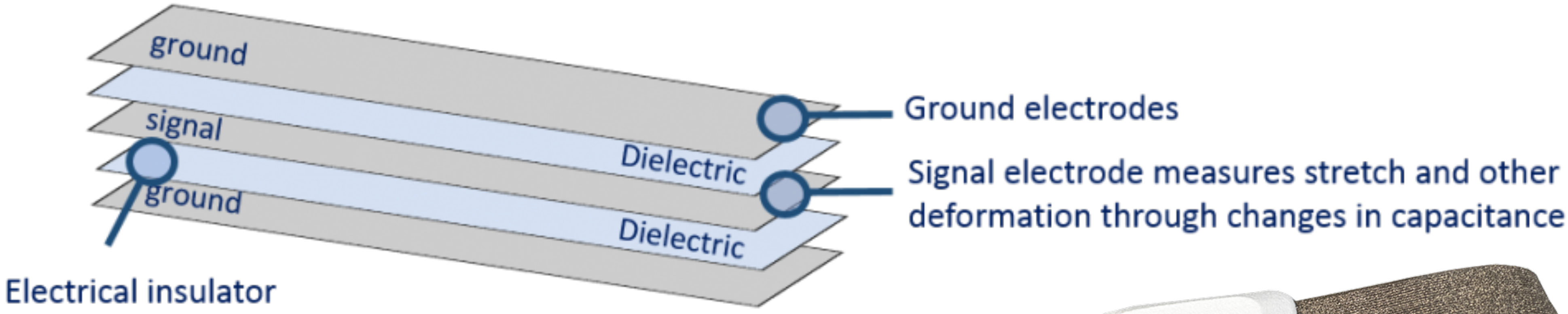


Demo Video



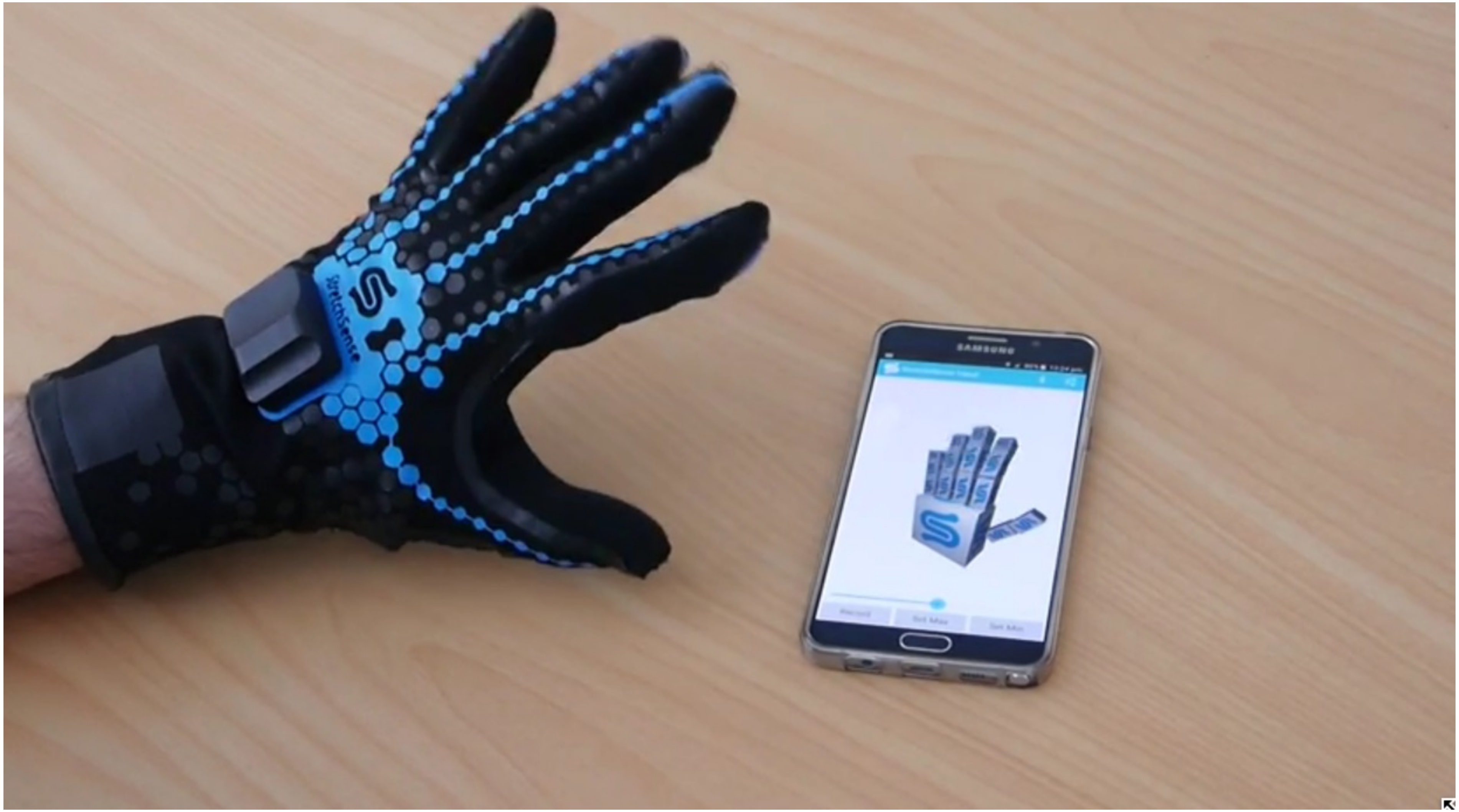
- https://www.youtube.com/watch?v=IUNx4FgQmas

StretchSense



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

StretchSense Glove Demo



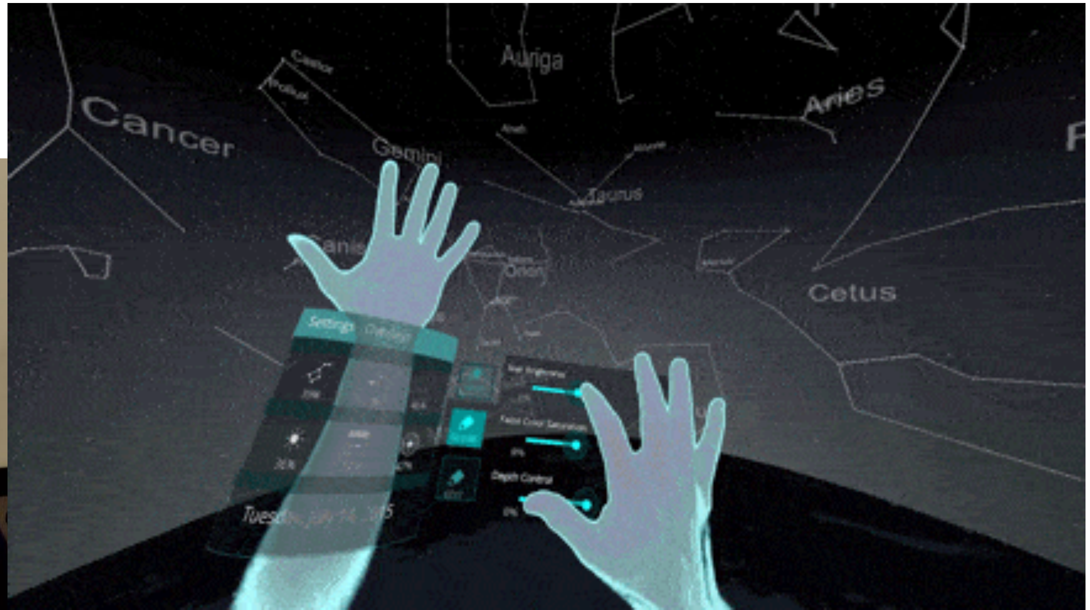
- https://www.youtube.com/watch?v=wYsZS0p5uu8

Comparison of Glove Performance

Specifications	Pinch Glove	5DT Data Glove	Didjiglove	CyberGlove
Number of sensors	7/glove (2 gloves)	5 or 14 /glove (1 glove)	10/glove (2 gloves)	18 or 22/glove (1 glove)
Sensor type	Electrical	Fiber-optic	Capacitive	Strain gauge
Records/sec	NA	100 (5DT 5W), 200 (5DT 5)	70	150 (unfiltered), 112 (filtered)
Sensor resolution	1 bit (2 points)	8 bit (256 points)	10 bit (1024 points)	0.5°
Communication rates	Wired (19.2 kb)	Wireless (9.600 kb), wired (19.2 kb)	Wired (19.2 kb)	Wired (115 kb)
Wrist sensors	None	Pitch (5DT 5 model)	None	Pitch and yaw

From Burdea, Virtual Reality Technology, 2003

Bare Hands



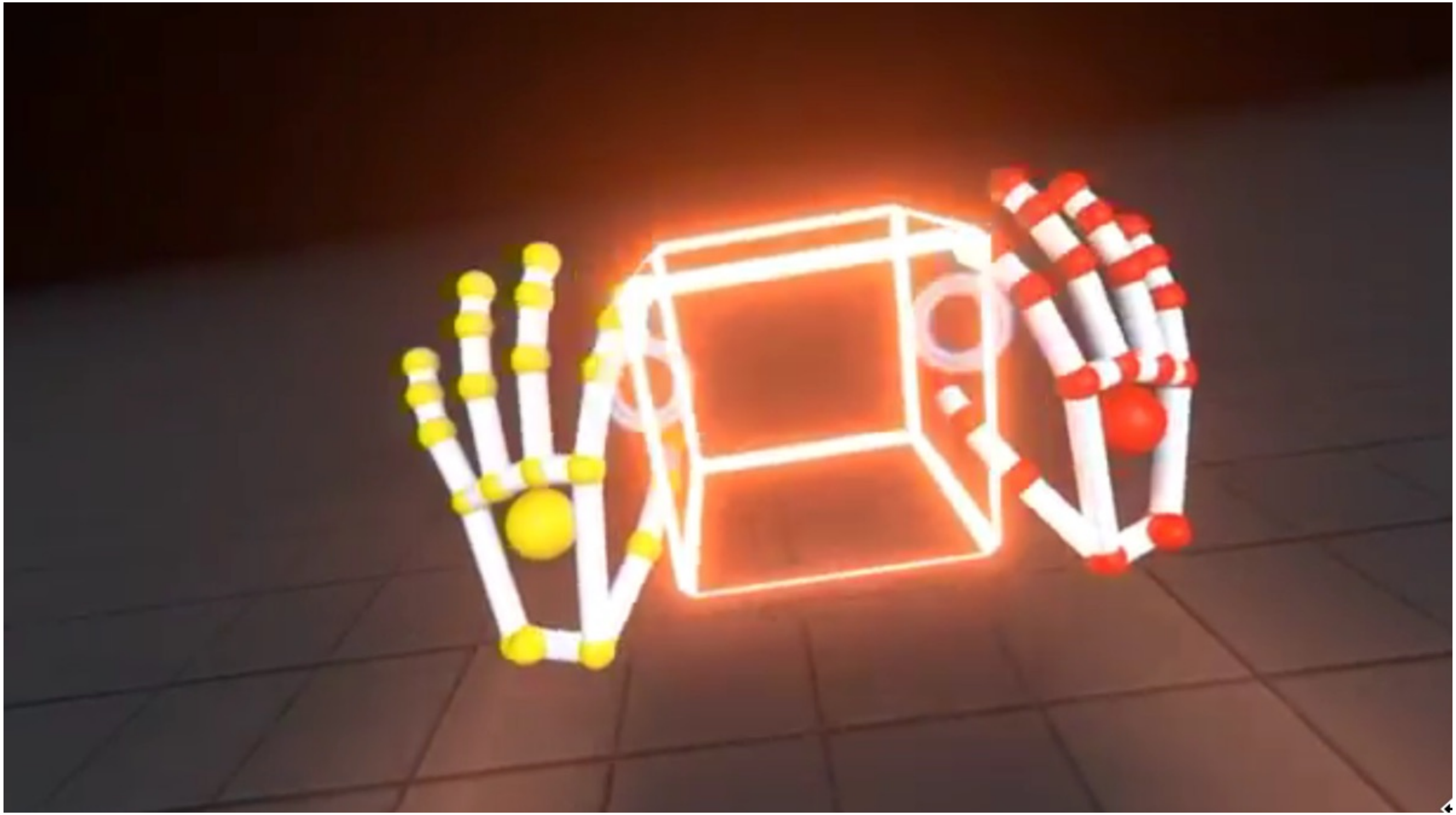
- Using computer vision to track bare hand input
- Creates compelling sense of Presence, natural interaction
- Challenges need to be solved
  - Not having sense of touch
  - Line of sight required to sensor
  - Fatigue from holding hands in front of sensor

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

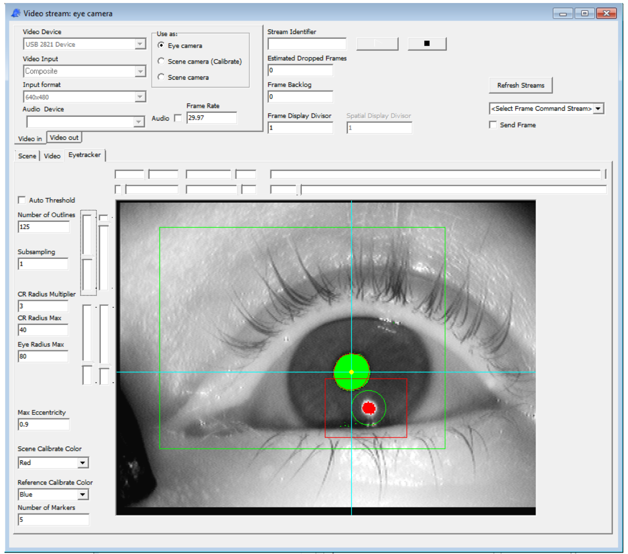


- https://www.youtube.com/watch?v=QD4qQBL0X80

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

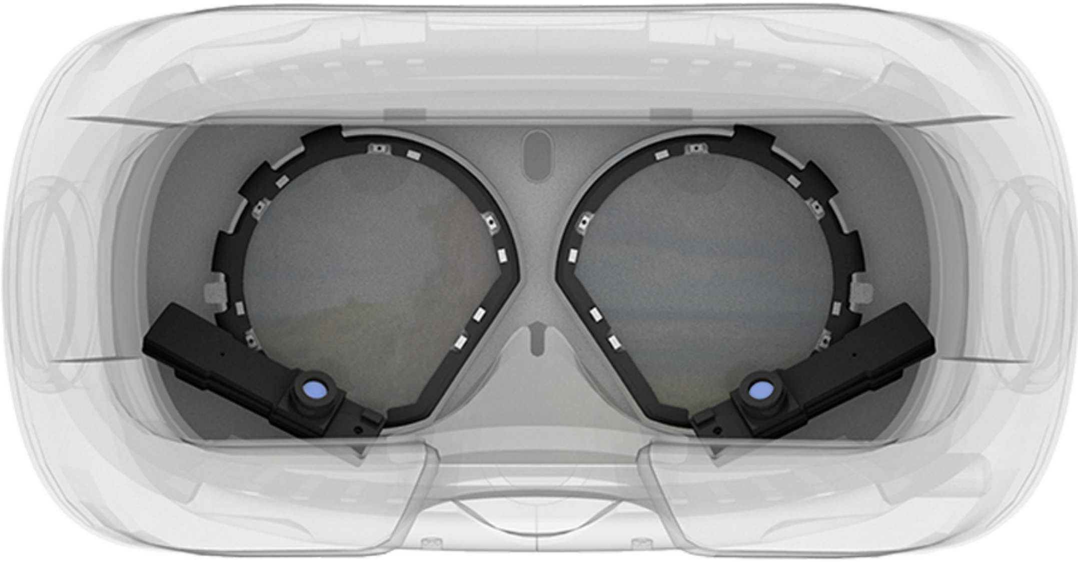


- Technology
  - Shine IR light into eye and look for reflections
- Advantages
  - Provides natural hands-free input
  - Gaze provides cues as to user attention
  - Can be combined with other input technologies

Example: FOVE VR Headset

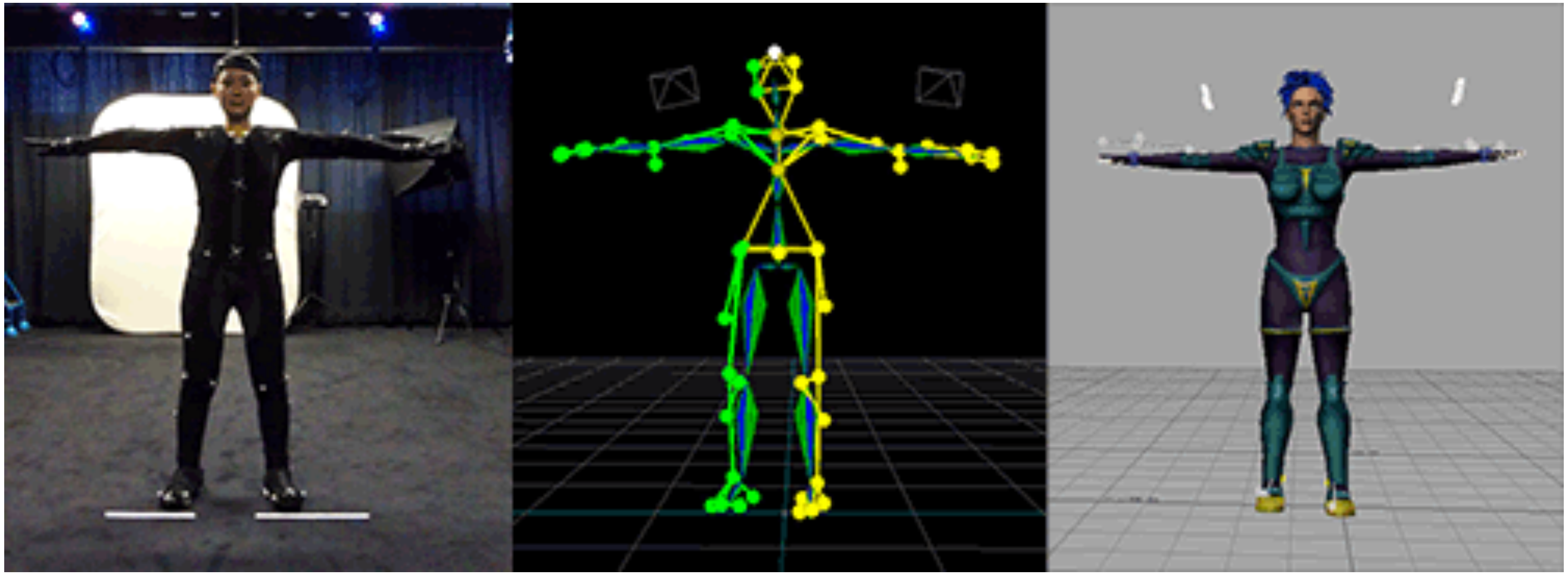
- Eye tracker integrated into VR HMD
- Gaze driven user interface, foveated rendering
- https://www.youtube.com/watch?v=8dwdzPaqsDY

Pupil Labs VIVE/Oculus Add-ons



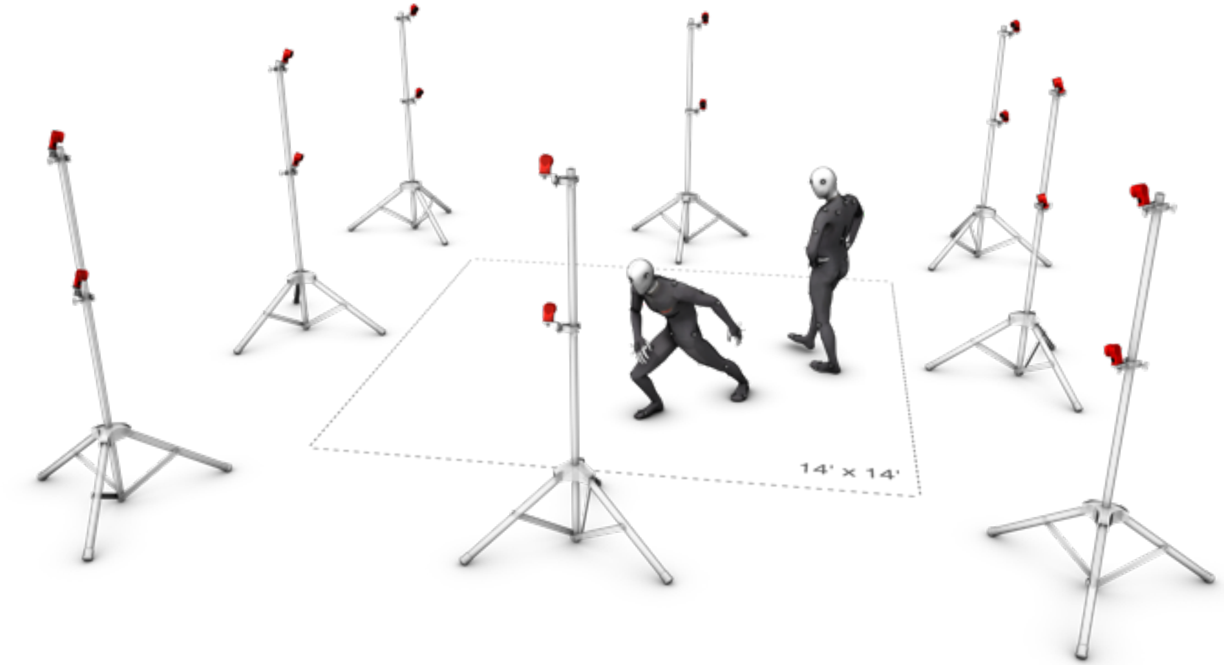
- Adds eye-tracking to HTC Vive/Oculus Rift HMDs
  - Mono or stereo eye-tracking
  - 120 Hz eye tracking, gaze accuracy of 0.6° with precision of 0.08°
  - Open source software for eye-tracking
- https://pupil-labs.com/pupil/

Full Body Tracking



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

Camera Based Motion Capture

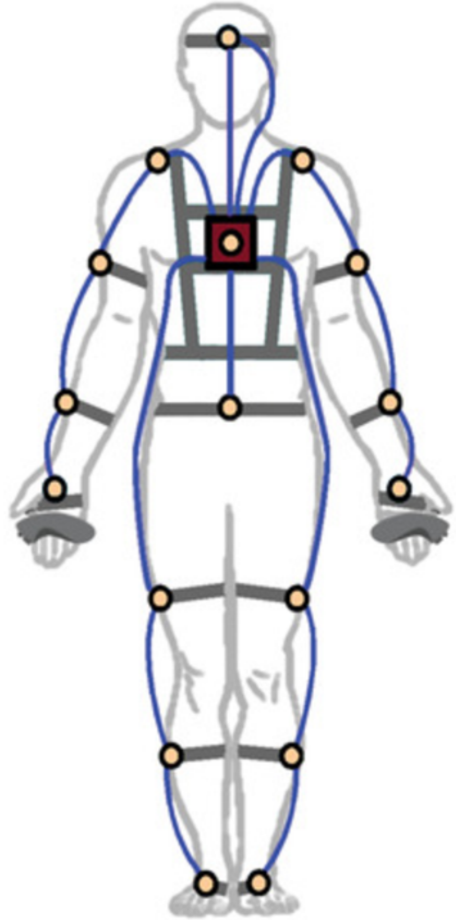


- Use multiple cameras
- Reflective markers on body
- Eg – Opitrack (www.optitrack.com)
  - 120 – 360 fps, < 10ms latency, < 1mm accuracy

Optitrack Demo

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

Wearable Motion Capture: PrioVR



17 sensor suit
Pro

- Wearable motion capture system
  - 8 – 17 inertial sensors + wireless data transmission
  - 30 – 40m range, 7.5 ms latency, 0.09^{o} 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=R8Imf3OFrms

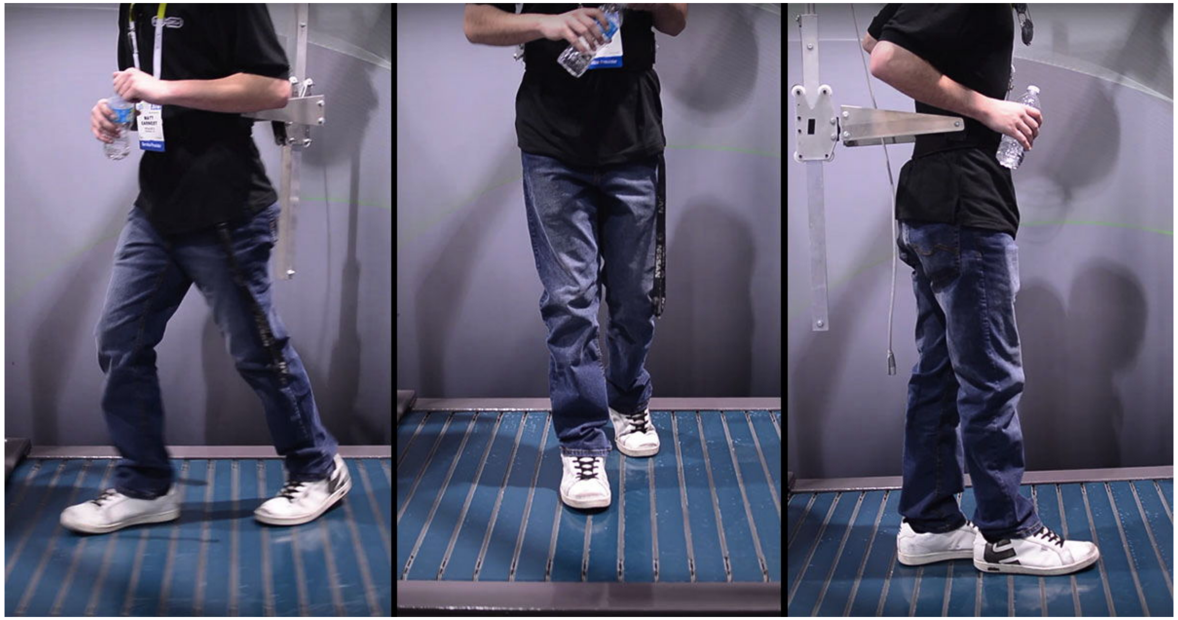
Virtusphere

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

Virtusphere Demo

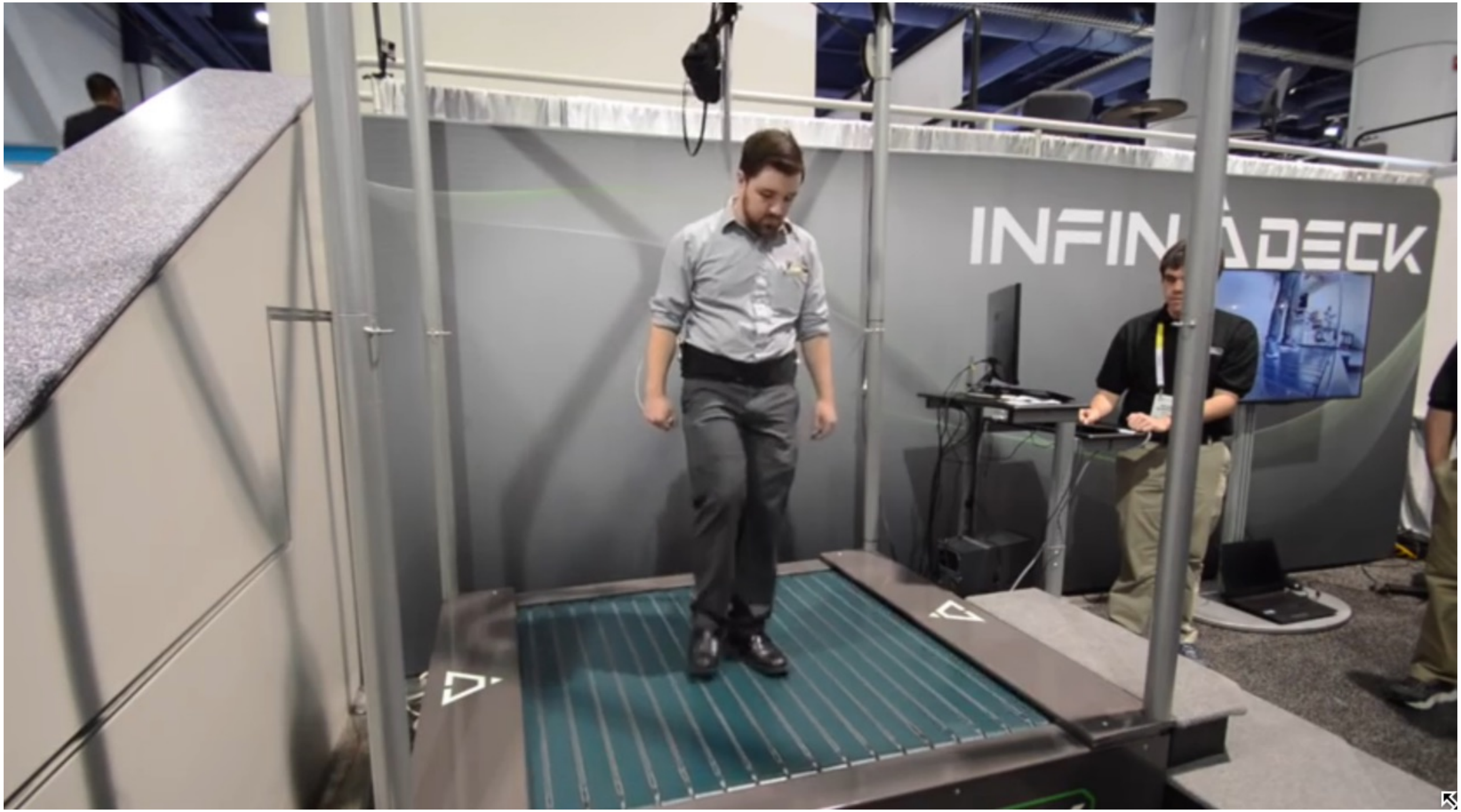
- https://www.youtube.com/watch?v=5PSFCnrk0GI

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

Comparison Between Devices

From Jerald (2015)

Comparing between hand and non-hand input

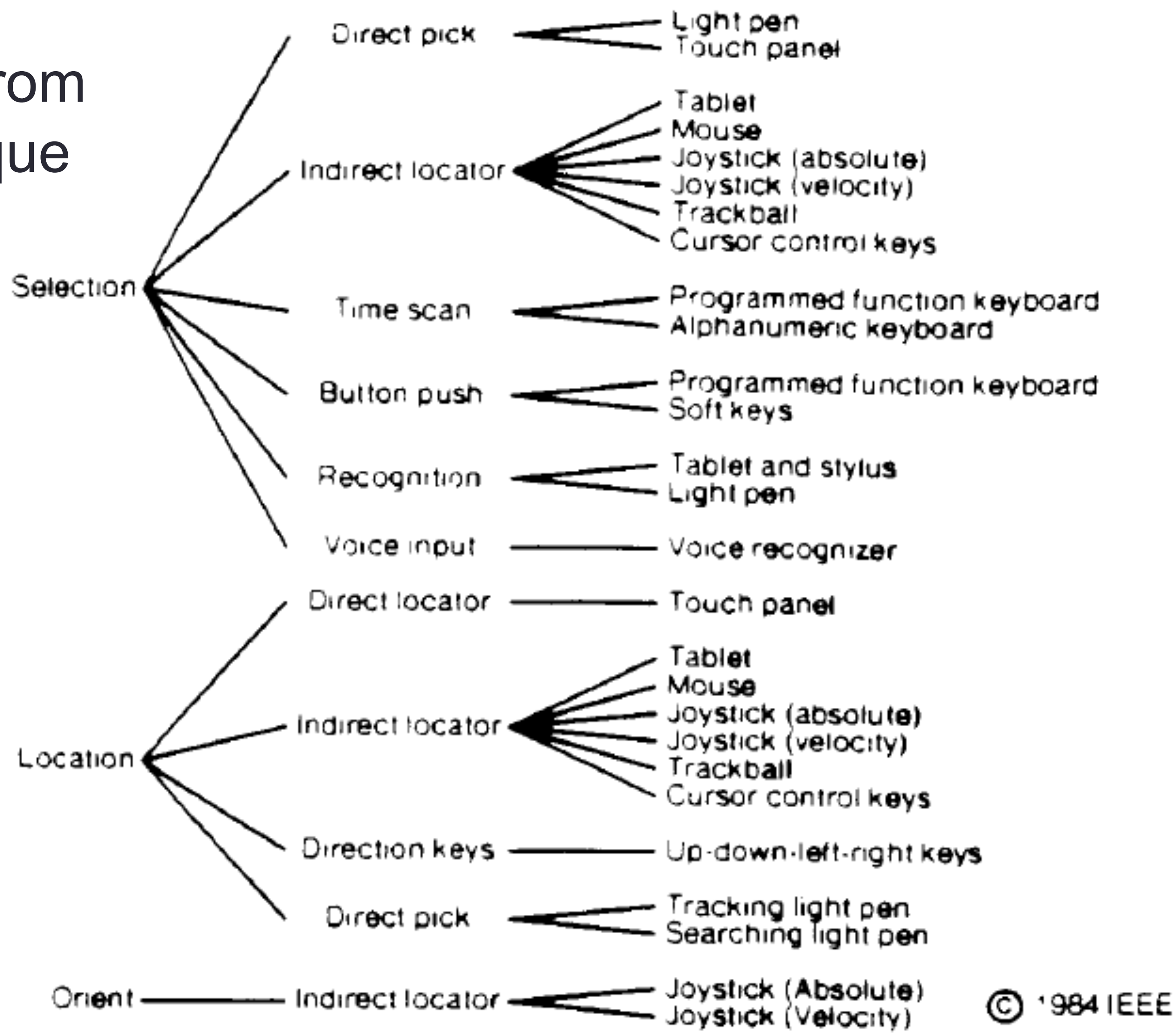
	Proprioception	Consistent	Usable in Lap or the Side	Haptics Capable	Unencumbered	Physical Buttons	Hands Free to Interact with Real World	General Purpose
Hand Input Device Class								
World-Grounded Devices	✓	✓		✓	✓	✓	✓	
Non-Tracked Hand-Held Controllers		✓	✓	✓		✓		
Bare Hands	✓				✓		✓	✓
Tracked Hand-Held Controllers	✓	✓	✓	✓		✓		✓
Hand Worn	✓	✓	✓	✓		✓	✓	✓
Non-Hand Input Device Class								
Head Tracking	✓	✓					✓	✓
Eye Tracking							✓	
Microphone			✓		✓		✓	✓
Full-Body Tracking	✓	✓	✓	✓			✓	✓
Treadmills	✓	✓			✓		✓	

Input Device Taxonomies

- Helps to determine:
  - Which devices can be used for each other
  - What devices to use for particular tasks
- Many different approaches
  - Separate the input device from interaction technique (Foley 1974)
  - Mapping basic interactive tasks to devices (Foley 1984)
    - Basic tasks – select, position, orient, etc.
    - Devices – mouse, joystick, touch panel, etc.
  - Consider Degrees of Freedom and properties sensed (Buxton 1983)
    - motion, position, pressure
  - Distinguish bet. absolute/relative input, individual axes (Mackinlay 1990)
    - separate translation, rotation axes instead of using DOF

Foley and Wallace Taxonomy (1974)

Separate device from interaction technique



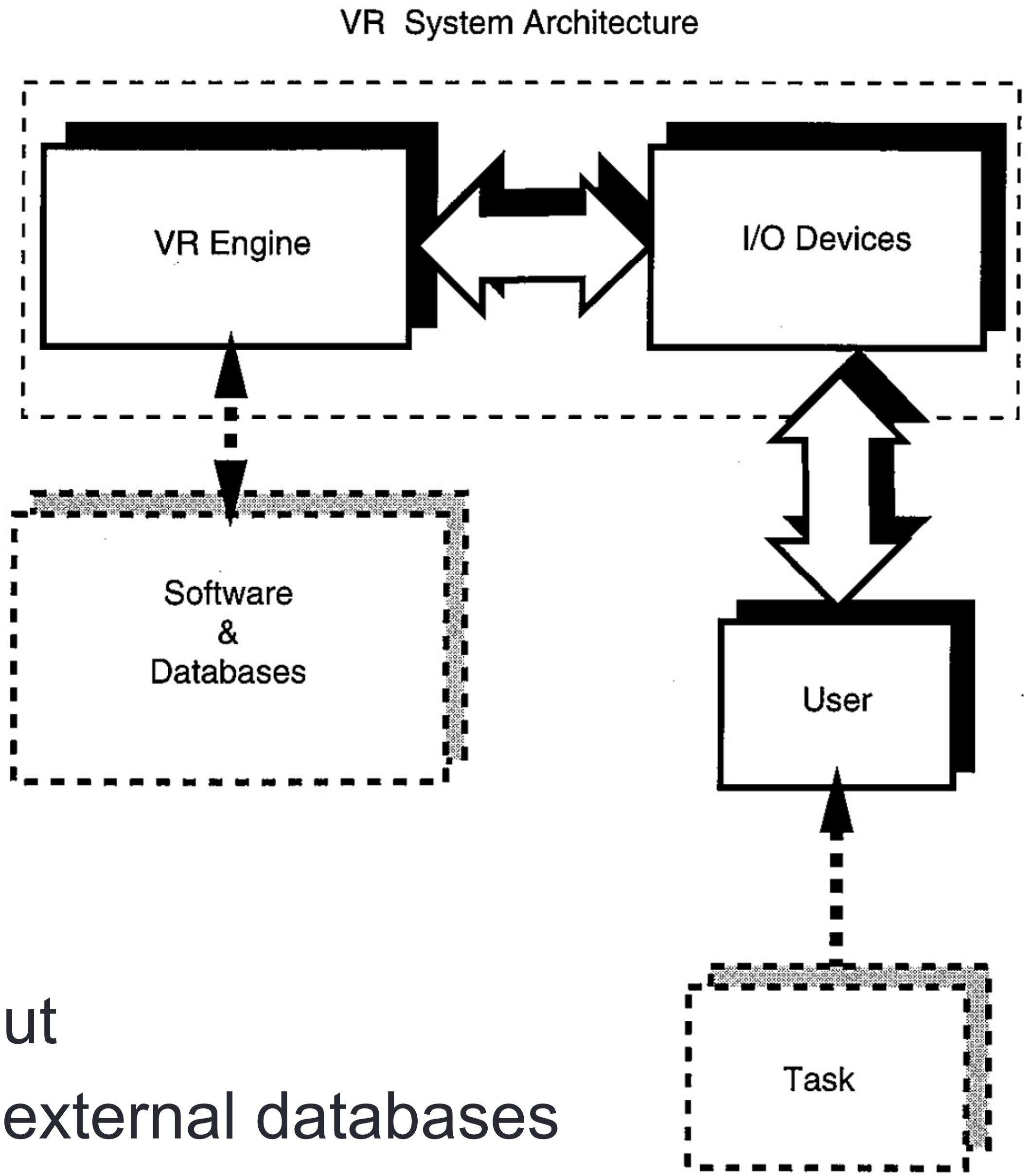
Buxton Input Device Taxonomy (Buxton 1983)

Property Sensed		Number of Dimensions					
		1		2		6	
Position		Bend Sensor	Linear Slider	Tablet and Stylus	Isotonic Joystick	Trackers (Position & Orientation)	M
				Touch Tablet			T
Motion			Treadmill	Mouse	TrackBall		M
Pressure		Torque Sensor			Isometric Joystick	SpaceBall & SpaceMouse	T

- Classified according to degrees of freedom and property sensed
  - M = devise uses an intermediary between hand and sensing system
  - T = touch sensitive

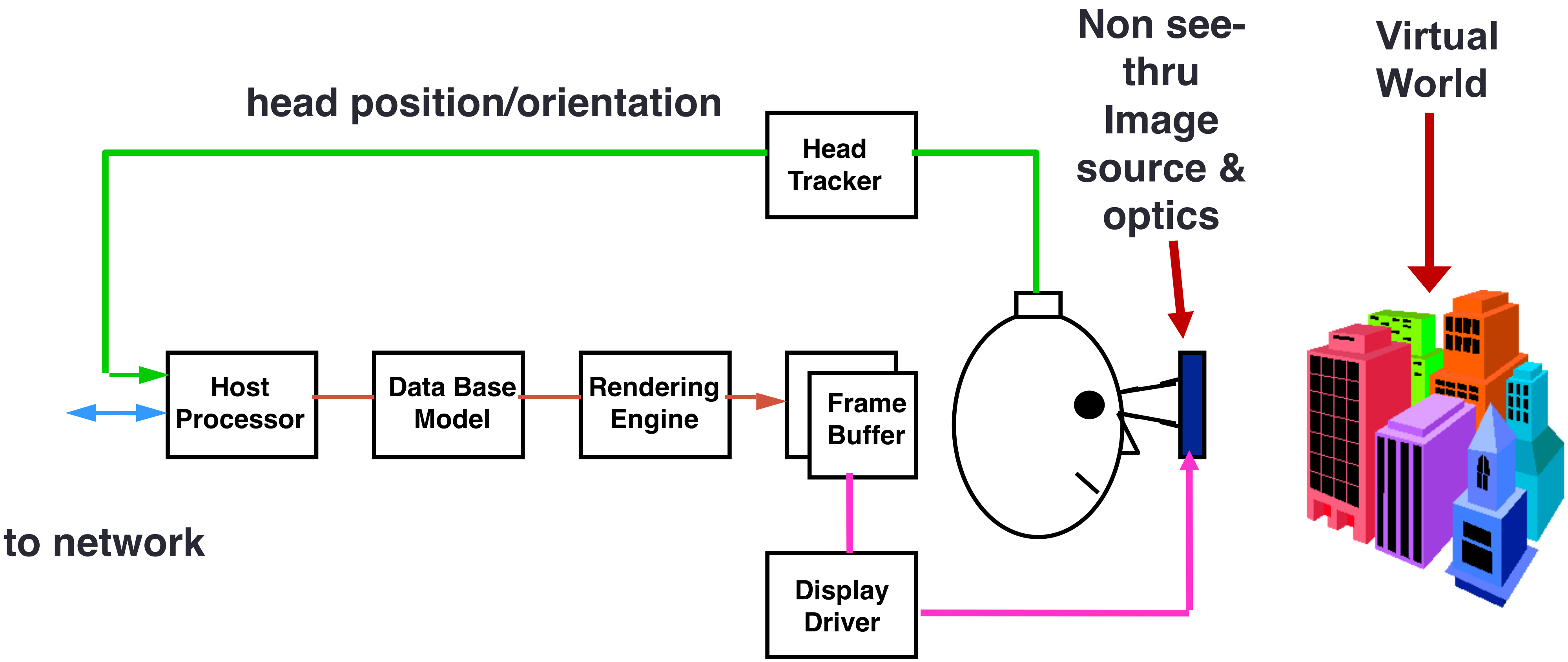
VR SYSTEMS

Basic VR System

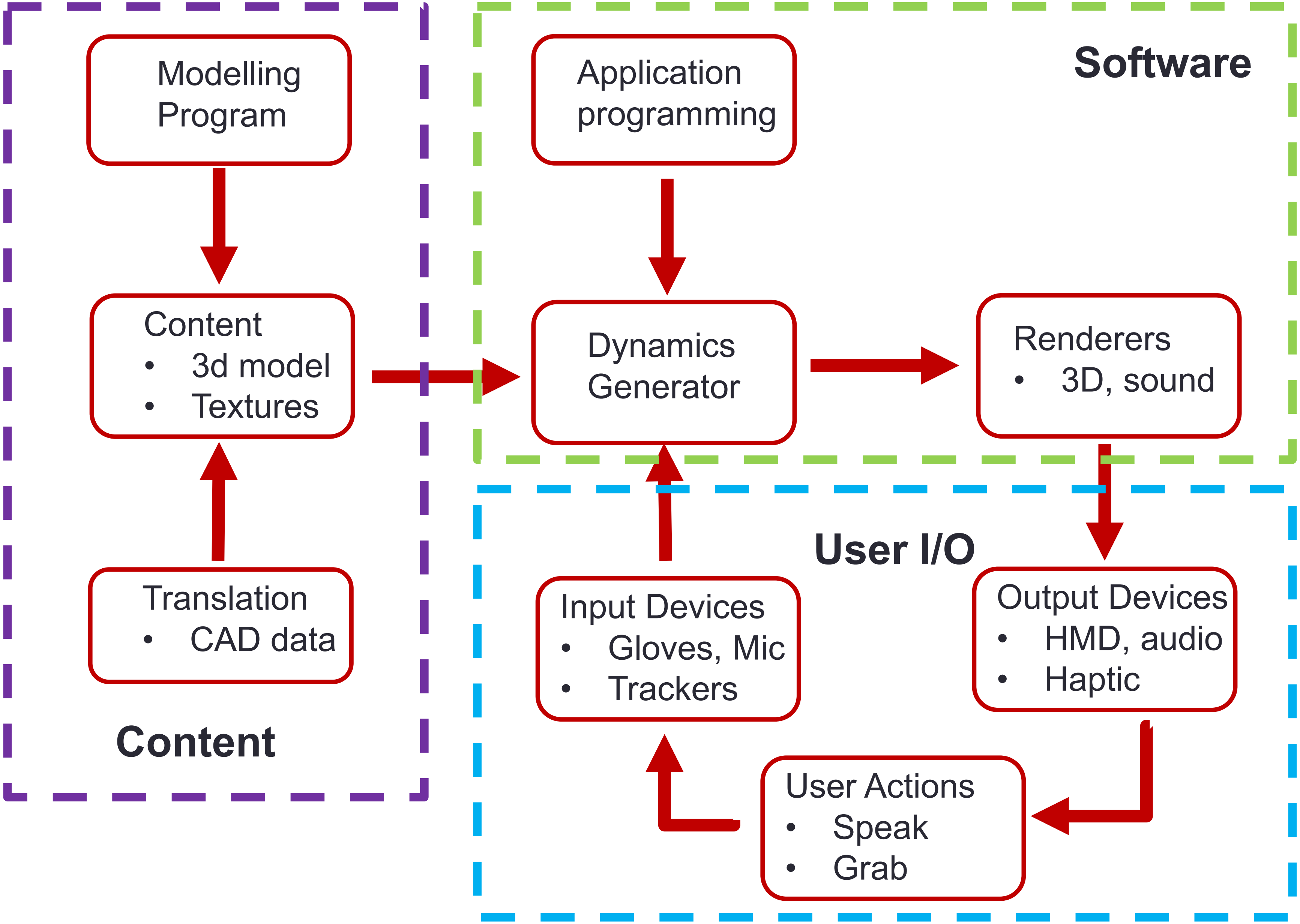


- High level overview
  - User engaged in task
  - User provides input
  - VR engine provides output
  - VR engine connected to external databases

Simple System Architecture



From Content to User

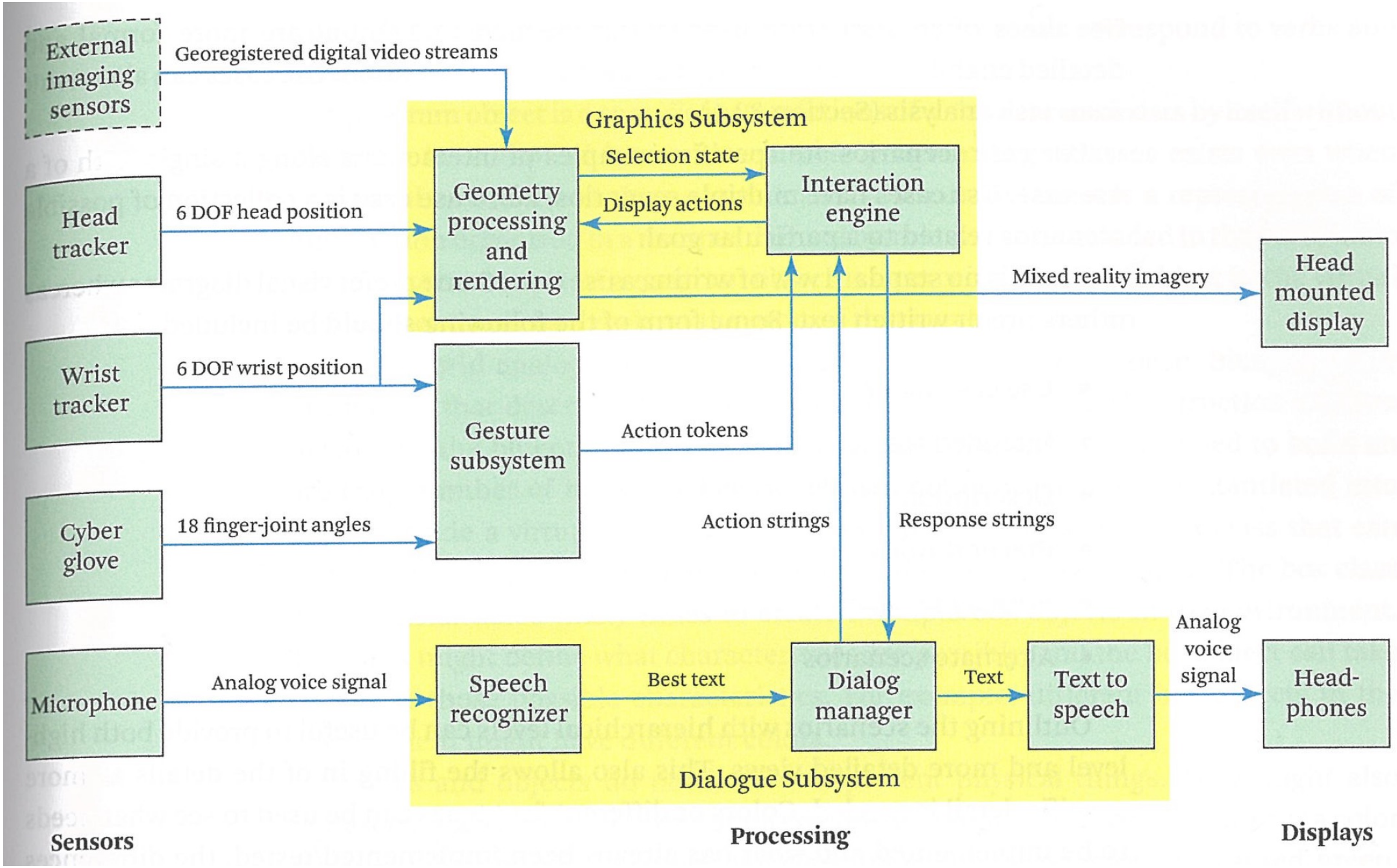


Case Study: Multimodal VR System

- US Army project
  - Simulate control of an unmanned vehicle
- Sensors (input)
  - Head/hand tracking
  - Gesture, Speech (Multimodal)
- Displays (output)
  - HMD, Audio
- Processing
  - Graphics: Virtual vehicles on battlefield
  - Speech processing/understanding

Neely, H. E., Belvin, R. S., Fox, J. R., & Daily, M. J. (2004, March). Multimodal interaction techniques for situational awareness and command of robotic combat entities. In *Aerospace Conference, 2004. Proceedings. 2004 IEEE* (Vol. 5, pp. 3297-3305). IEEE.

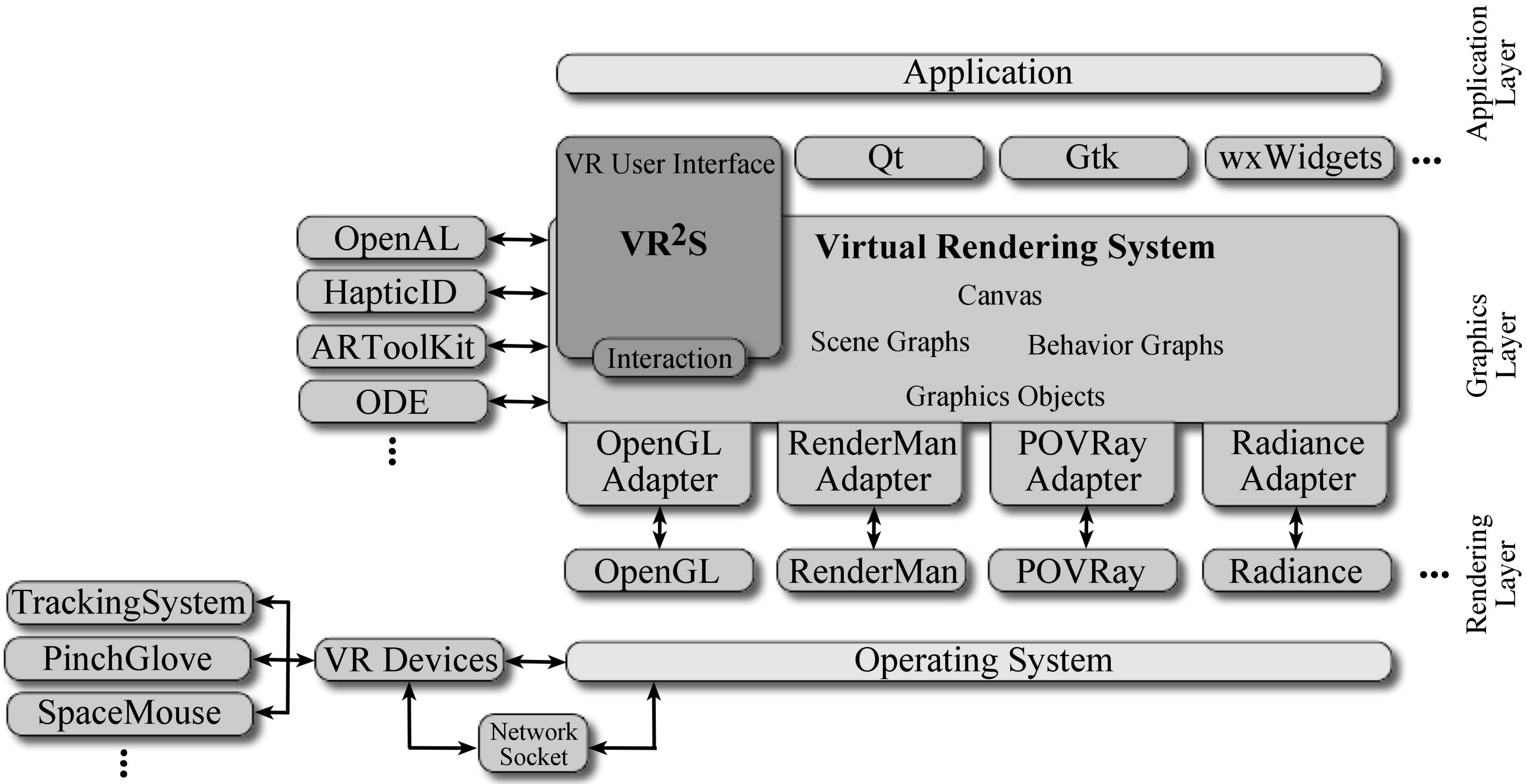
System Diagram



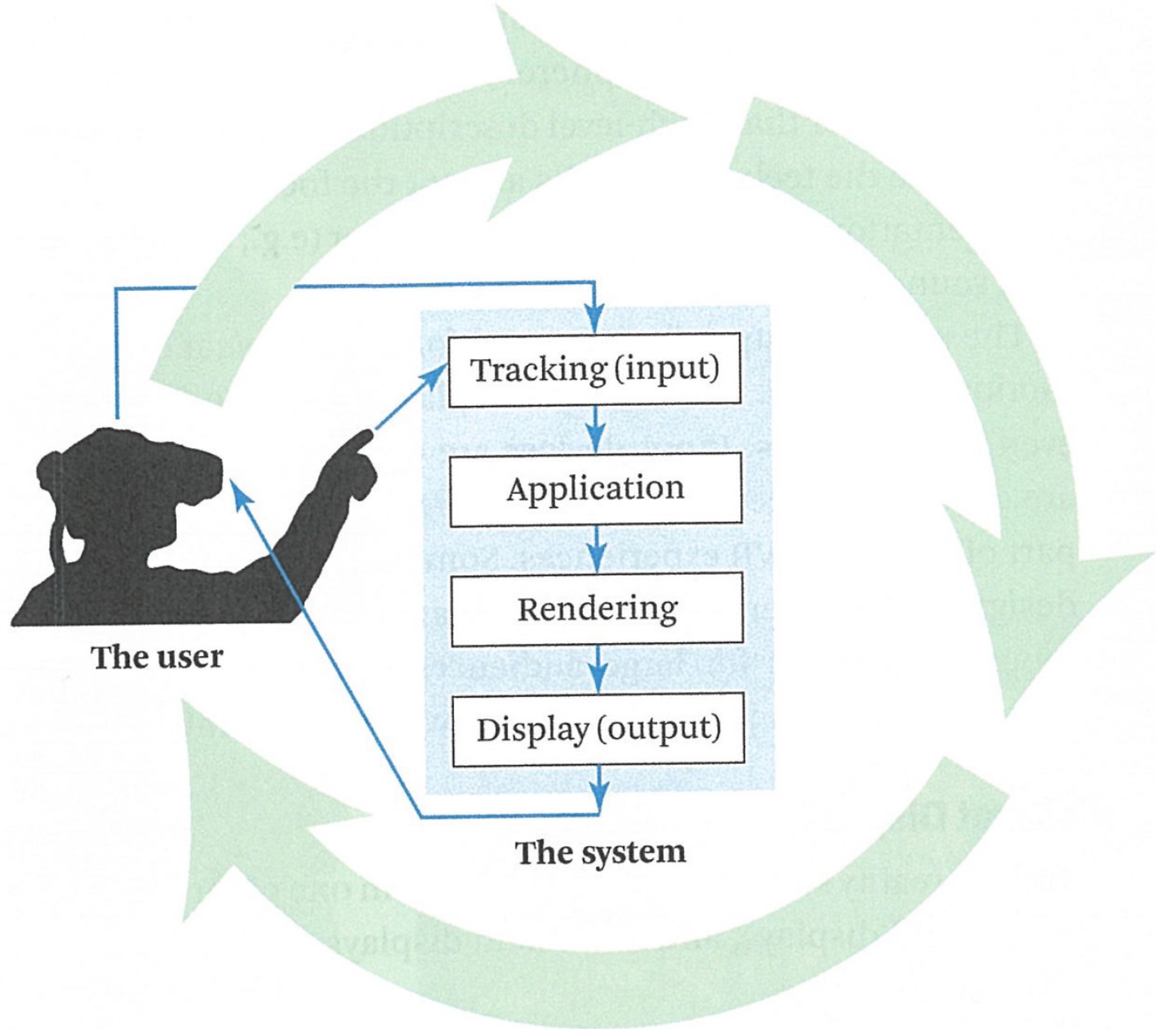
VR Graphics Architecture

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

Typical Graphics Architecture

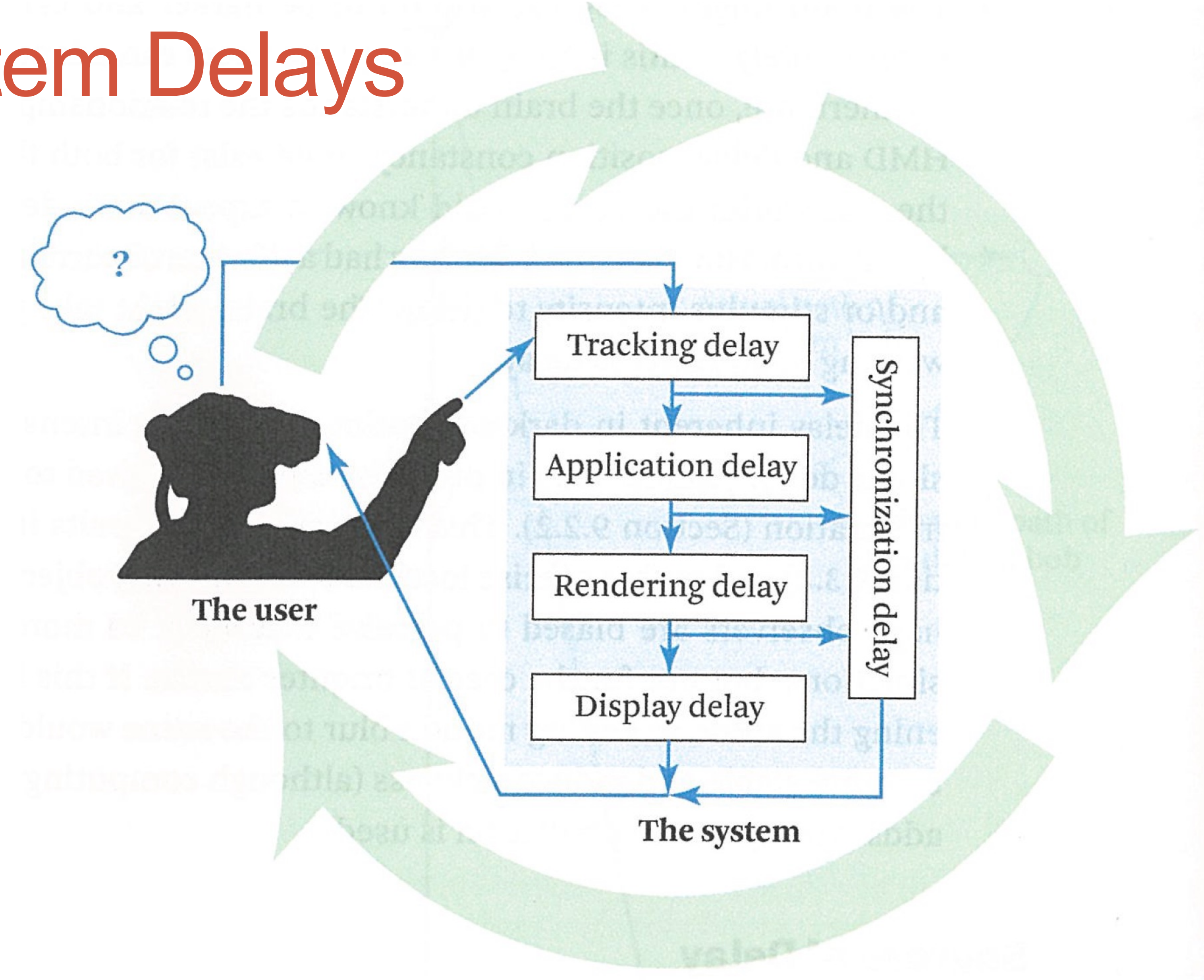


Typical VR Simulation Loop



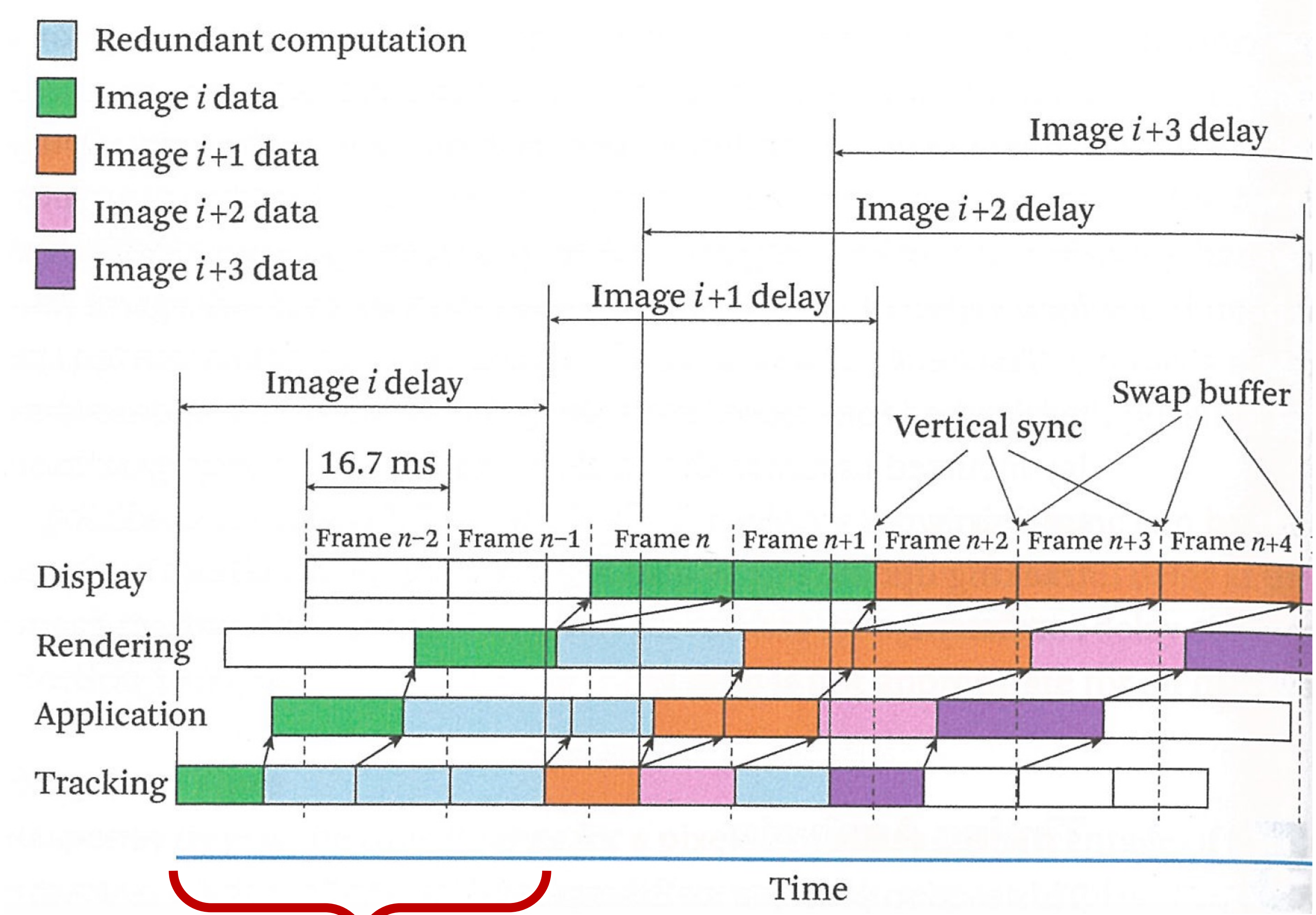
- User moves head, scene updates, displayed graphics change

System Delays



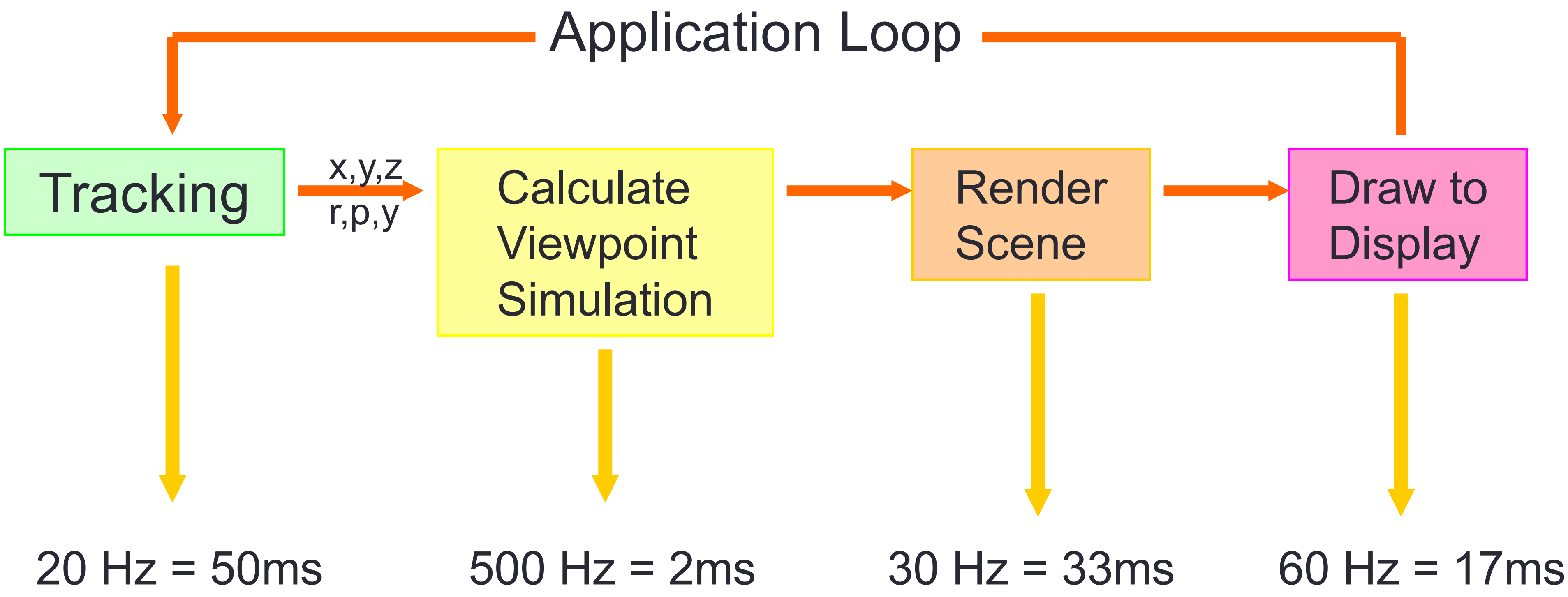
- Need to synchronize system to reduce delays

Typical Delay from Tracking to Rendering



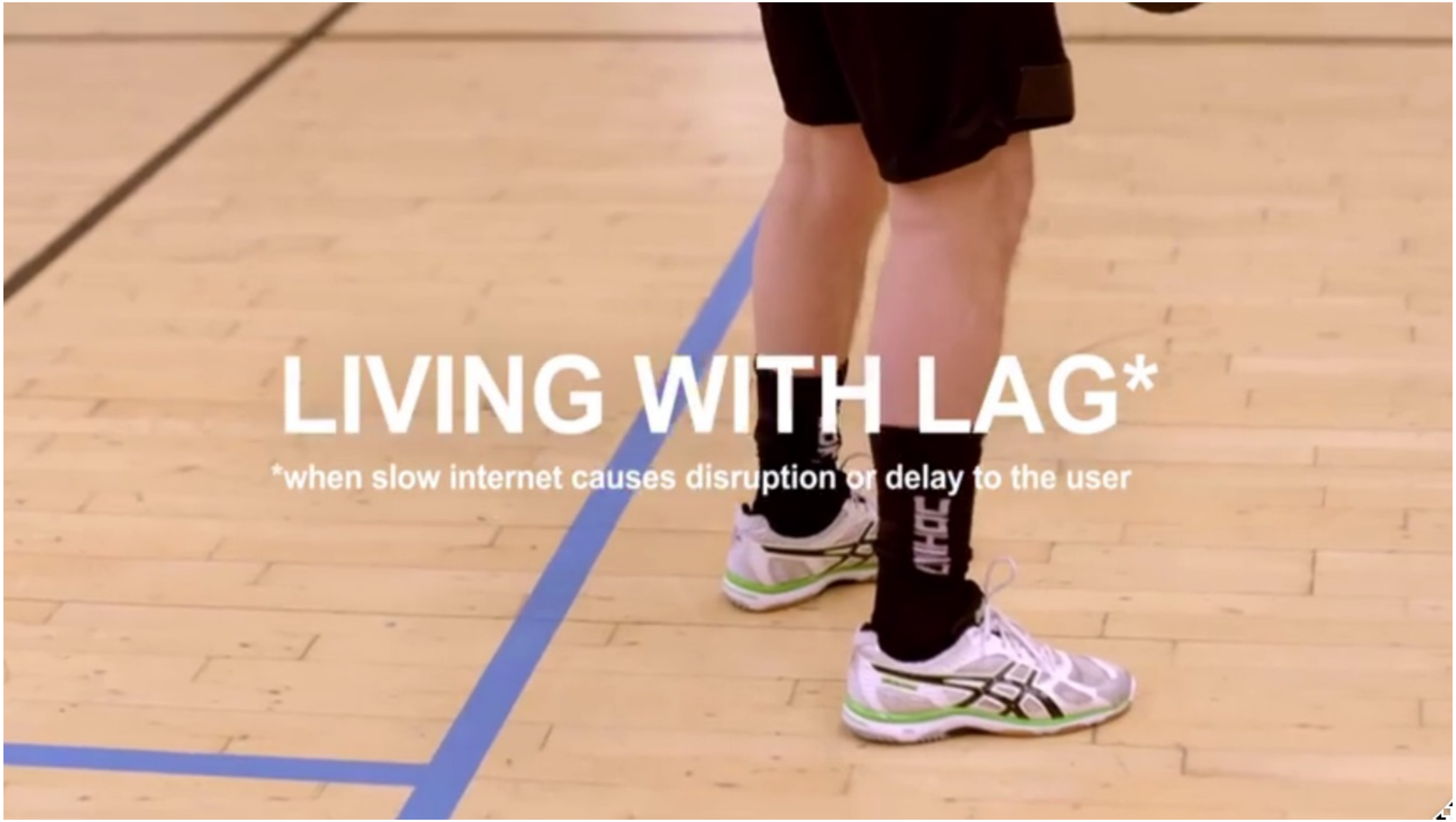
System Delay

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 total of 33mm error from when user begins moving to when object drawn

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

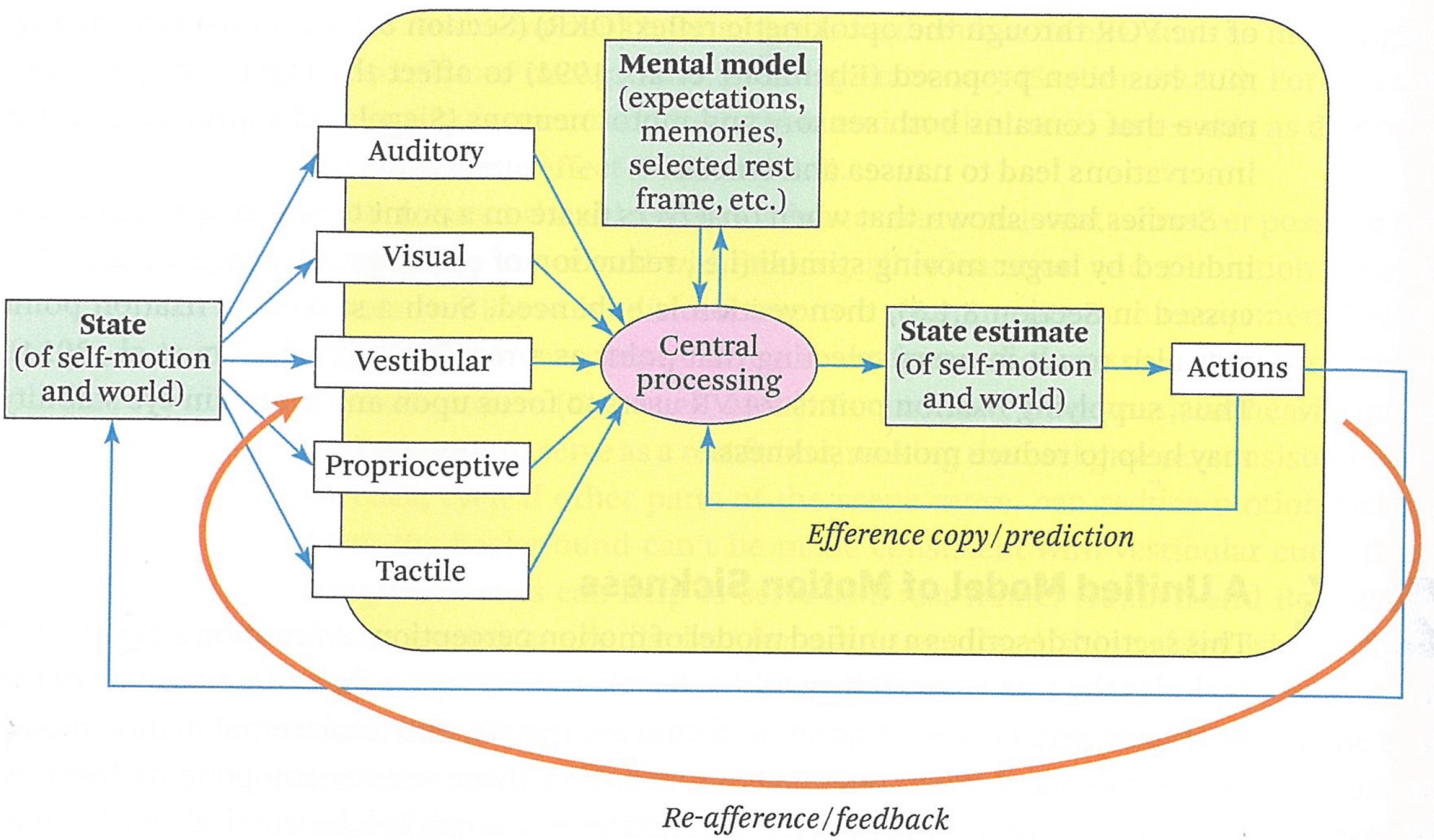


- https://www.youtube.com/watch?v=_fNp37zFn9Q

Effects of System Latency

- Degraded Visual Acuity
  - 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

Simulator Sickness

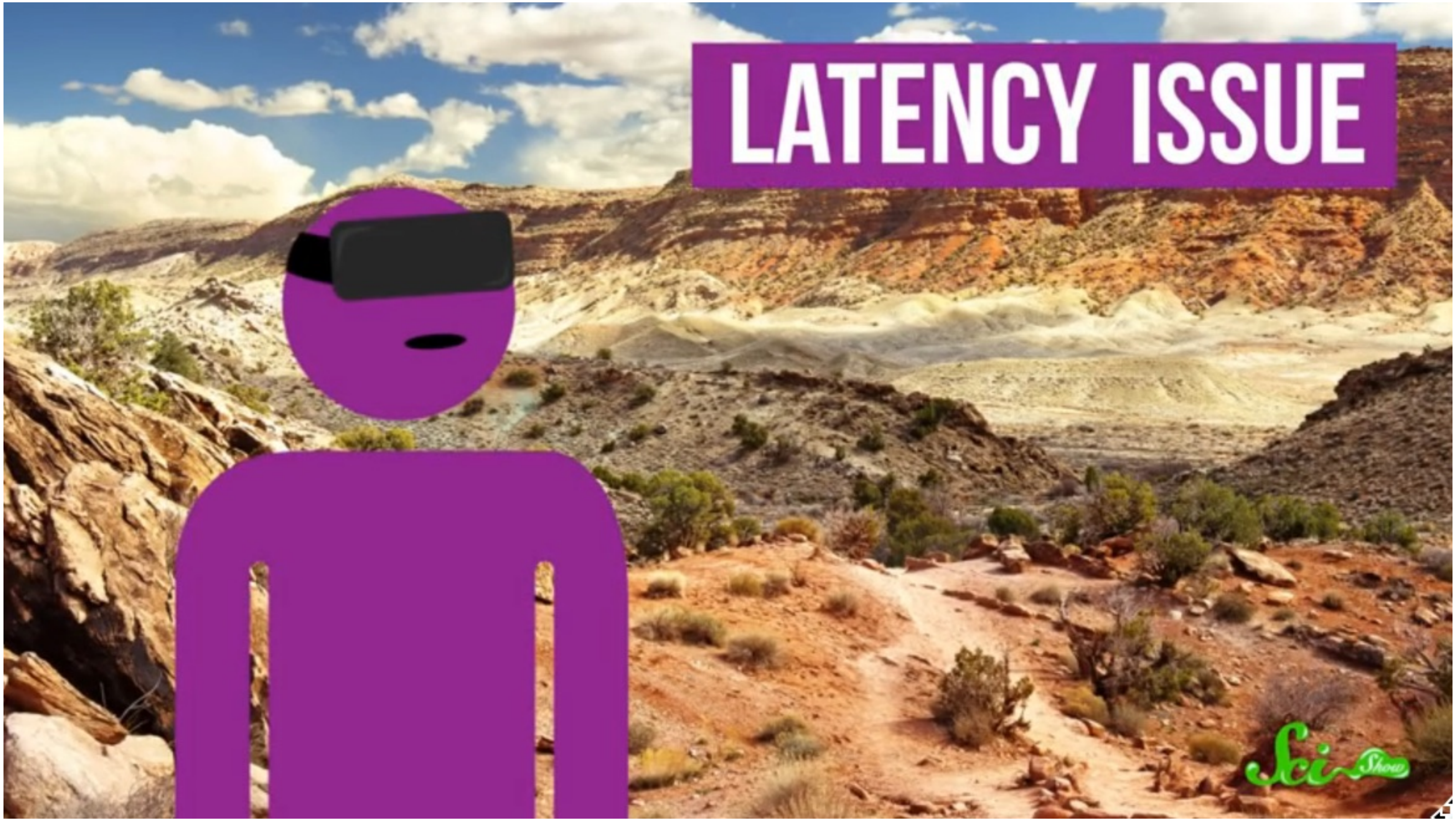


- Visual input conflicting with vestibular system

Many Causes of Simulator Sickness

- 25-40% of VR users get Simulator Sickness, due to:
- Latency
  - Major cause of simulator sickness
- Tracking accuracy/precision
  - Seeing world from incorrect position, viewpoint drift
- Field of View
  - Wide field of view creates more periphery vection = sickness
- Refresh Rate/Flicker
  - Flicker/low refresh rate creates eye fatigue
- Vergence/Accommodation Conflict
  - Creates eye strain over time
- Eye separation
  - If IPD not matching to inter-image distance then discomfort

Motion Sickness



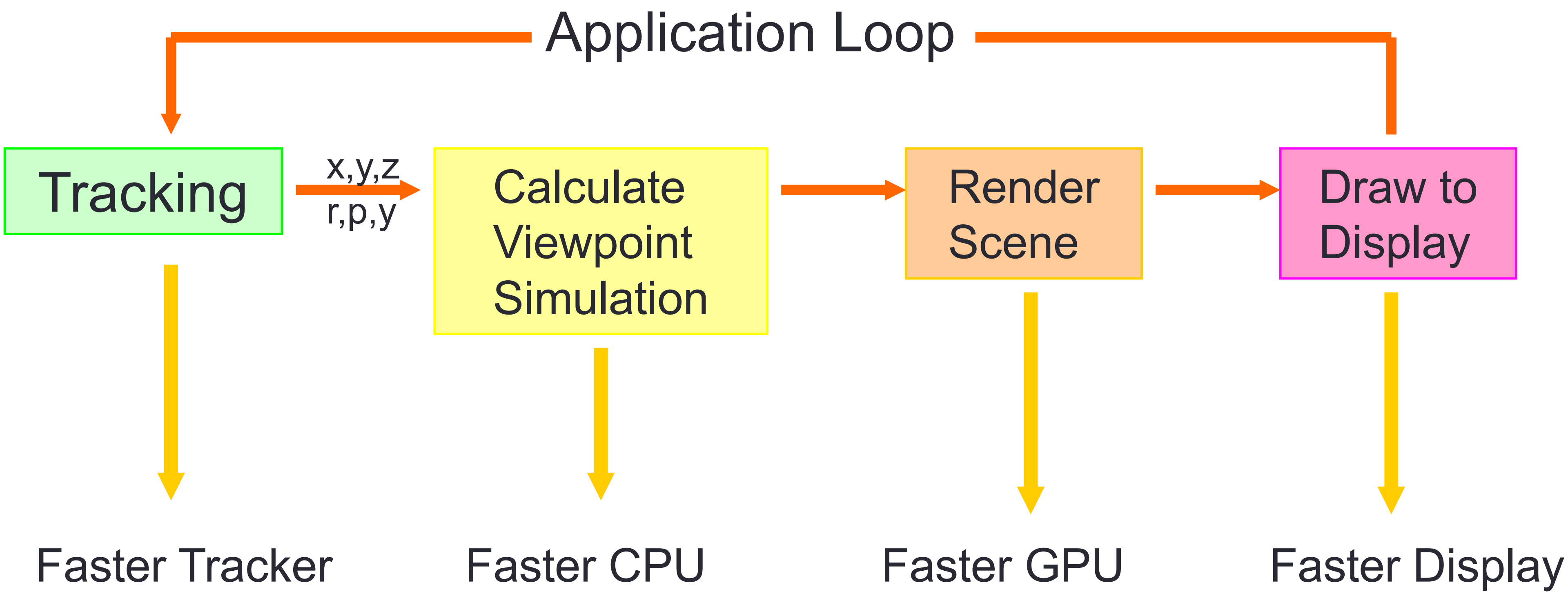
- https://www.youtube.com/watch?v=BznbIIW8iqE

How to Reduce System Delays

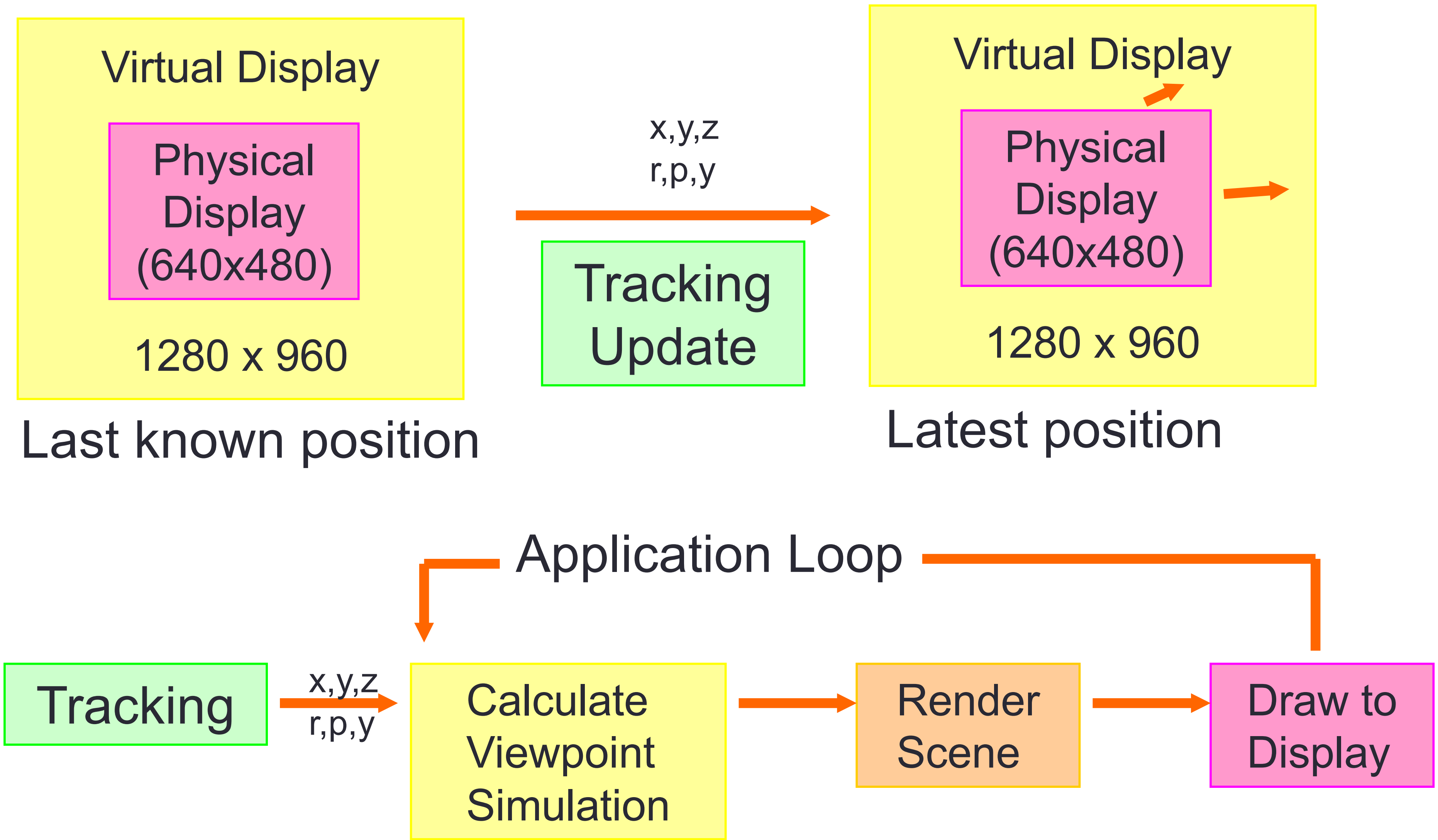
- Use faster components
  - Faster CPU, display, etc.
- Reduce the apparent lag
  - Take tracking measurement just before rendering
  - Remove tracker from the loop
- Use predictive tracking
  - Use fast inertial sensors to predict where user will be looking
  - Difficult due to erratic head movements

Jerald, J. (2004). *Latency compensation for head-mounted virtual reality*. UNC Computer Science Technical Report.

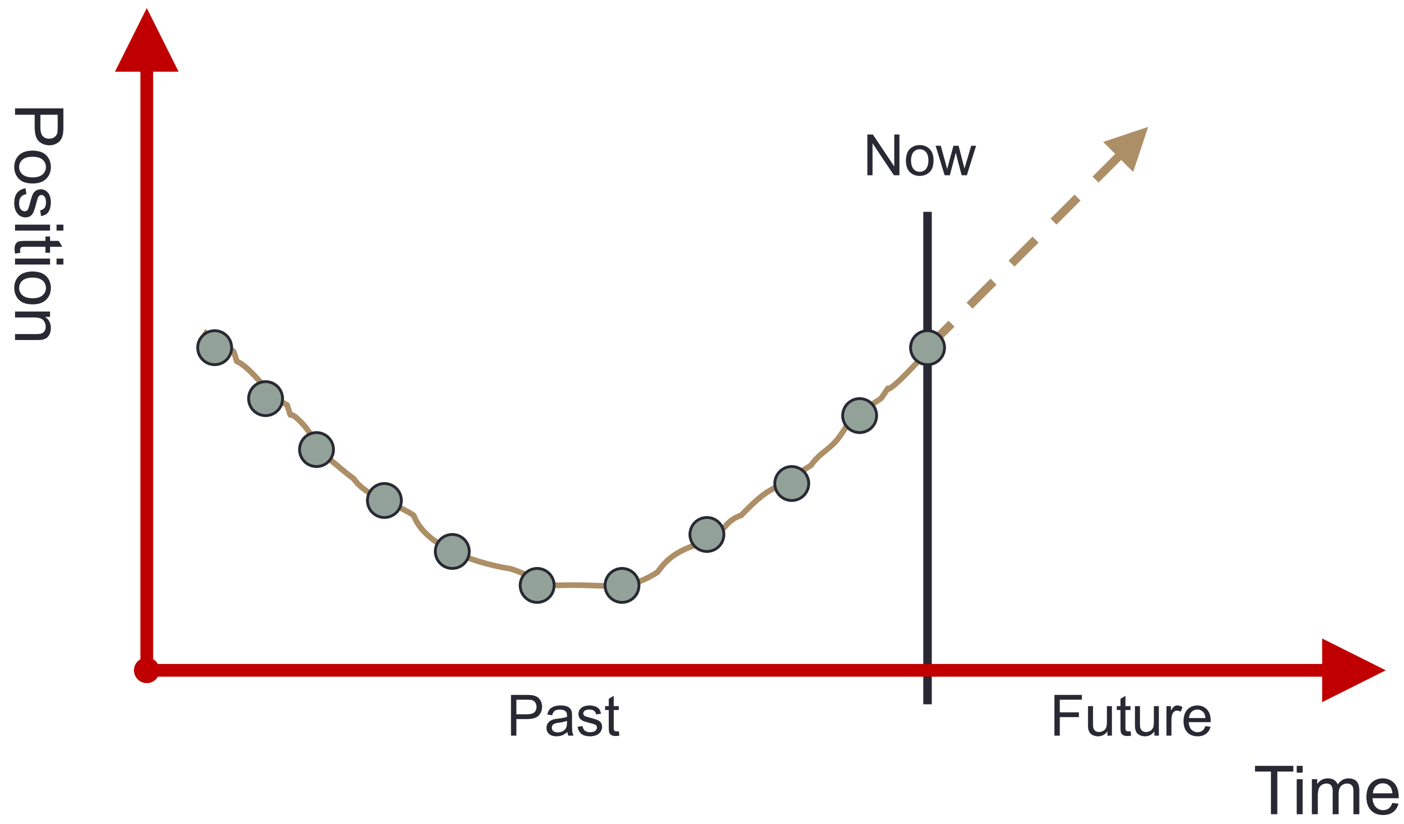
Reducing System Lag



Reducing Apparent Lag



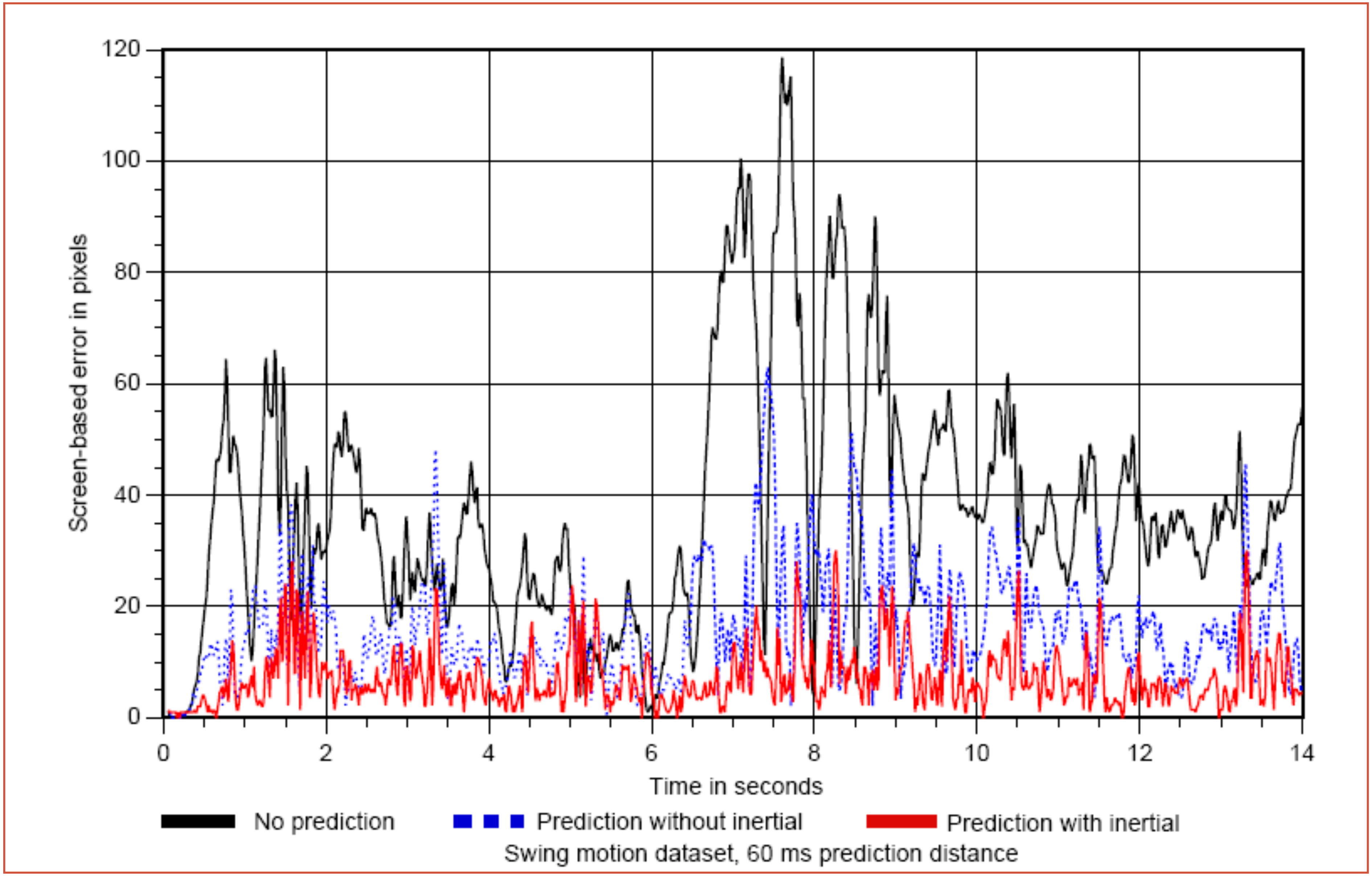
Predictive Tracking



Use additional sensors (e.g. inertial) to predict future position

- Can reliably predict up to 80 ms in future (Holloway)
- Use Kalman filters or similar to smooth prediction

Predictive Tracking Reduces Error (Azuma 94)



System Design Guidelines - I

- Hardware
  - Choose HMDs with fast pixel response time, no flicker
  - Choose trackers with high update rates, accurate, no drift
  - Choose HMDs that are lightweight, comfortable to wear
  - Use hand controllers with no line of sight requirements
- System Calibration
  - Have virtual FOV match actual FOV of HMD
  - Measure and set users IPD
- Latency Reduction
  - Minimize overall end to end system delay
  - Use displays with fast response time and low persistence
  - Use latency compensation to reduce perceived latency

Jason Jerald, *The VR Book*, 2016

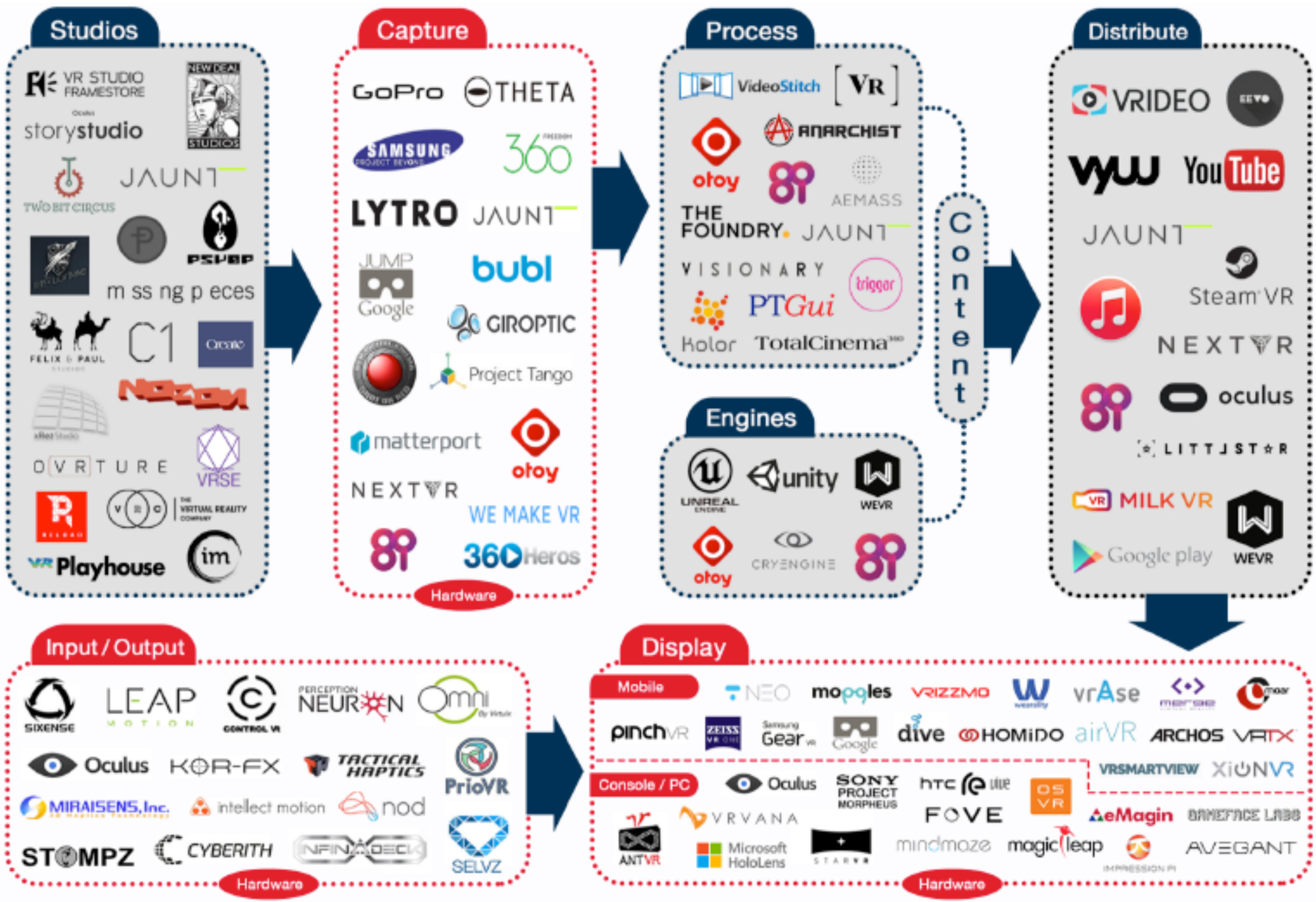
System Design Guidelines - II

- General Design
  - Design for short user experiences
  - Minimize visual stimuli closer to eye (vergence/accommodation)
  - For binocular displays, do not use 2D overlays/HUDs
  - Design for sitting, or provide physical barriers
  - Show virtual warning when user reaches end of tracking area
- Motion Design
  - Move virtual viewpoint with actual motion of the user
  - If latency high, no tasks requiring fast head motion
- Interface Design
  - Design input/interaction for user's hands at their sides
  - Design interactions to be non-repetitive to reduce strain injuries

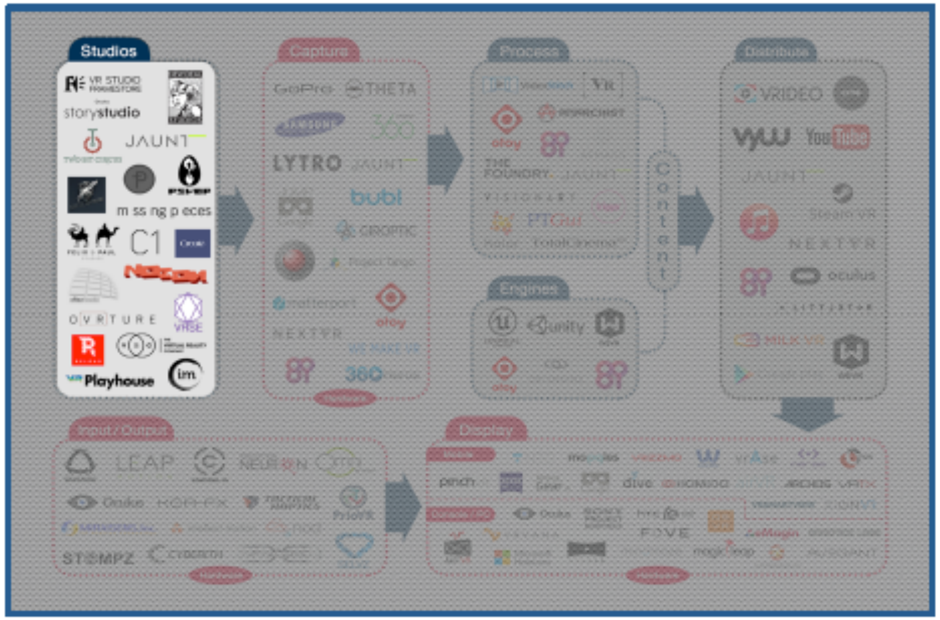
Jason Jerald, *The VR Book*, 2016

VR LANDSCAPE

Landscape of VR



VR Studios

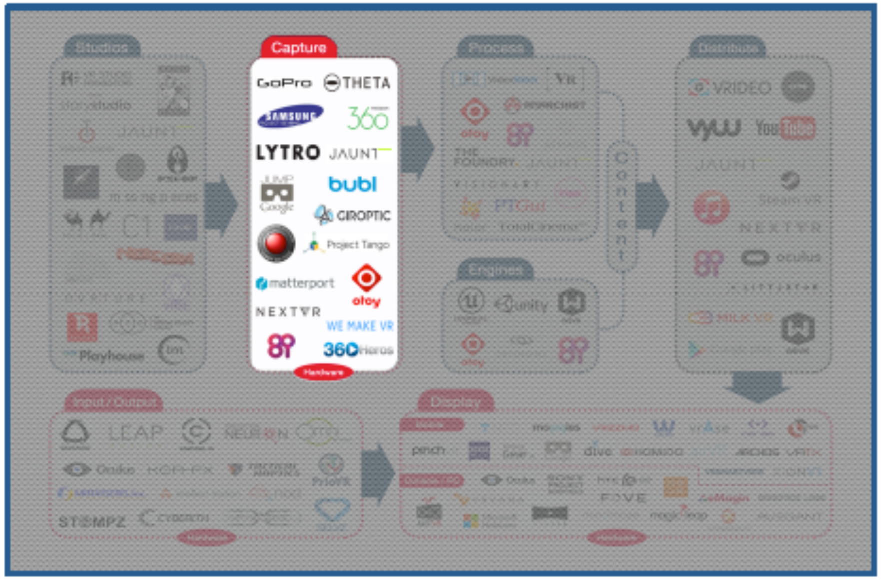

Studios
storystudio
JAUNT
Playhouse
LYTRO
bubl


Jurassic World
FILM | COMPUTER-GENERATED
FELIX & PAUL
Interact with an Apatosaurus up close and personal in this companion experience.


Paul McCartney
MUSIC | LIVE-ACTION
JAUNT
Watch Sir Paul McCartney in concert performing *Live and Let Die* in a cinematic VR experience.


Volvo Reality
ADVERTISING | BLENDED
FRAMESTORE
Test drive the Volvo XC90 in a beautiful journey through Vancouver.

VR Capture

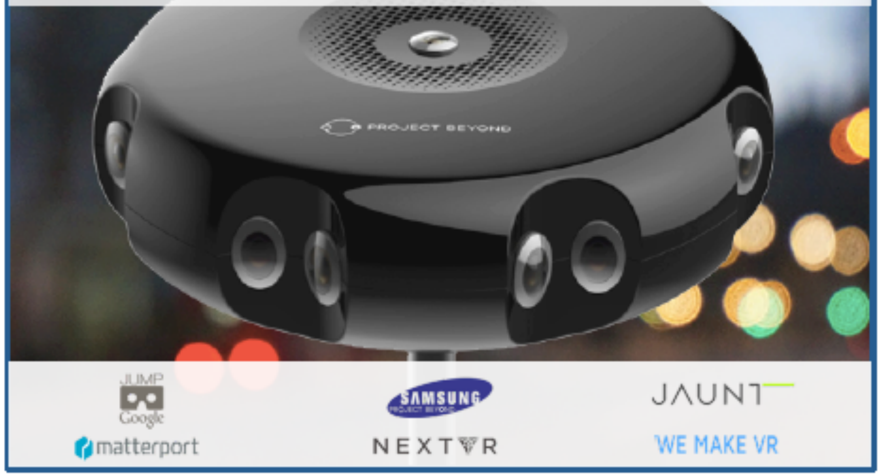


360 Degree

Multiple cameras are carefully angled to form a rig that captures 360° video.

Stereoscopic 3D

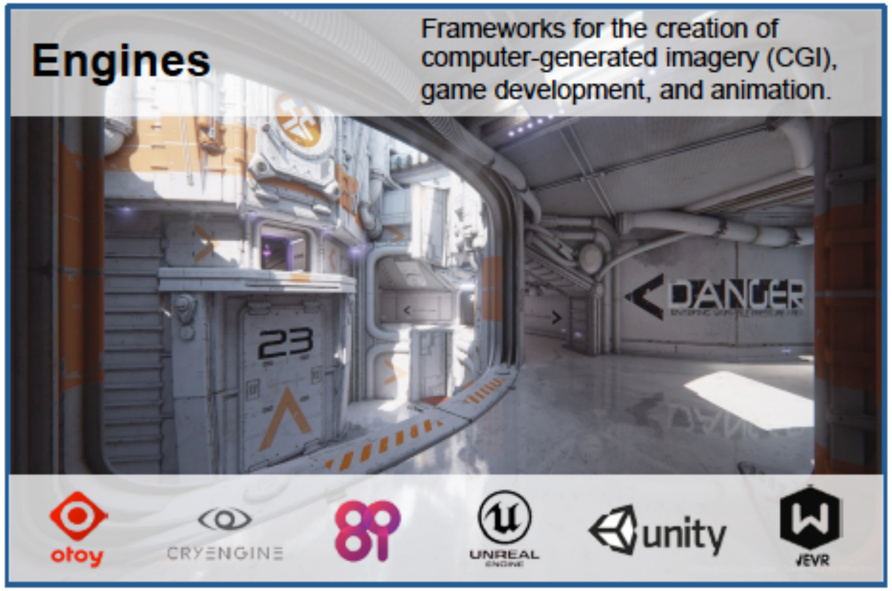
Two cameras are placed at each viewpoint and slightly angled, capturing different video for each eye that allows viewers to infer depth.

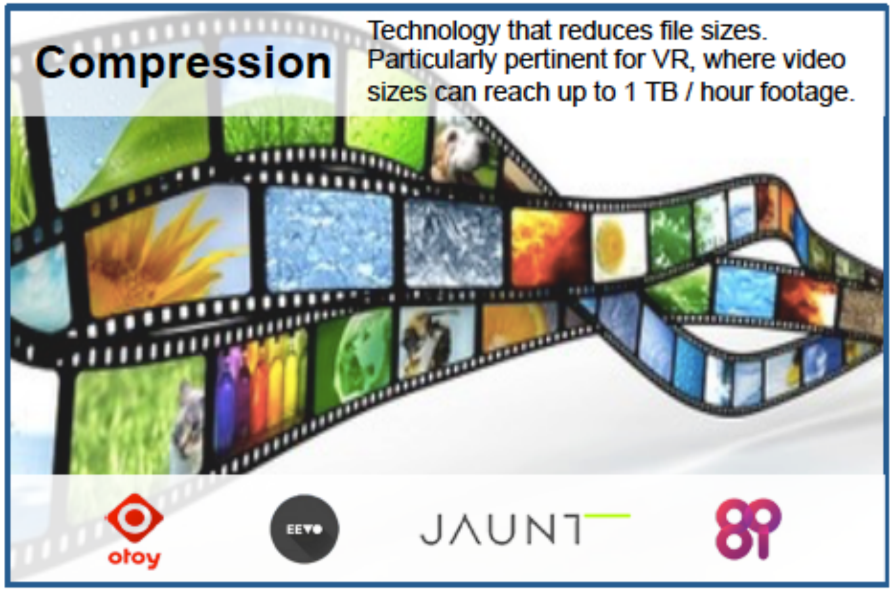


Lightfield

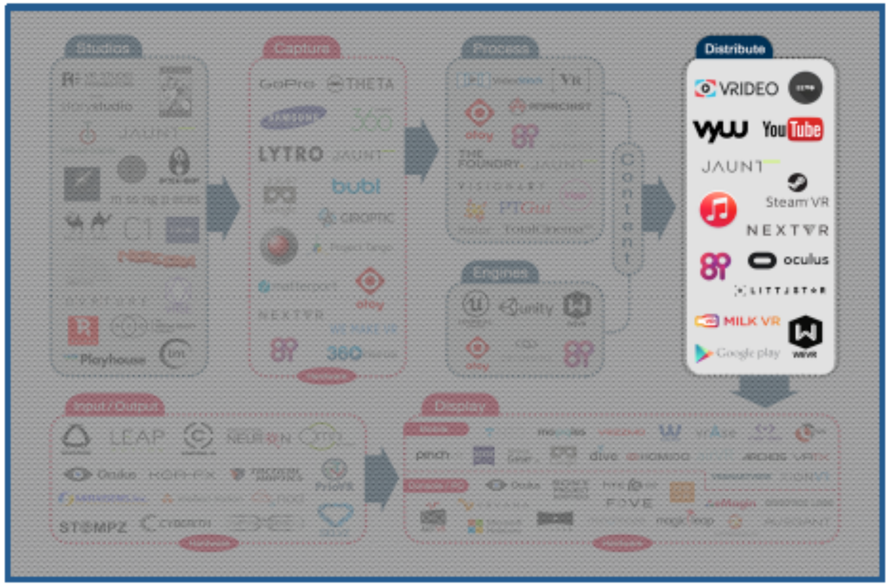
Lenses capture the intensity and direction of light in a scene, creating a map of the environment that lets users look around with 6° of freedom.

VR Processes and Engines





VR Distribution

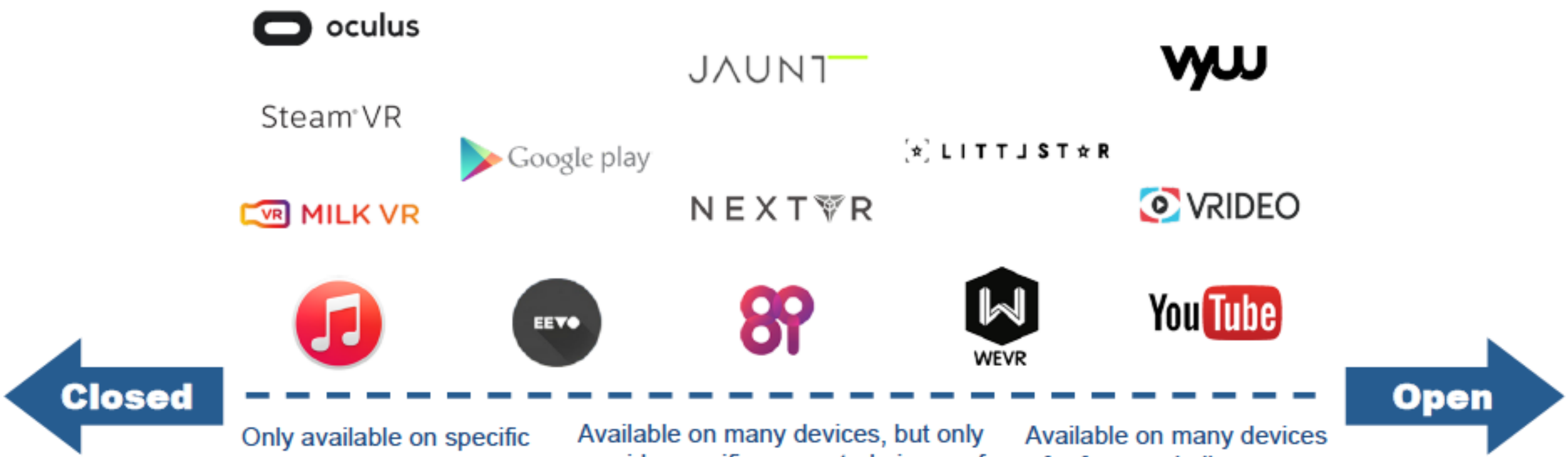


Companies in the distribution space provide platforms where users can access (stream or download) content. In regards to being closed / open, they can be evaluated across three dimensions:

Hardware – can be a closed ecosystem tied to a specific headset ('walled garden') or hardware-agnostic.

Content – can provide premium content ('Netflix of VR') or be open to any user-generated content ('YouTube of VR').

Price – can be fee-based (e.g., pay-per-download, subscription) or free for consumers.

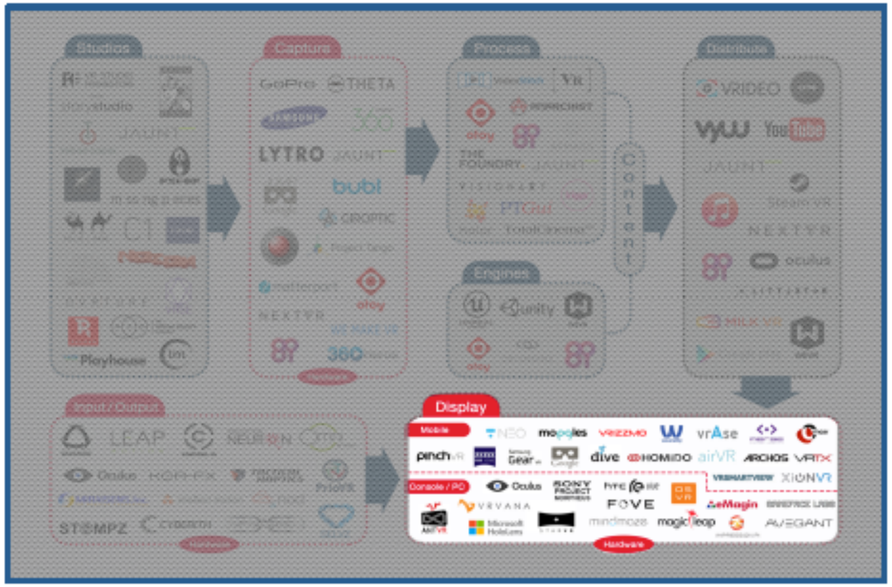


Only available on specific devices.

Available on many devices, but only provide specific or curated pieces of content, and can be fee-based.

Available on many devices for free, and allow open uploading of content.

VR Displays



Mobile Low-End – Best for first, introductory VR experiences and quick demonstrations.

- Pros – least expensive, portable, only requires smartphone
- Cons – basic tracking, limited input (i.e., button)

Mobile High-End – Best for casual consumption and viewing short-form content.

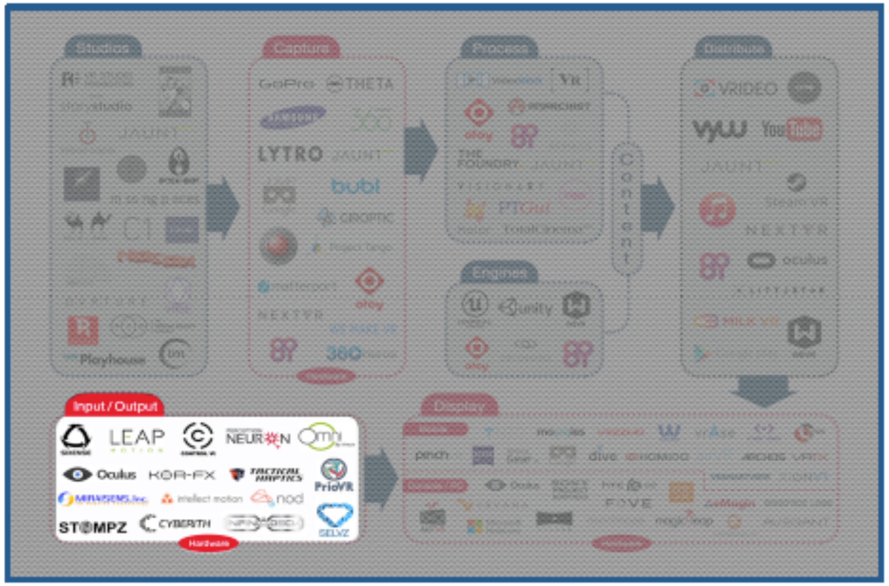
- Pros – input included, moderate tracking ability, portable, only requires smartphone
- Cons – limited computing power, basic input, can require specific smartphone

PC / Console – Best for early adopters and hardcore gaming enthusiasts.

- Pros – best tracking, most computing power, best content
- Cons – most expensive, not very portable, requires external computer

	Mobile Low-End		Mobile High-End		PC / Console	
						
Name	Google Cardboard	Wearality	MergeVR	Samsung Gear VR	Oculus Rift	PlayStation VR
Price	~$20-30	~$69	~$129	$200	$350-450	$300-400
Display	requires smartphone	requires smartphone	requires smartphone	requires Samsung S6 or Note 4	integrated	integrated
Computing	requires smartphone	requires smartphone	requires smartphone	requires Samsung S6 or Note 4	requires gaming PC (~$1000)	requires PS4 ($399)
Tracking	requires smartphone	requires smartphone	requires smartphone / integrated	integrated	integrated	integrated
Input	button on headset	not included	included	touchpad on headset	included	included

VR Input/Output



Hands

Input that uses hands to interact with VR environments.

Leap Motion
$80
camera

Nod Backspin
$149
controller

Perception Neuron
$200
glove w/sensors

Feet

Input that uses feet to move within VR environments.

Virtuix Omni
$599
treadmill

Stompz
$150
foot strap w/sensors

Haptic

Output that recreates the sense of touch by applying motions, forces, or vibrations.

KOR-FX
$150
vest

Tactical Haptics
$160
hand controller

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