MECH1905
VR, AR, MR and Metaverse

Prof. Yi-Kuen Lee

Department of Mechanical and Aerospace Engineering
Hong Kong University of Science and Technology

Star Trek VR game: https://youtu.be/romB8e5nMp8

HTC Vive VR has 70 sensors, Google map has new AR fuction, try your smartphone App
Youtube has VR channel: vr.youtube.com
Amazon: Primze Video VR web, Microsoft Hololens (MR), Windows 10 MR
Facebook acquired Occular VR startup by 2 billion US dollars in 2014, **Oculus Quest 2019**
www.vive.com/us/experiences/

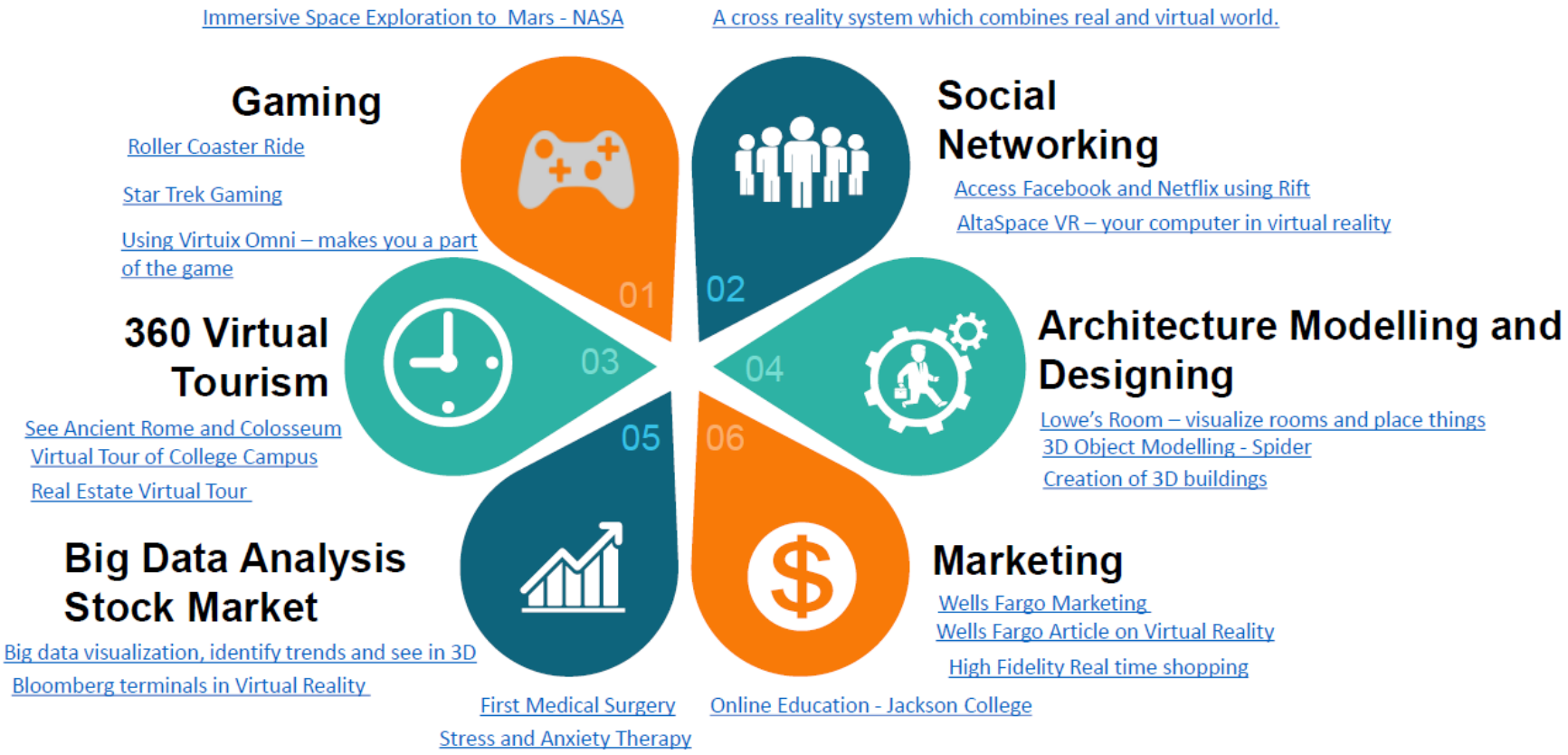
Lenovo - Star Wars : Jedi Challenges Lenovo - 星球大戰：絕地挑戰

https://youtu.be/yshCJRnGsYA, Star Trek Bridge Crew VR https://youtu.be/3Sg3lEIGQyo
NASA ISS (International Space Station) free VR App https://youtu.be/dwHBpykTloY

Smartphone-power AR: Lenovo and Disney

Amazon.com https://tinyurl.com/vrcer7x

VR/AR Applications

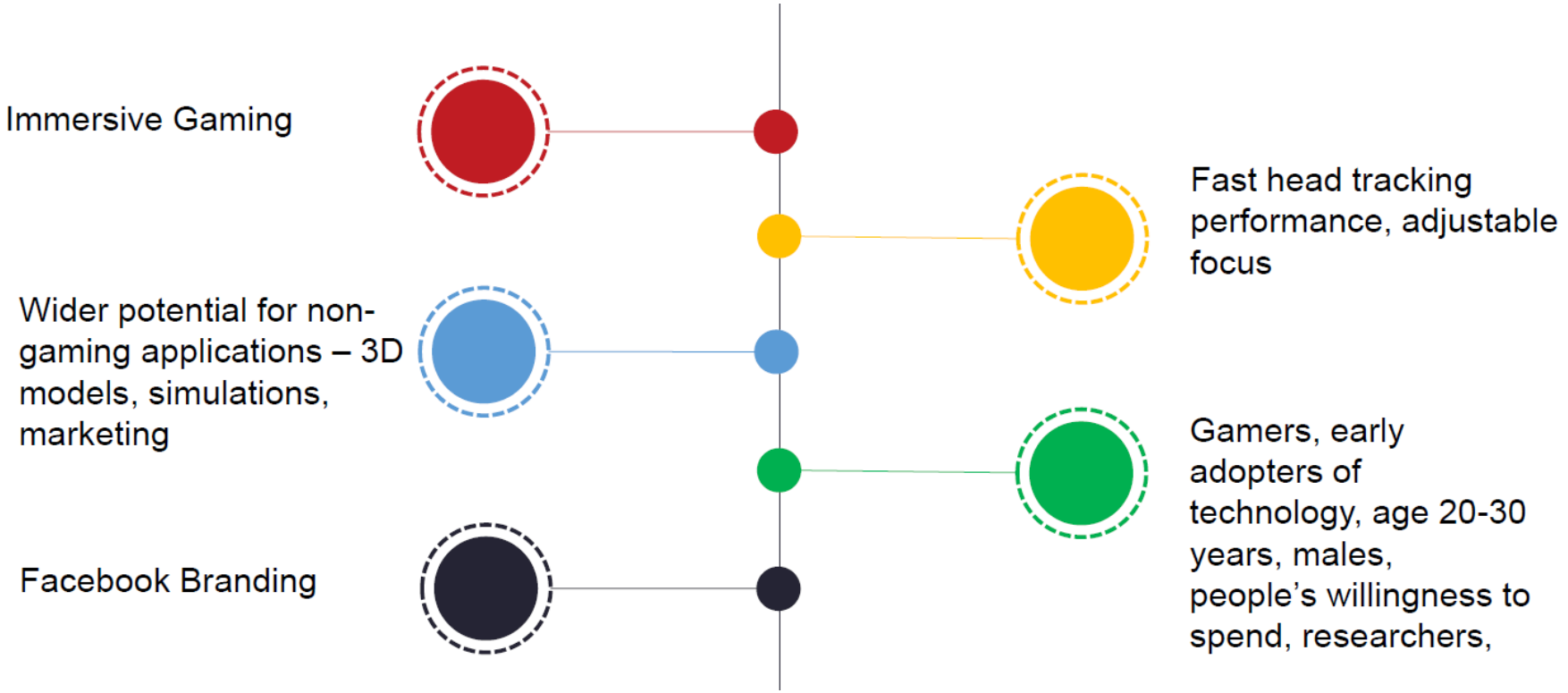


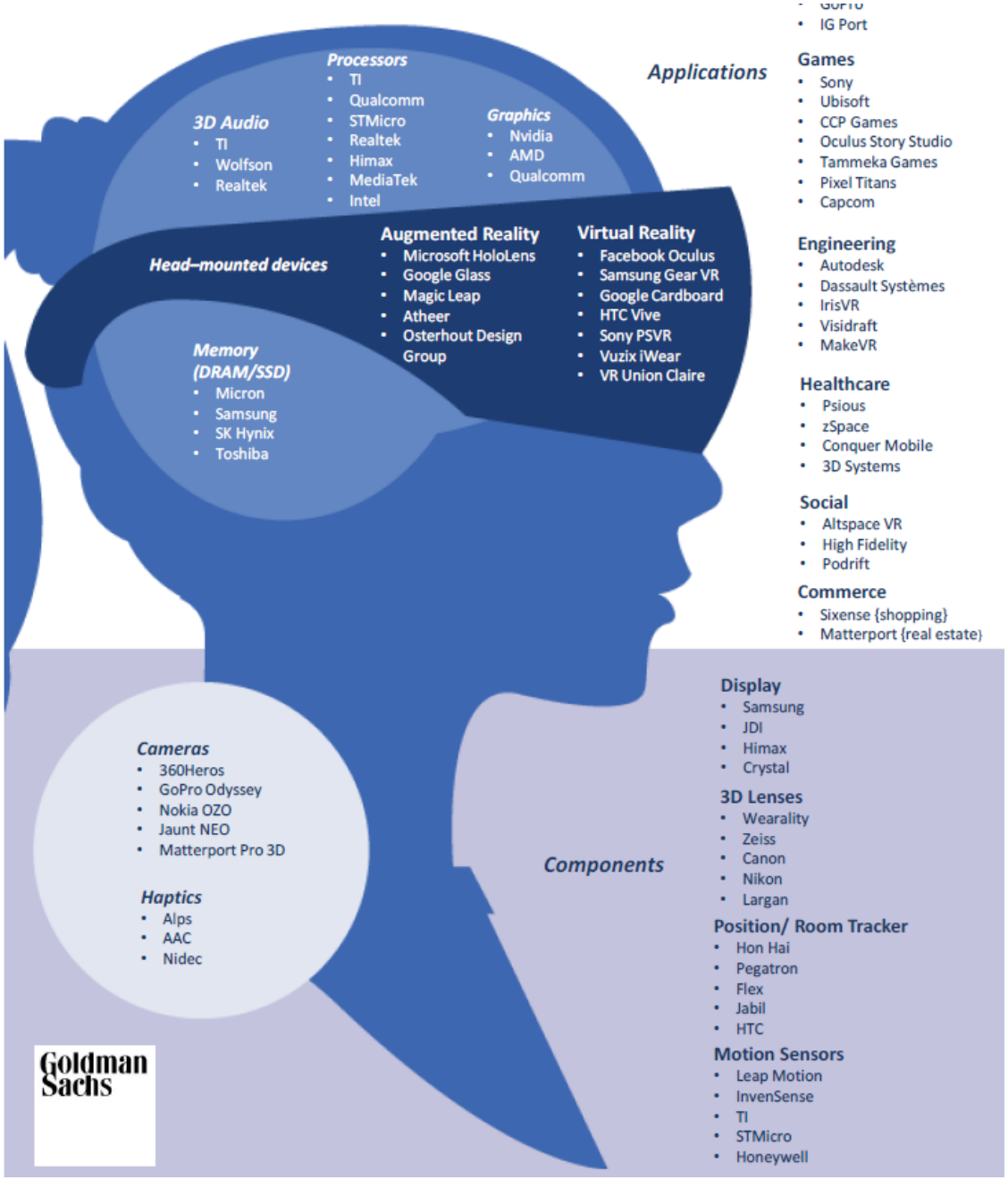
Global Market for VR: US$15.8 billion in 2020, AGR: 18% till 2028

https://www.grandviewresearch.com/industry-analysis/virtual-reality-vr-market

Architecture Engineering and Construction (AEC): Kalloc CEO (Henry YU)'s slides on Canvas (https://tinyl.io/6256) + Youtube: https://youtu.be/54I32NoxNmg

Value Proposition – Oculus Rift




Processors
TI
Qualcomm
STMicro
Realtek
Himax
MediaTek
Intel
3D Audio
TI
Wolfson
Realtek
Graphics
Nvidia
AMD
Qualcomm
Head–mounted devices
Augmented Reality
Microsoft HoloLens
Google Glass
Magic Leap
Atheer
Osterhout Design Group
Virtual Reality
Facebook Oculus
Samsung Gear VR
Google Cardboard
HTC Vive
Sony PSVR
Vuzix iWear
VR Union Claire
Memory (DRAM/SSD)
Micron
Samsung
SK Hynix
Toshiba
Applications
IG Port
Games
Sony
Ubisoft
CCP Games
Oculus Story Studio
Tammeka Games
Pixel Titans
Capcom
Engineering
Autodesk
Dassault Systèmes
IrisVR
Visidraft
MakeVR
Healthcare
Psious
zSpace
Conquer Mobile
3D Systems
Social
Altspace VR
High Fidelity
Podrift
Commerce
Sixense {shopping}
Matterport {real estate}
Cameras
360Heros
GoPro Odyssey
Nokia OZO
Jaunt NEO
Matterport Pro 3D
Haptics
Alps
AAC
Nidec
Components
Display
Samsung
JDI
Himax
Crystal
3D Lenses
Wearality
Zeiss
Canon
Nikon
Largan
Position/ Room Tracker
Hon Hai
Pegatron
Flex
Jabil
HTC
Motion Sensors
Leap Motion
InvenSense
TI
STMicro
Honeywell
Goldman Sachs

Immersion vs. Presence

• Immersion: the extent to which technology delivers a vivid illusion of reality to the senses of a human participant.

• Presence: a state of consciousness, the (psychological) sense of being in the virtual environment.
• So Immersion produces a sensation of Presence
• Goal of VR: Create a high degree of Presence
• Make people believe they are really in Virtual Environment

How to Create Strong Presence?

Use Multiple Dimensions of Presence

- Create rich multi-sensory VR experiences
- Include social actors/agents that interact with user
- Have environment respond to user

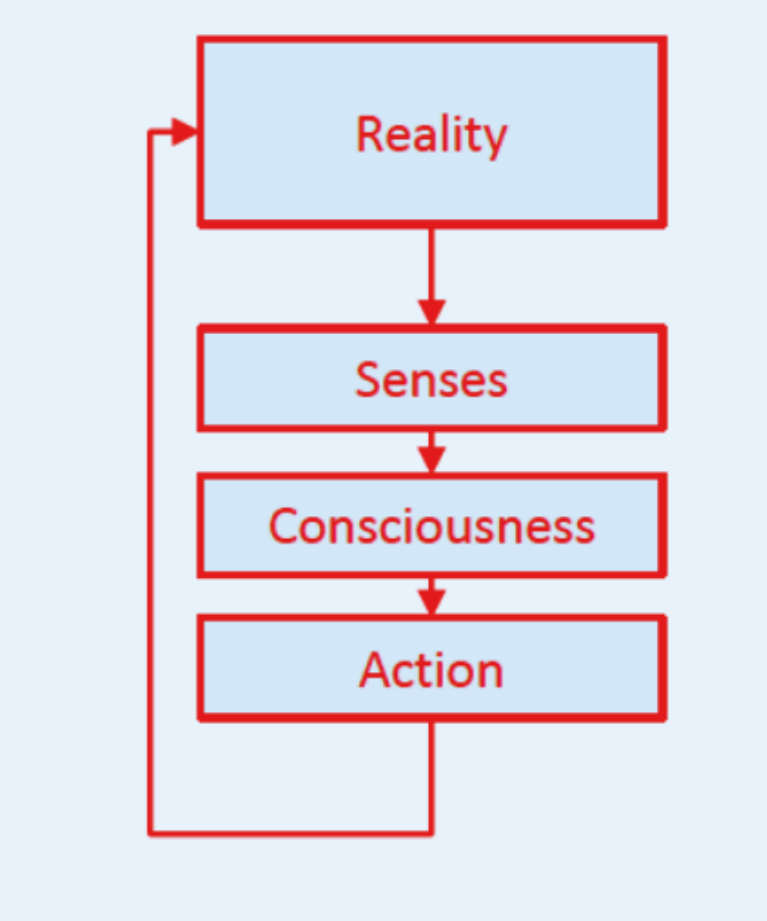
What Influences Presence

- Vividness – ability to provide rich experience (Steuer 1992)
- Using Virtual Body – user can see themselves (Slater 1993)
- Internal factors – individual user differences (Sadowski 2002)
- Interactivity – how much users can interact (Steuer 1992)
- Sensory, Realism factors (Witmer 1998)

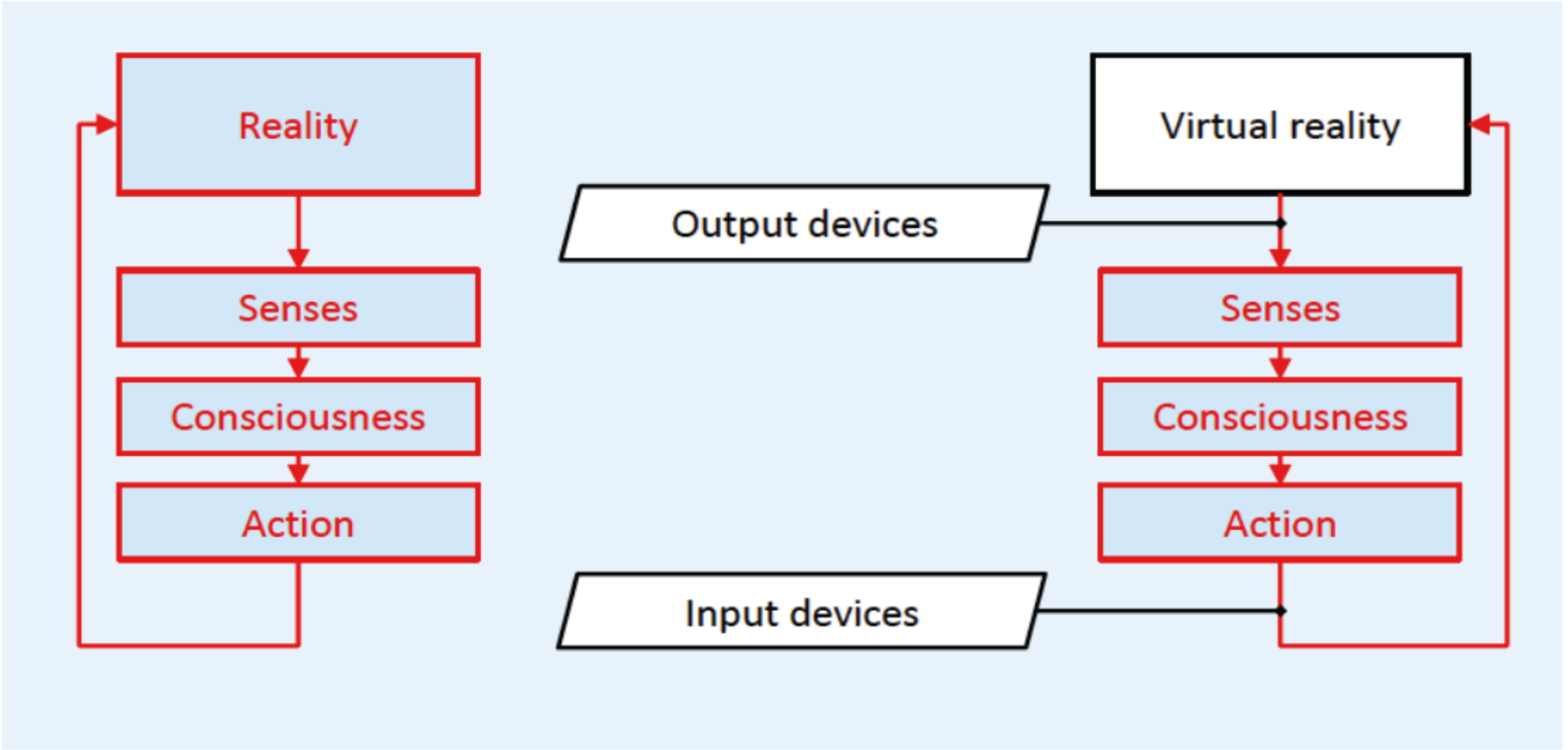
How do We Perceive Reality?

- We understand the world through our senses:
  - Sight, Hearing, Touch, Taste, Smell (and others..)
- Two basic processes:
  - Sensation – Gathering information
  - Perception – Interpreting information

Simple Sensing/Perception Model



Reality vs. Virtual Reality

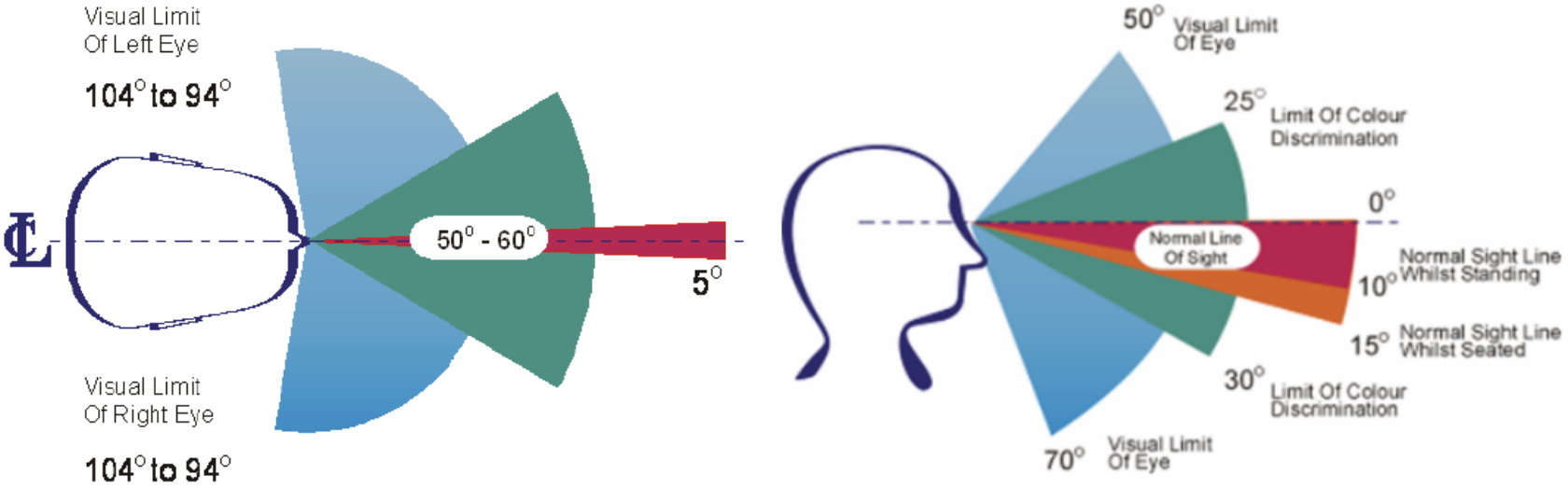


Birdly Product: VR Google with Actuators (wind, haptic)
Swiss company: www.somniacs.co

- Create illusion of flying like a bird
- Multisensory VR experience
  - Visual, audio, wind, haptic

https://youtu.be/cqBCd0VnN7A

Human Horizontal and Vertical Field of View (FOV)



- Humans can see ~135° vertical (60° above, 75° below)
- See up to ~ 210° horizontal FOV, ~ 115° stereo overlap
- Colour/stereo in centre, Black & White/mono in periphery

Properties of the Human Visual System

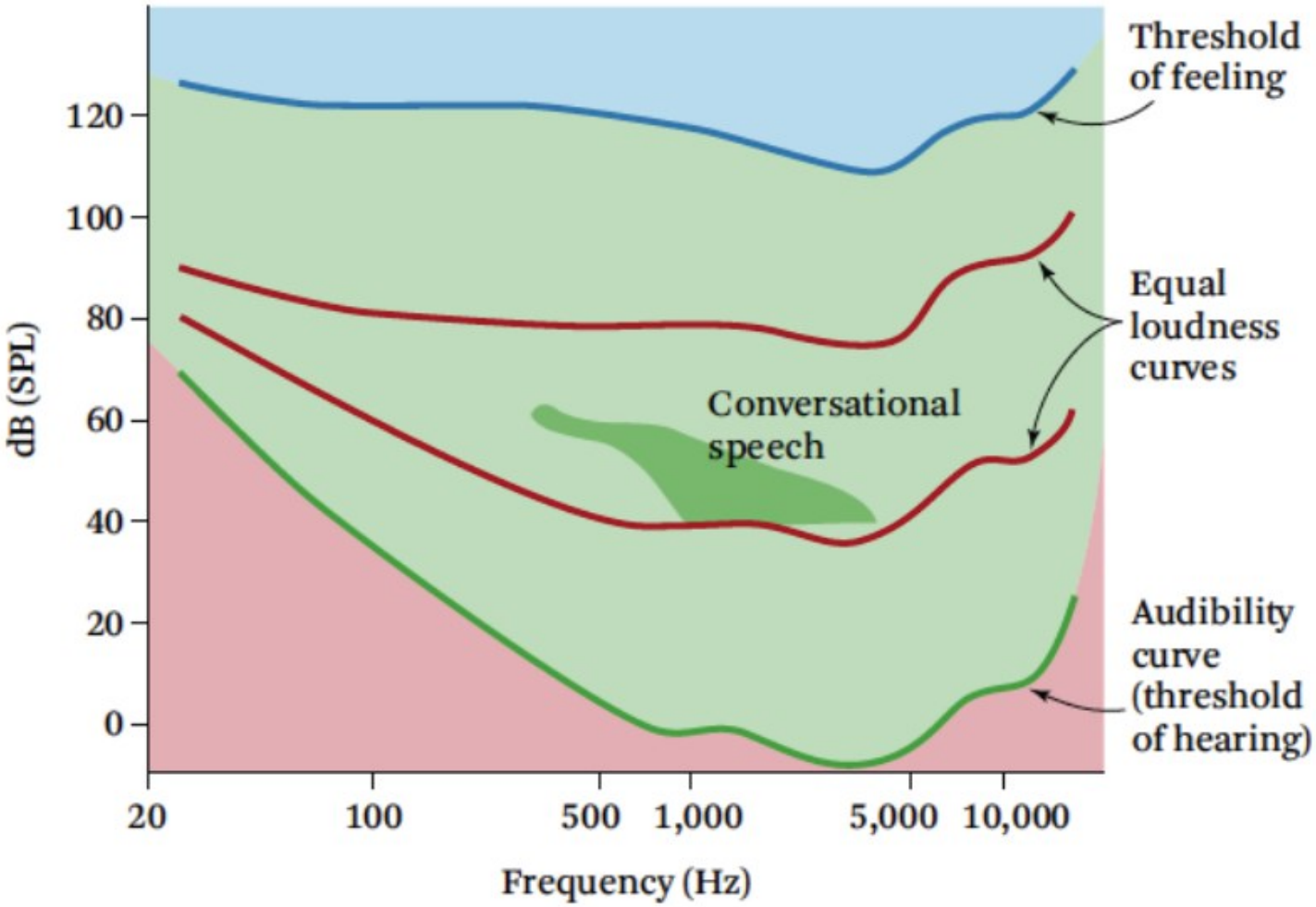
- visual acuity: 20/20 is ~1 arc min
- field of view: ~200° monocular, ~120° binocular, ~135° vertical
- resolution of eye: ~576 megapixels
- temporal resolution: ~60 Hz (depends on contrast, luminance)
- dynamic range: instantaneous 6.5 f-stops, adapt to 46.5 f-stops
- colour: everything in CIE xy diagram
- depth cues in 3D displays: vergence, focus, (dis)comfort
- accommodation range: ~8cm to ∞, degrades with age

Comparison between Eyes and Head-Mount Display (HMD)

	Human Eyes	HTC Vive
FOV	200° x 135°	110° x 110°
Stereo Overlap	120°	110°
Resolution	30,000 x 20,000	2,160 x 1,200
Pixels/inch	>2190 (100mm to screen)	456
Update	60 Hz	90 Hz

See http://doc-ok.org/?p=1414
http://www.clarkvision.com/articles/eye-resolution.html
http://wolfcrow.com/blog/notes-by-dr-optoglass-the-resolution-of-the-human-eye/

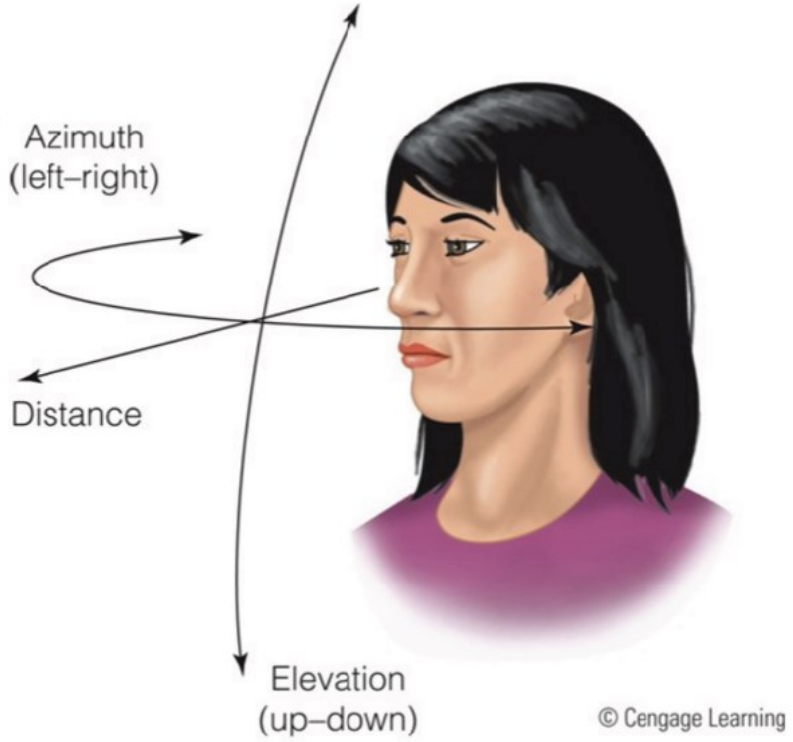
Auditory Thresholds



Humans hear frequencies from 20-22k Hz
Most everyday sounds from 80-90 dB

Sound Localization

- Humans have two ears
  - localize sound in space
- Sound can be localized using 3 coordinates
  - Azimuth, elevation, distance



Touch

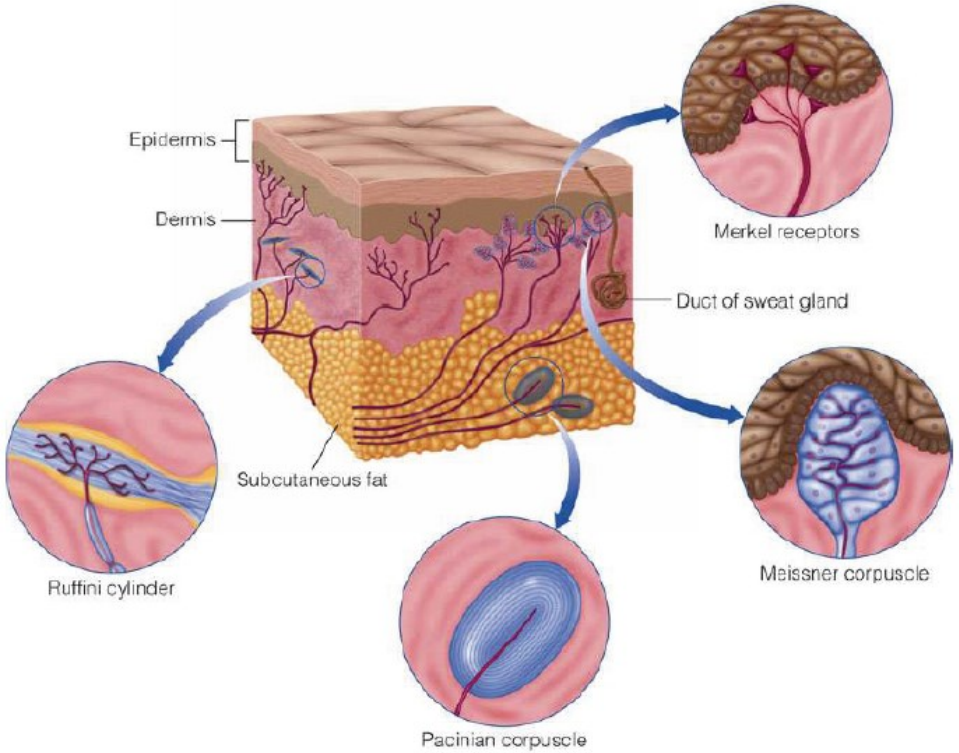
- Mechanical/Temp/Pain stimuli transduced into Action Potentials (AP)
- Transducing structures are specialized nerves:
  - Mechanoreceptors: Detect pressure, vibrations & texture
  - Thermoreceptors: Detect hot/cold
  - Nocireceptors: Detect pain
  - Proprioreceptors: Detect spatial awareness
- This triggers an AP which then travels to various locations in the brain via the somatosensory nerves

Haptic Sensation

- Somatosensory System
  - complex system of nerve cells that responds to changes to the surface or internal state of the body
- Skin is the largest organ
  - 1.3-1.7 square m in adults
- Tactile: Surface properties
  - Receptors not evenly spread
  - Most densely populated area is the tongue
- Kinesthetic: Muscles, Tendons, etc.
  - Also known as proprioception

Cutaneous System

- Skin – heaviest organ in the body
  - Epidermis outer layer, dead skin cells
  - Dermis inner layer, with four kinds of mechanoreceptors



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

VR/AR/MR will grow Bigger Biz

1. VR/AR is just going through a **Cambrian explosion**
2. Four Major Problems to Solve in VR and AR
3. An example application:

   Scope+ : A Stereoscopic Video See-Through Augmented Reality Microscope

Definition of Virtual Reality, Augmented Reality and MR

- **Virtual Reality (VR):** use computer to generate realistic images or video, sounds and other sensations that replicate a real environment; eg: Facebook Oculus Rift
- **Augmented Reality (AR):** a live view of a physical, real-world environment whose elements are *augmented* (or supplemented) by computer-generated sound, image or video Computer generate content on top of real world

  eg: Google Map AR in smartphone; Google glass
- **Mixed Reality:**

  Virtual objects interact with real objects and spaces

  eg: Microsoft Hololens

VR/AR: **Cambrian explosion**

- Google glass (product cancelled)
- Oculus Rift/Rift 2 (purchased by Facebook, 2 billion US$), Oculus Quest (2019-2020)
- Google Cardboard VR project
- Magic Leap secures 542M by Google Inc.
- Microsoft HoloLens project

all these happened in 2014/2015!

Four major problems in VR/AR/MR

1. Display resolution: wide angle display, without seeing pixels in display
2. Latency: should be less than 20 to 50ms
   If greater than 50 to 100 ms, will cause dizziness, even nausea.
3. Fixed focus vs. variable focus in observation through HMD or others.
4. Registration of real objects and virtual environments in AR

https://antilatency.com/

Extremely cheap HMD: Google Cardboard: US$6-20

https://www.price.com.hk/product.php?p=188046

https://www.price.com.hk/product.php?p=202391

Half a million sold in one week!

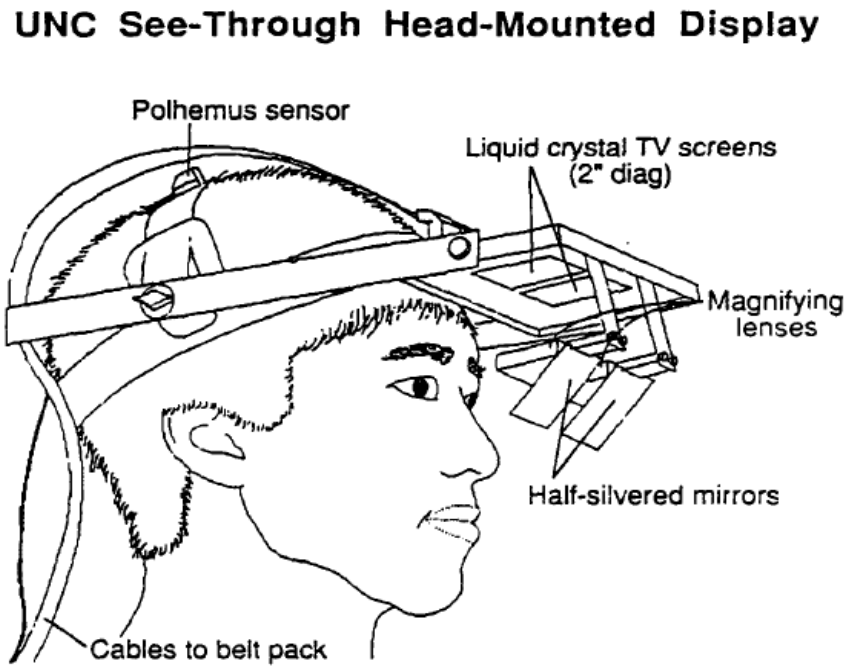
(December 16, 2014 news)

- Less than a week after going on sale and dropping rather quietly on an unsuspecting America, Project Cardboard has rocketed past the 500,000 sales mark. Such is the popularity of the DIY virtual reality toy that Google has even built and launched a dedicated area of the Play Store for apps created for or ideally suited for use with the unusual piece of facewear.

Why so popular?

- “The growth of mobile, and the acceleration of open platforms like Android make it an especially exciting time for VR,” beamed Andrew Nartker, project manager for Google Cardboard.

30 years from UNC HMD: much cheaper! (Display, Sensors)(Ref: paper in 1989!)

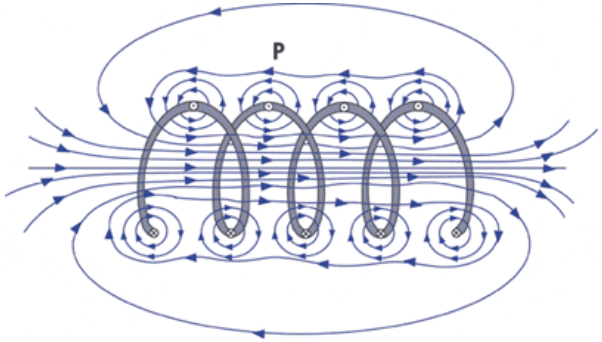


Polhemus position/orientation sensor: US$2000, 25 years ago.

Display: LCD TV screens: US$400 per set, and need 2 of them!

Polhemus EM Trackers

- Polhemus pioneered the original AC electromagnetic head tracking in the late 1960's and has advanced the technology in tracking excellence ever since.
- full six-degrees-of-freedom (6DOF) motion tracking



- Emitter
  - Apply current through coil
  - Magnetic field formed
  - 3 orthonormal coils to generate fields
- Sensor
  - Strength attenuated by distance
  - 3 orthonormal magnetic-field-strength sensors
  - Determine the absolute position and orientation of a tracker relative to a source.
    - Polhemus (a.c.)

polhemus.com

Android Apps

For HTC, Samsung, Xiaomi Inc. etc.: best VR Apps,

- *1. Rollercoaster VR*
- *2. Cardboard VR app*
- *3. Cosmic Rollercoaster VR app*
- *4. Jurassic Dino VR*
- *5. Crazy Swing VR*
- *6. Space Terror (need Bluetooth controller to play)*

iOS Apps

- For iPhone 4, iPhone 5, iPhone 6s, and 6 plus, iPad Air,

1. Cardboard VR
2. City Rollercoaster (Best effects, ok)
3. Moorente, (not ok for small stereo)
4. DiveZombie
5. Appartment (need additional Bluetooth controller)
6. VR sport (need controller)
7. The Height
8. Google Street View

Machu Picchu, Queensland, Australia (underwater) , India Taj Mahal, England Westminster Abbey, London, Nabatean Theater, Palace Tomb, Bynantine Church

3D Video from Youtube

Key word: “3D” or “3D trailers” “360 vr” for 3D glasses

Example titles:

Air Racers, real airplane stunt show

Samsung 3D demo

Avatar 3D

WoW, World of Warcraft

Finding Nimos, is one good example,

NYT vrse,

Google Street View (VR mode)

- Lower falls of the Yellowstone,
  Old Faithful, Yellowstone
  Musee d'Orsay, Paris
  Musee du Lourve, Paris,
  Niagara falls, On, Canada, (Google, on boat move forward)
  Himalayas (ABC， Annapurna Base Camp， by Jonathan Jenkins, clear view of Everest
  Avila Spain (City walls, ancient one）
  Segovia Spain, Sevilla, Spain
  Toledo, Spain

Google Daydream View VR

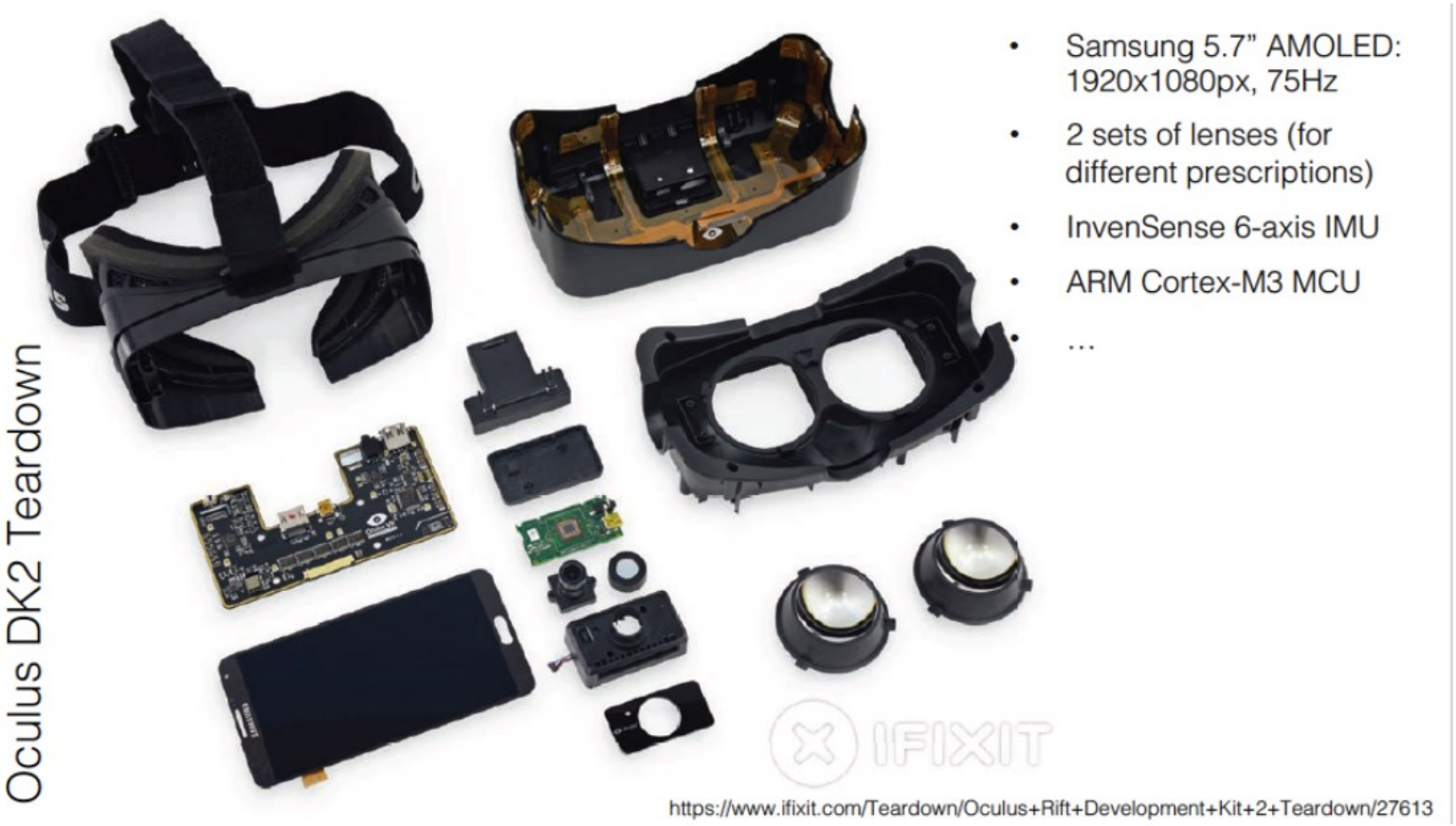
Daydream View VR FOV: 90 degrees

- For Pixel, you're looking at 1080 x 1920 pixels, 5 inch AMOLED (441ppi) and while the XL is 1440 x 2560 pixels, 5.5 inch AMOLED display (534ppi).
- There are only five buttons including a trackpad that doubles as a button. Below the trackpad, you'll find an app button, which can show menus, pause, go back or change modes depending on the app itself.
- When you look at the screen in your VR headset, you will often see a regular grid of lines.

Oculus Rift (US$199)

- Cost: $399 USD
- FOV: 110° Horizontal
- Refresh rate: 90 Hz
- Resolution 1080x1200/eye
- 3 DOF orientation tracking
- 3 axis positional tracking

Inside an Oculus Rift



Oculus

96˚ Field of View

Sensor:

MEMS Accelerometers, gyro, micro magnetic sensors, proximity sensors

Motion to Photon Latency: < 20ms

Focal Adjustment:

Covers Nearsighted / Farsighted Eyes

Interpupillary Distance Coverage

55 ~ 71 mm

HTC Vive HMD

- Vive has a refresh rate of 90Hz,
- two screens, one per eye, each having a resolution of 1080x1200.[6]
- uses more than 70 sensors including a MEMS gyro, accelerometer and laser position sensors, and is said to operate in a 15 feet by 15 feet (4.5 by 4.5 meters) tracking space if used with a passive "Lighthouse" base station (x2)

Need very powerful GPU for display, and that powerful PC can be very expensive!

- HTC VIVE: Nvidia GeForce GTX 970 /AMD Radeon RX 480 equivalent or greater

- Occulus Rift 2: Nvidia GeForce GTX 960 / AMD Radeon RX 470 or greater

- Because the FOV is 110 degrees, we can easily see pixel grid in the display (The display resolution of 2160 x 1200 is NOT enough for 110 degrees field-of-view. 10K by 10K is the optimal solution in the future)

Comparison Between HMDs

					
Name	**Oculus Rift**	**HTC Vive**	**PlayStation VR**	**StarVR**	**OSVR HDK**
Manufacturer	Oculus VR	HTC, Valve	Sony	Starbreeze	Razer, Sensics
Display	2x OLED	2x OLED	OLED	2x LCD	LCD
Resolution	2160x1200px	2160x1200px	1920x1080px	5120x1440px	1920x1080px
Framerate	90fps	90fps	120fps	60fps	60fps
Field of view	>110°	>110°	100°	210°	100°
Positional tracking	6DOF	6DOF Valve Lighthouse	6DOF	6DOF	6DOF
Controller	Xbox One controller/Oculus Touch	two SteamVR controllers, one for each hand	Playstation Move/DualShock 4	-	-

Mobile VR

$80-$100 + smartphone

Samsung Gear

Google Daydream View

Standalone VR

$200-$400

Oculus Go

Vive Focus

Lenovo Mirage

Low Cost PC VR

$400-$450 + standard PC

Samsung Odyssey

HP

Dell

Asus

Acer

Lenovo

High End and Console

$500-$800 + high end PC

Vive Pro

LG (18MP prototype)

Sony PSVR

Oculus Rift

Driving greater mass adoption

Driving enterprise VR

Driving high end gaming

GPU Developers

NVIDIA. AMD

Reference Designs

Qualcomm

ODMs

Goertek Quanta Computer

Smartglasses

$1000-$3000

Vuzix Blade

Intel Vaunt

ODG R-9

Google Glass

Sleeker form factor helping to drive market acceptance

Holographic AR

$3000+

Magic Leap One

Avegant

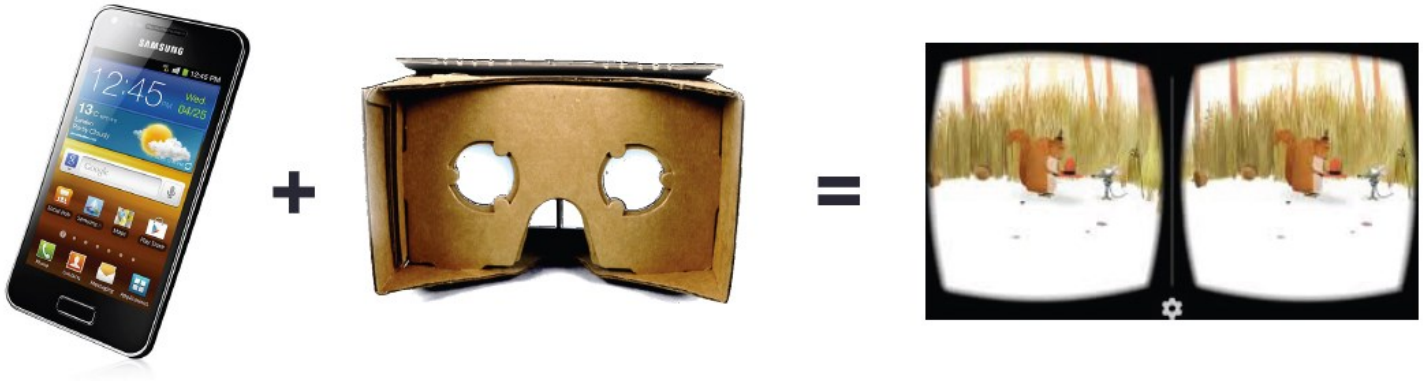
Meta

Microsoft Hololens

More immersive holographic experiences starting to shift to consumer

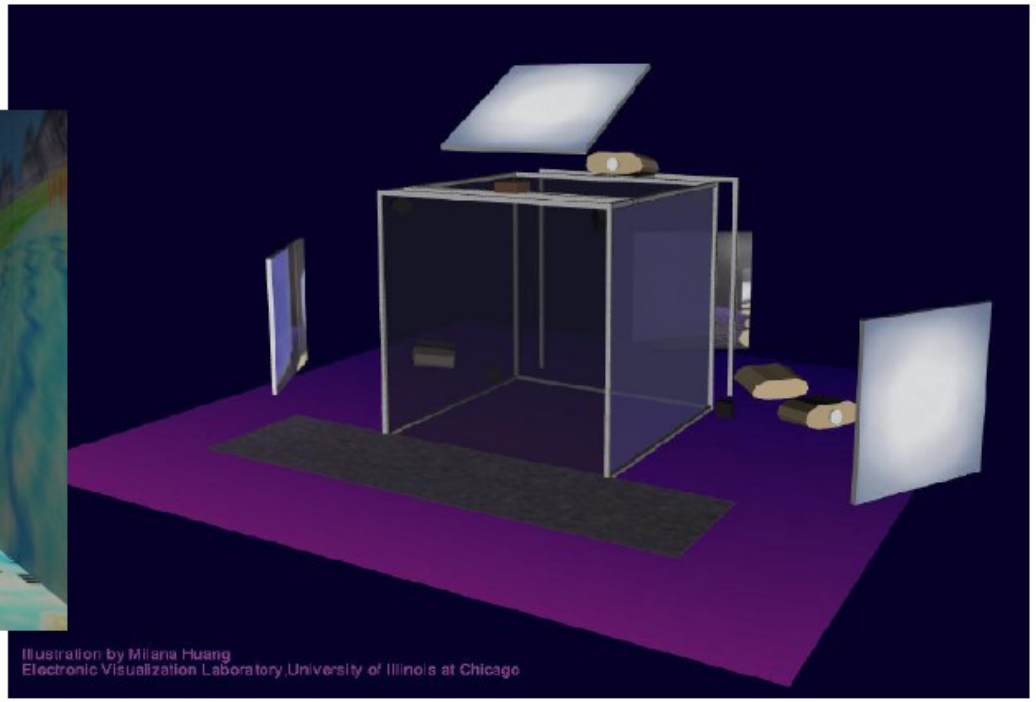
AR is expected to undergo a shift from enterprise to consumer as form factors become sleeker, experiences become more immersive and greater content emerges (eg. ARKit and ARCore)

Google Cardboard



- Released 2014 (Google 20% project)
- >5 million shipped/given away
- Easy to use developer tools

CAVE



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

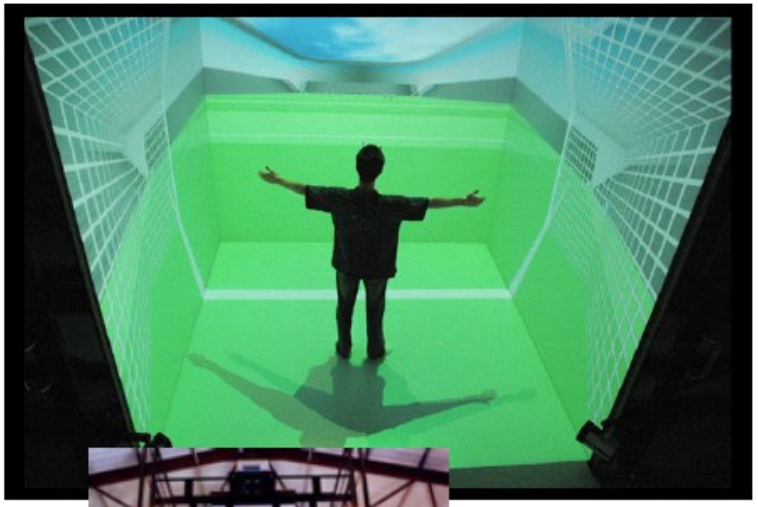
Cruz-Neira, C., Sandin, D. J., DeFanti, T. A., Kenyon, R. V., & Hart, J. C. (1992). The CAVE: audio visual experience automatic virtual environment. *Communications of the ACM*, *35*(6), 64-73.

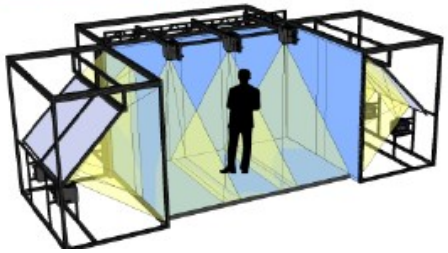
Hong Kong Museum of Science has one CAVE system

Demo Video – Wisconsin CAVE

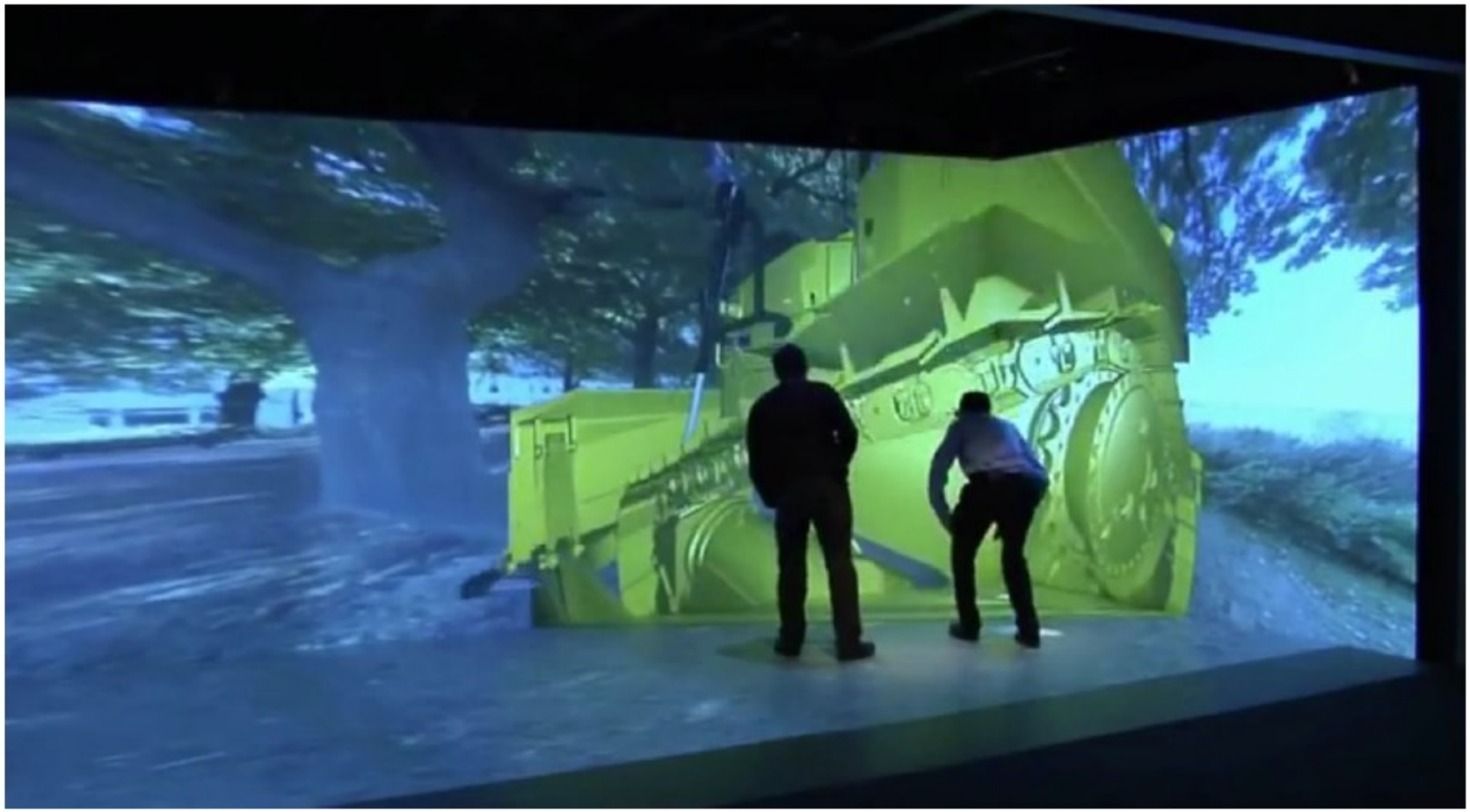
https://chaintechdev.com/tag/vr-cave-hk/ https://youtu.be/mBs-OGDoPDY

CAVE Variations





Caterpillar Demo



https://youtu.be/r9N1w8PmD1E

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

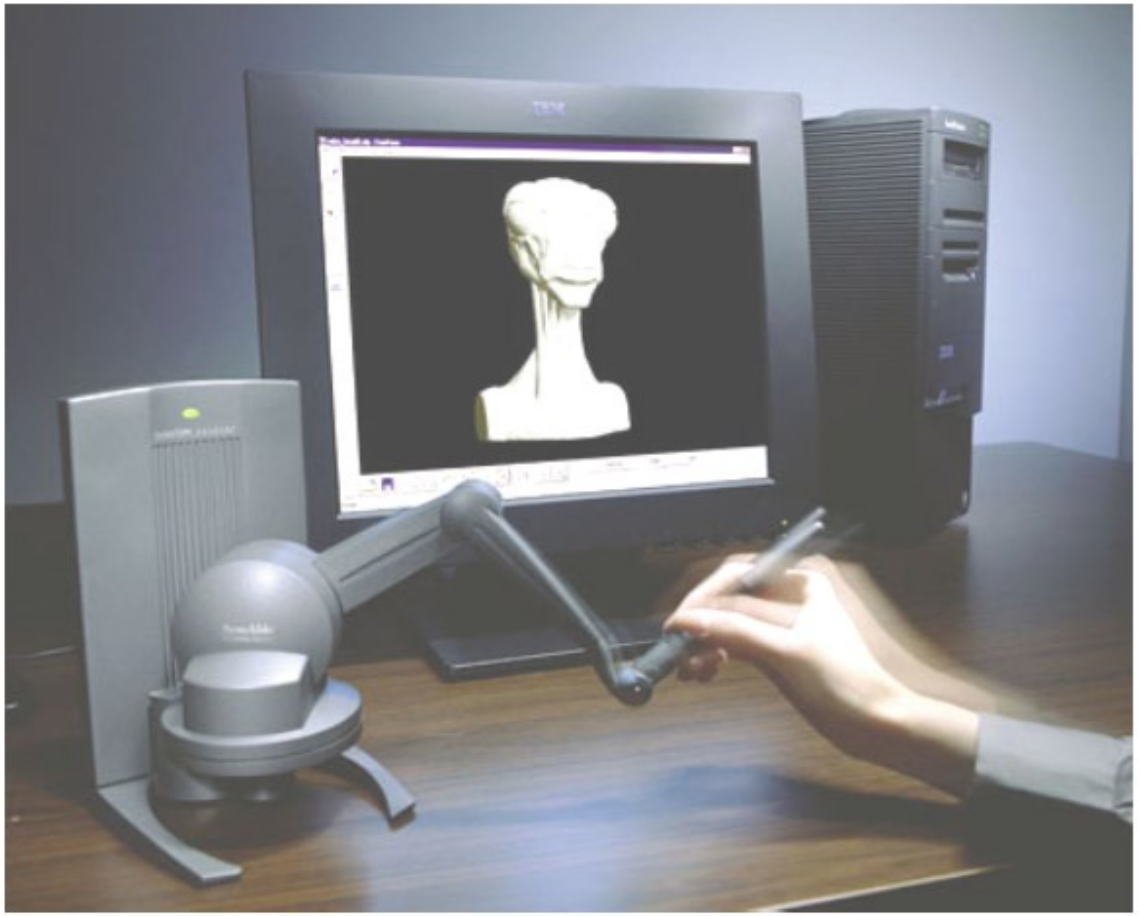
Haptic Feedback

- Greatly improves realism
- Hands and wrist are most important
  - 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

Active Haptics

- Actively resists motion
- Key properties
  - Force resistance
  - Frequency Response
  - Degrees of Freedom
  - Latency

Example: Phantom Omni

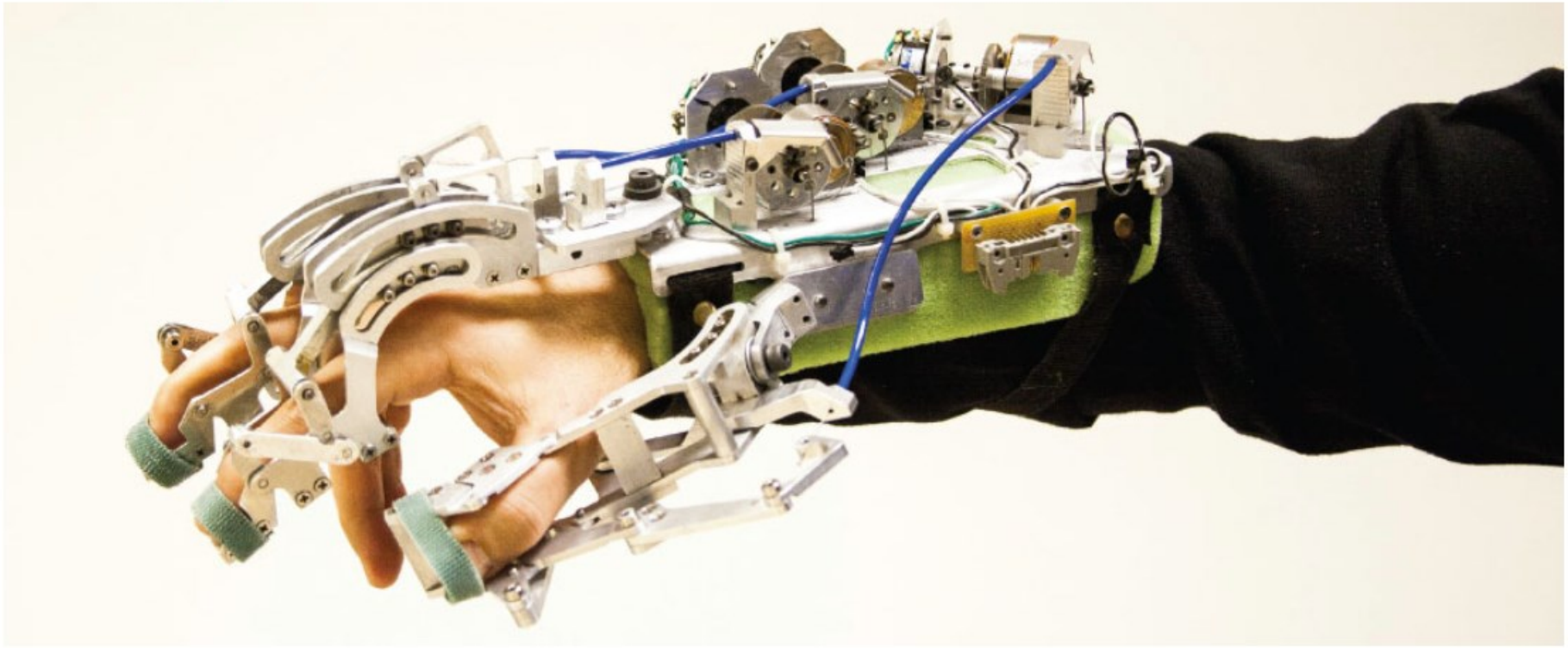


- Combined stylus input/haptic output
- 6 DOF haptic feedback

Phantom Omni Demo

- https://www.youtube.com/watch?v=REA97hRX0WQ

Haptic Glove

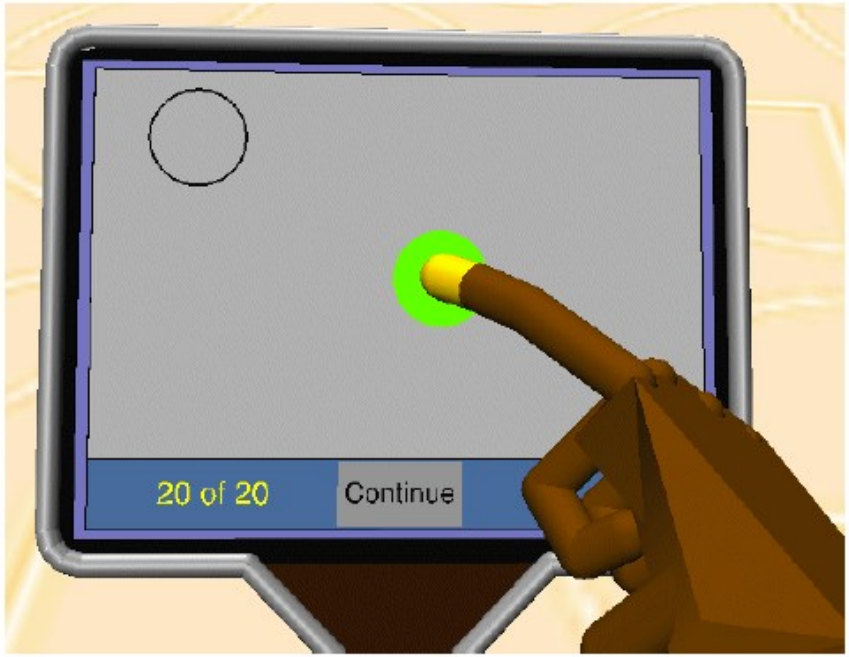


- Many examples of haptic gloves
- Typically use mechanical device to provide haptic feedback

Passive Haptics

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

Passive Haptic Paddle



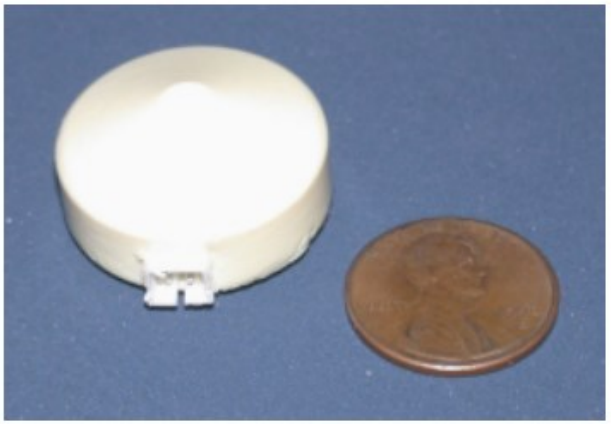
- Using physical props to provide haptic feedback
- http://www.cs.wpi.edu/~gogo/hive/

Tactile Feedback Interfaces

- Goal: Stimulate skin tactile receptors
- Using different technologies
  - Air bellows
  - Jets
  - Actuators (commercial)
  - Micropin arrays
  - Electrical (research)
  - Neuromuscular stimulations (research)

Vibrotactile Cueing Devices

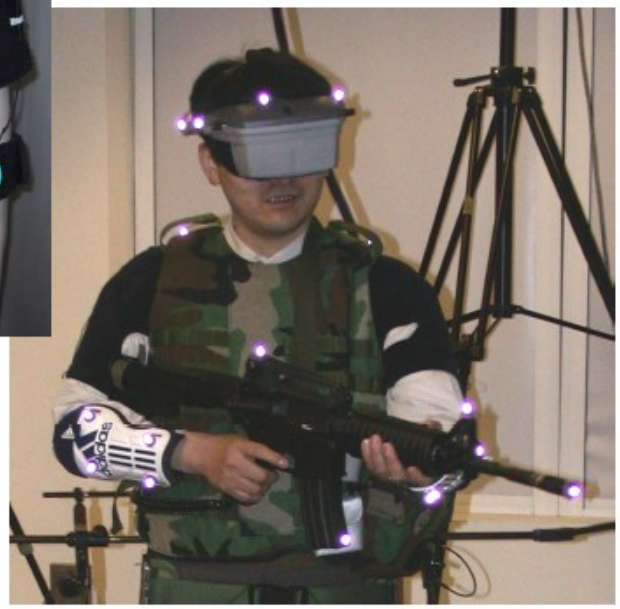
- Vibrotactile feedback has been incorporated into many devices
- Can we use this technology to provide scalable, wearable touch cues?



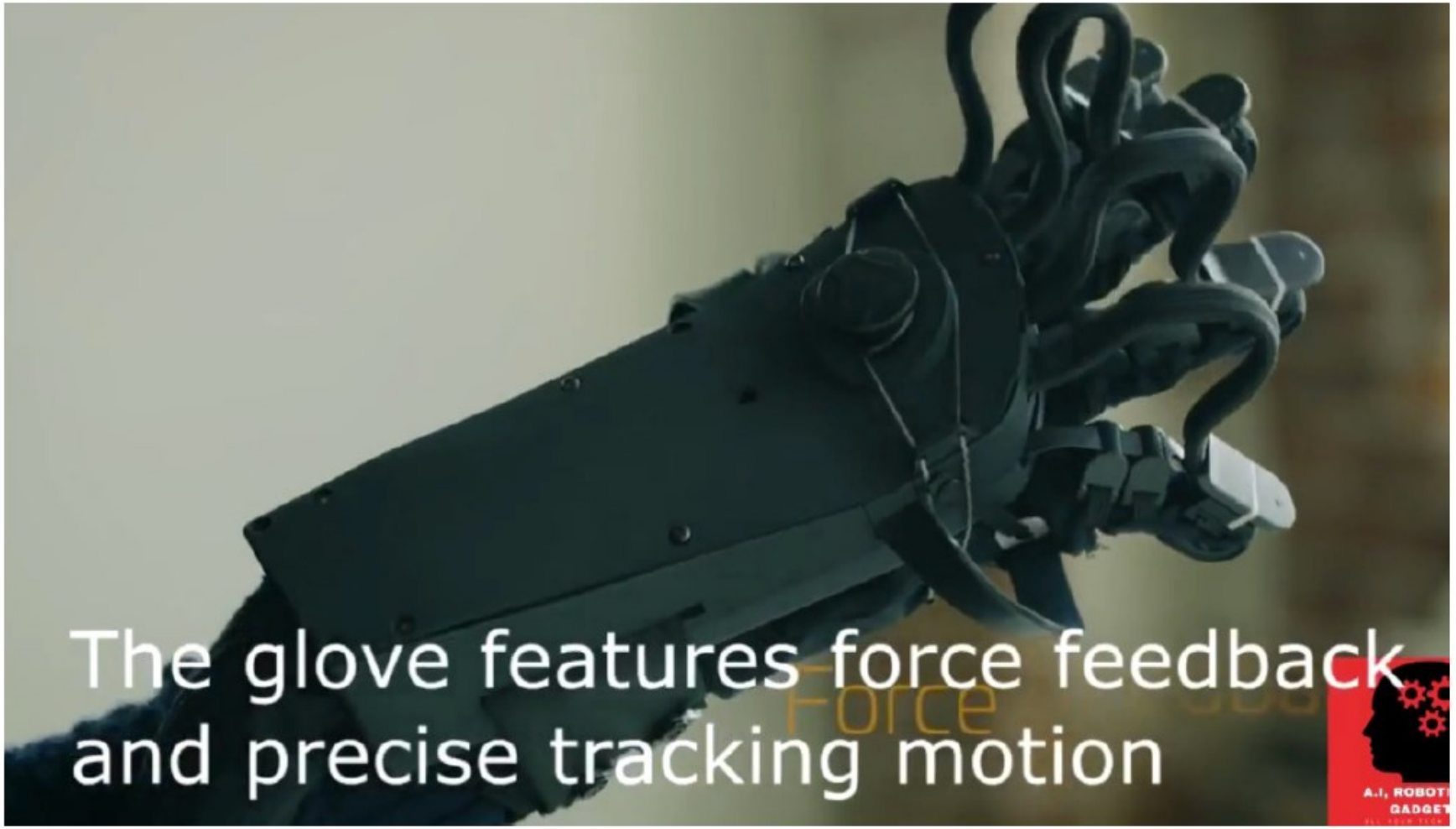
Vibrotactile Feedback Projects

Navy TSAS Project

TactaBoard and TactaVest



Example: HaptX Glove



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

Example: Vive Lighthouse Tracking

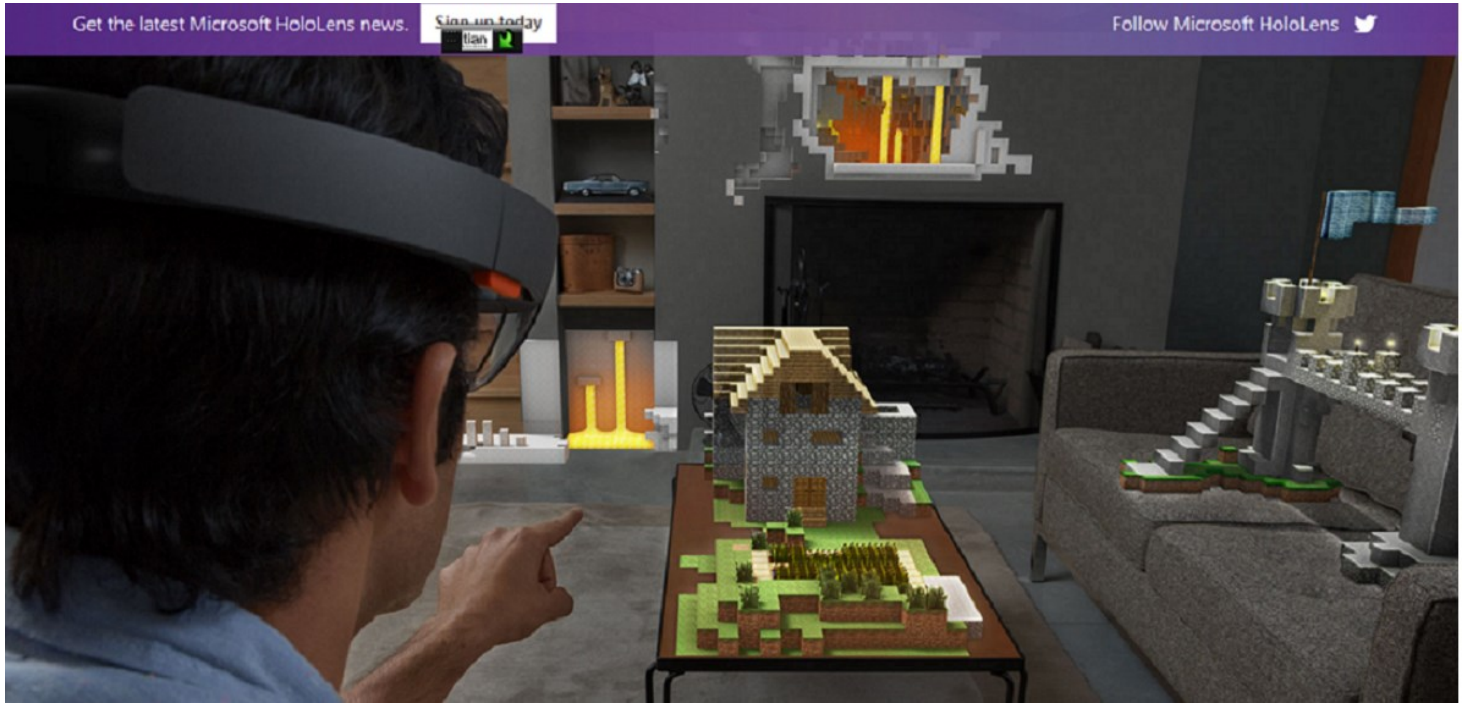
- Outside-in tracking system
- 2 base stations
  - Each with 2 laser scanners, LED array
- Headworn/handheld sensors
  - 37 photo-sensors in HMD, 17 in hand
  - Additional IMU sensors (500 Hz)
- Performance
  - Tracking server fuses sensor samples
  - Sampling rate 250 Hz, 4 ms latency
- See http://doc-ok.org/?p=1478

One of the best apps in AR in the future, if combined with machine learning, (Taiwan has 26 sets!)

- DaVinci surgery machine

Microsoft HoloLens Project

Head-Mounted Holographic Computer: MR

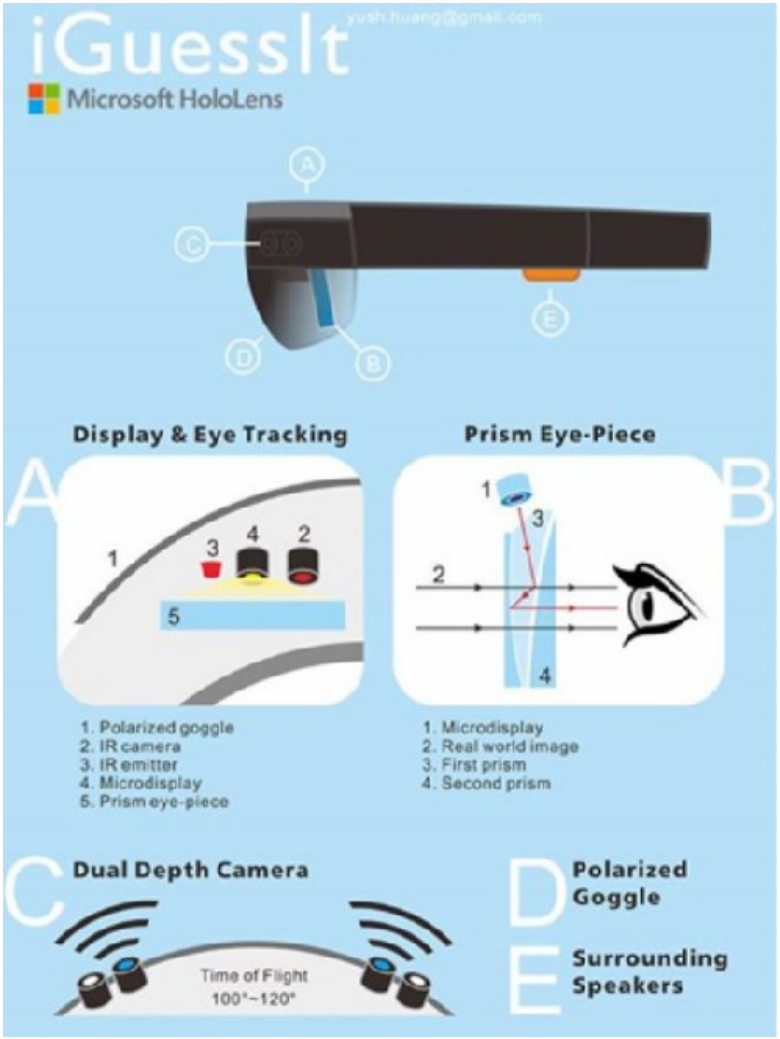


- running Windows 10
- V1 in 2015, V2 in 2019
- Self-contained, head-worn
- Multiple sensors, advanced optics, custom chips
- Displays mixed reality (holograms)
- Learns about the environment (spatial mapping)
- Recognizes gestures, voice
- Cost $3000 - $5000 per unit

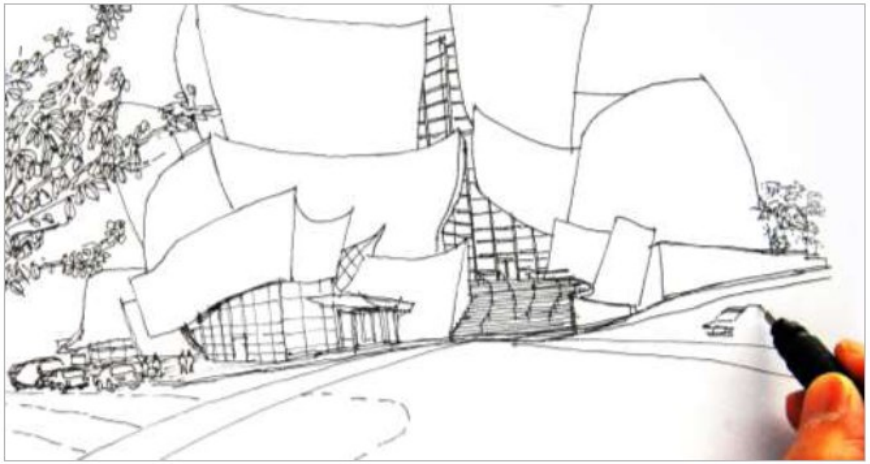
HoloLens Project

It is an optical see-through AR, but not really Holography

Very similar to Google Glass and Epson Moverio



Nvidia Holodeck System
Collaborative Design Engineering via VR

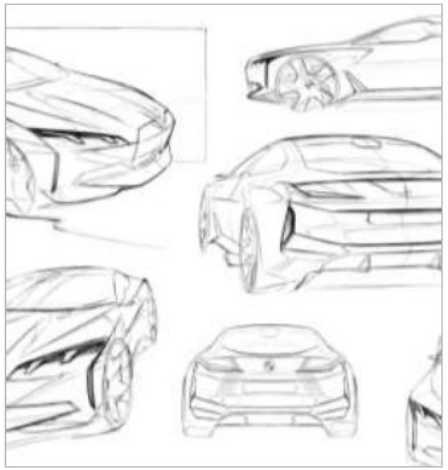
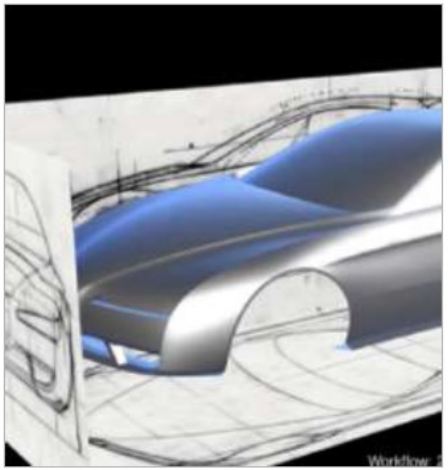


Very similar to Google Glass and Epson Moverio

Holodeck system: VR platform that brings designers, peers, and stakeholders together from anywhere in the world to build and explore creations in a highly realistic, collaborative, and physically simulated VR environment

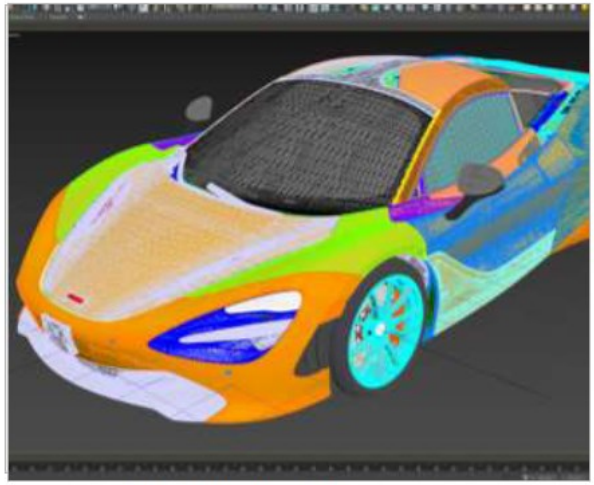
https://www.nvidia.com/en-us/design-visualization/technologies/holodeck/

Nvidia Holodeck System
From concept to reality

Nvidia Holodeck System
The Promise of VR

Professional Designer Require High-Quality VR



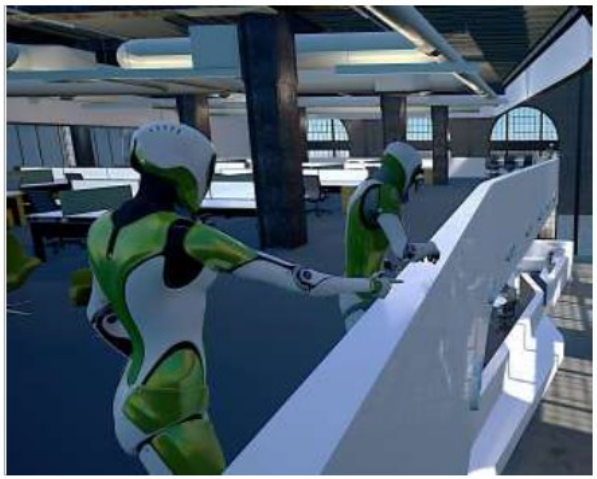
Detailed and Accurate

Photoreal

Interactive and Dynamic

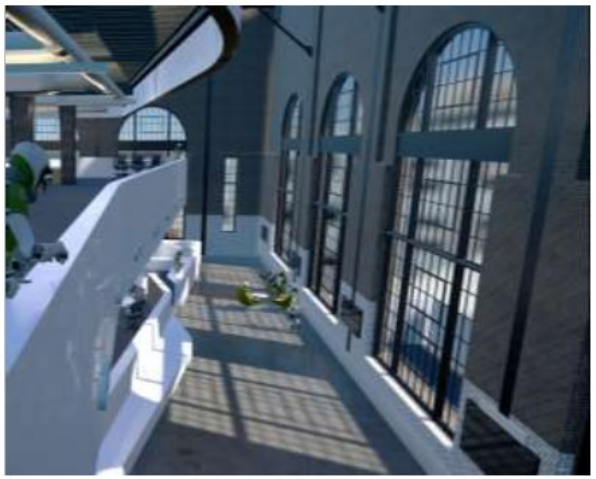

NVIDIA HOLODECK
The Design Lab of the Future
Photorealistic Models
Physically Simulated Environment
Virtual Team Collaboration
Artificial Intelligence

Building Design in Holodeck



Collaboration

Scale



Simulation

Bridging the Virtual and the Physical World

Video Chat - Google Hangouts in Holodeck

Train AI powered Robots in Holodeck

Isaac Playing Dominoes
SIGGRAPH 2017

Isaac Making Pretzels
GTC 2018

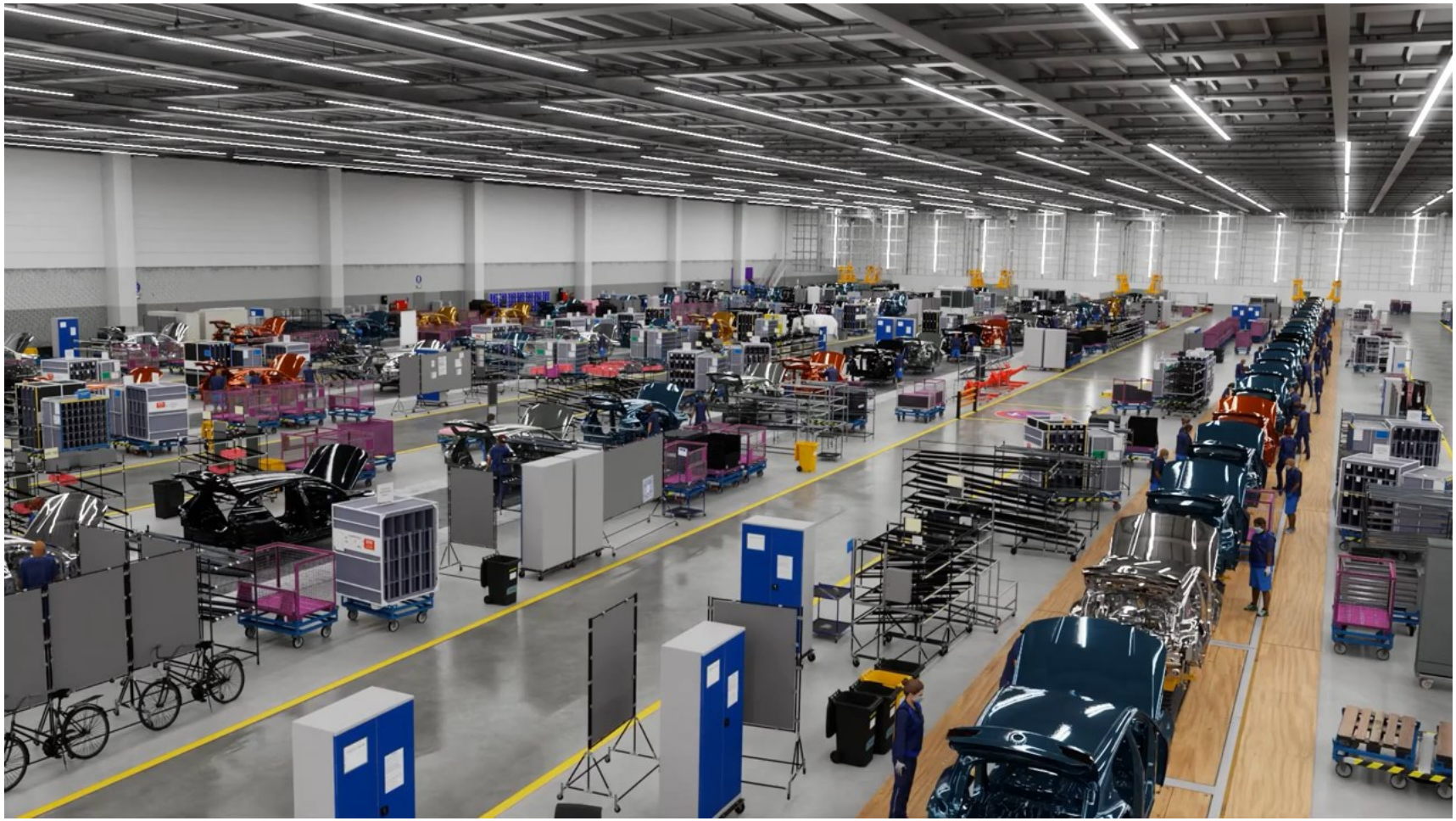
www.nvidia.com/holodeck

GTC 2017 demo: https://youtu.be/mlE9gVZjIIw

GTC 2017 Nvidia Holodeck Demo

https://youtu.be/mlE9gVZjIIw , Canvas:

GTC 2021 Nvidia Omniverse for BMW Digital Twin Factory design, optimization and operation

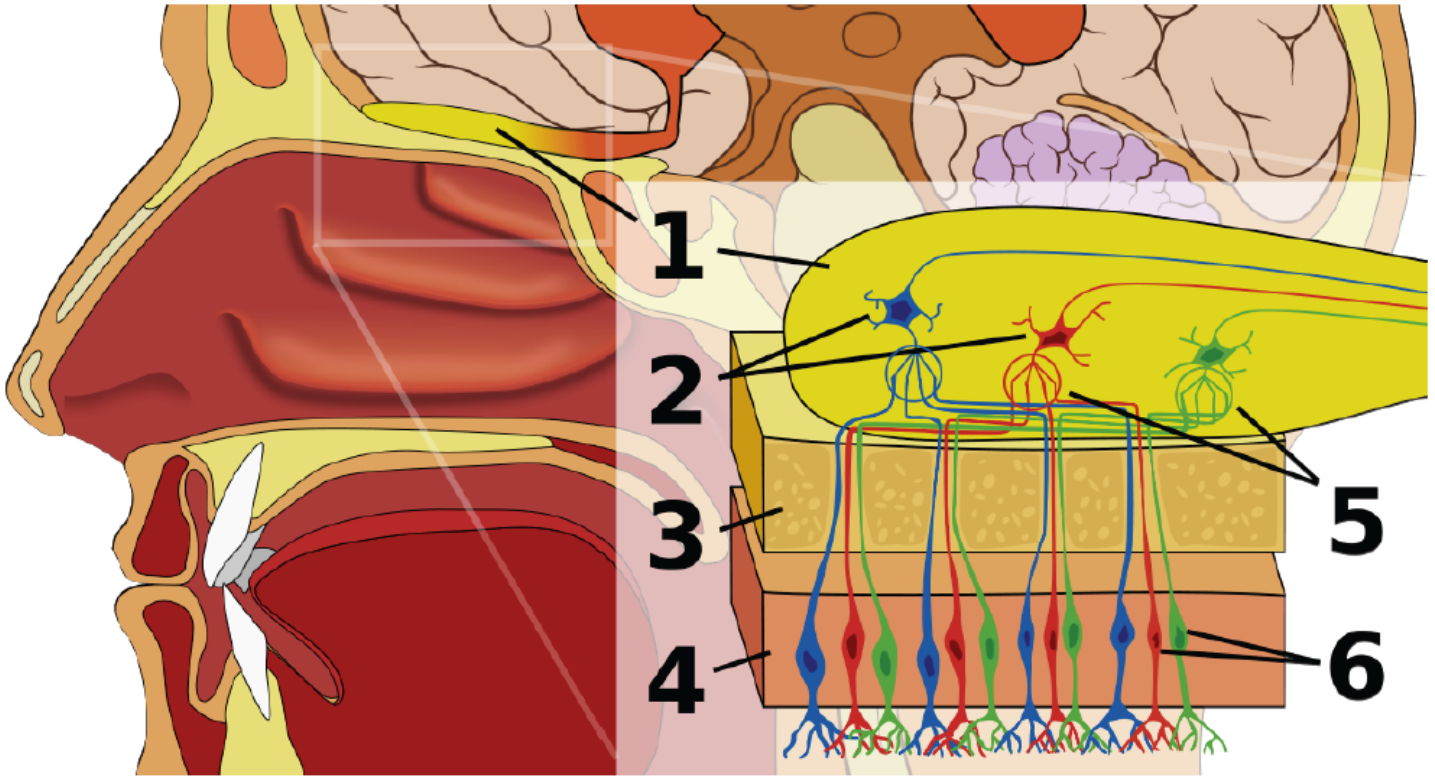


Use Digital Human & motion-capture suite to make real engineers work in virtual collaboration with 31 BMW manufacturing plants in the world: increase 30% efficiency

https://youtu.be/6-DaWgg4zF8

The End

Olfactory System



- Human olfactory system. 1: Olfactory bulb 2: Mitral cells 3: Bone 4: Nasal epithelium 5: Glomerulus 6: Olfactory receptor neurons

How the Nose Works

https://www.youtube.com/watch?v=zaHR2MAxywg

Smell

- Smells are sensed by olfactory sensory neurons in the olfactory epithelium
  - 10 cm^2 with hundreds of different types of olfactory receptors
  - Human's can detect at least 10,000 different odors
    - Some researchers say trillions of odors
- Sense of smell closely related to taste
  - Both use chemo-receptors
  - Olfaction + taste contribute to flavour
- The olfactory system is the only sense that bypasses the thalamus and connects directly to the forebrain

Human can detect 1 trillion odors by Andreas Keller, Nature , 2014: http://tinyurl.com/stcuwed

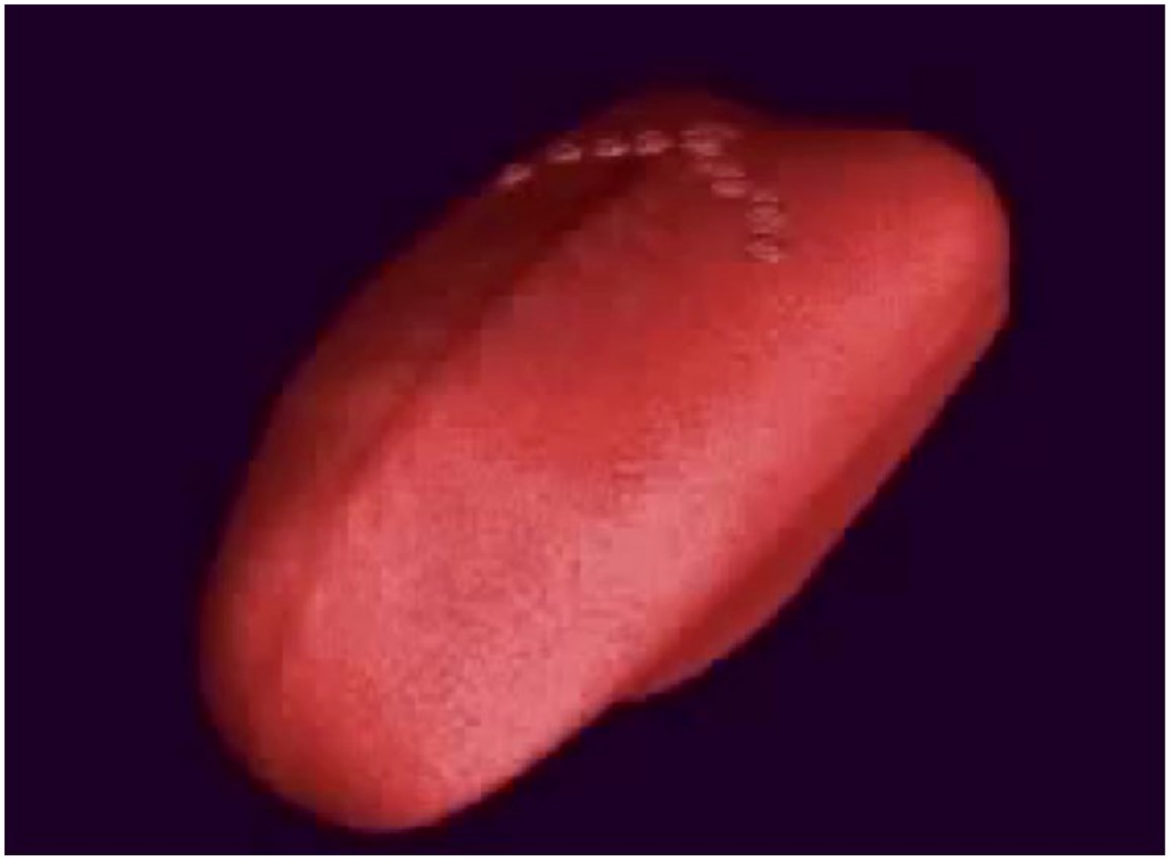
Vaqsco VR: Smell in VR

5 types of cartridge in Vaqso VR, Japan: https://vaqso.com/
https://youtu.be/tDzJmd57FA0

Vaqsco VR: Smell in VR

You can install the device in all HMD by using the adaptor.

Sense of Taste



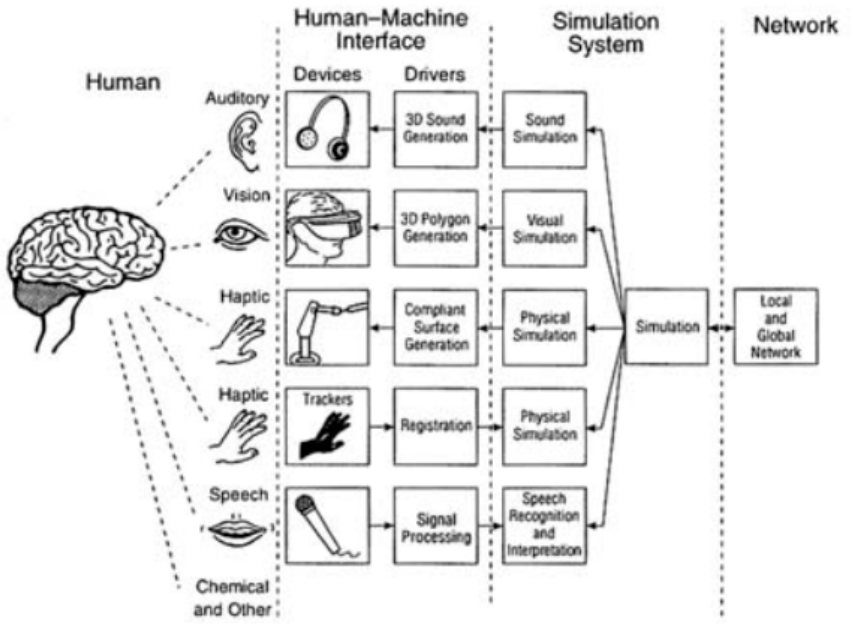
https://www.youtube.com/watch?v=FSHGucgnvLU

Basics of Taste

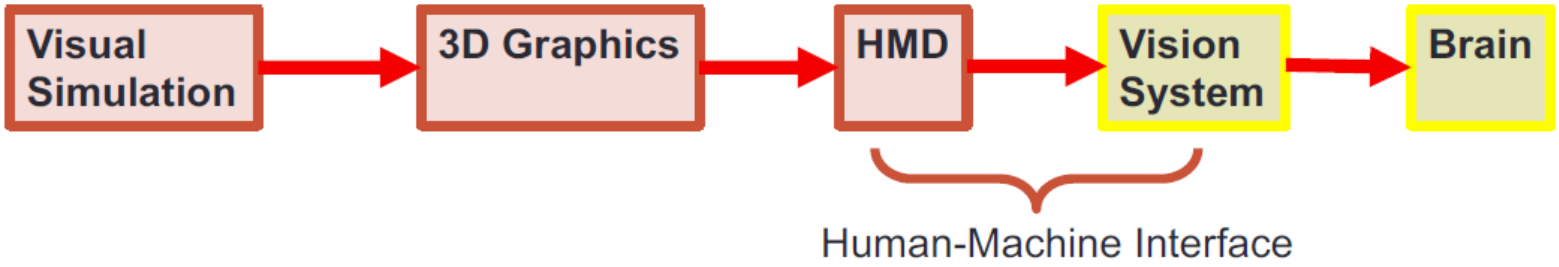
- Sensation produced when a substance in the mouth reacts chemically with taste receptor cells
- Taste receptors mostly on taste buds on the tongue
  - 2,000 – 5,000 taste buds on tongues/100+ receptors each
- Five basic tastes:
  - sweetness, sourness, saltiness, bitterness, and umami
- Flavour influenced by other senses
  - smell, texture, temperature, “coolness”, “hotness”

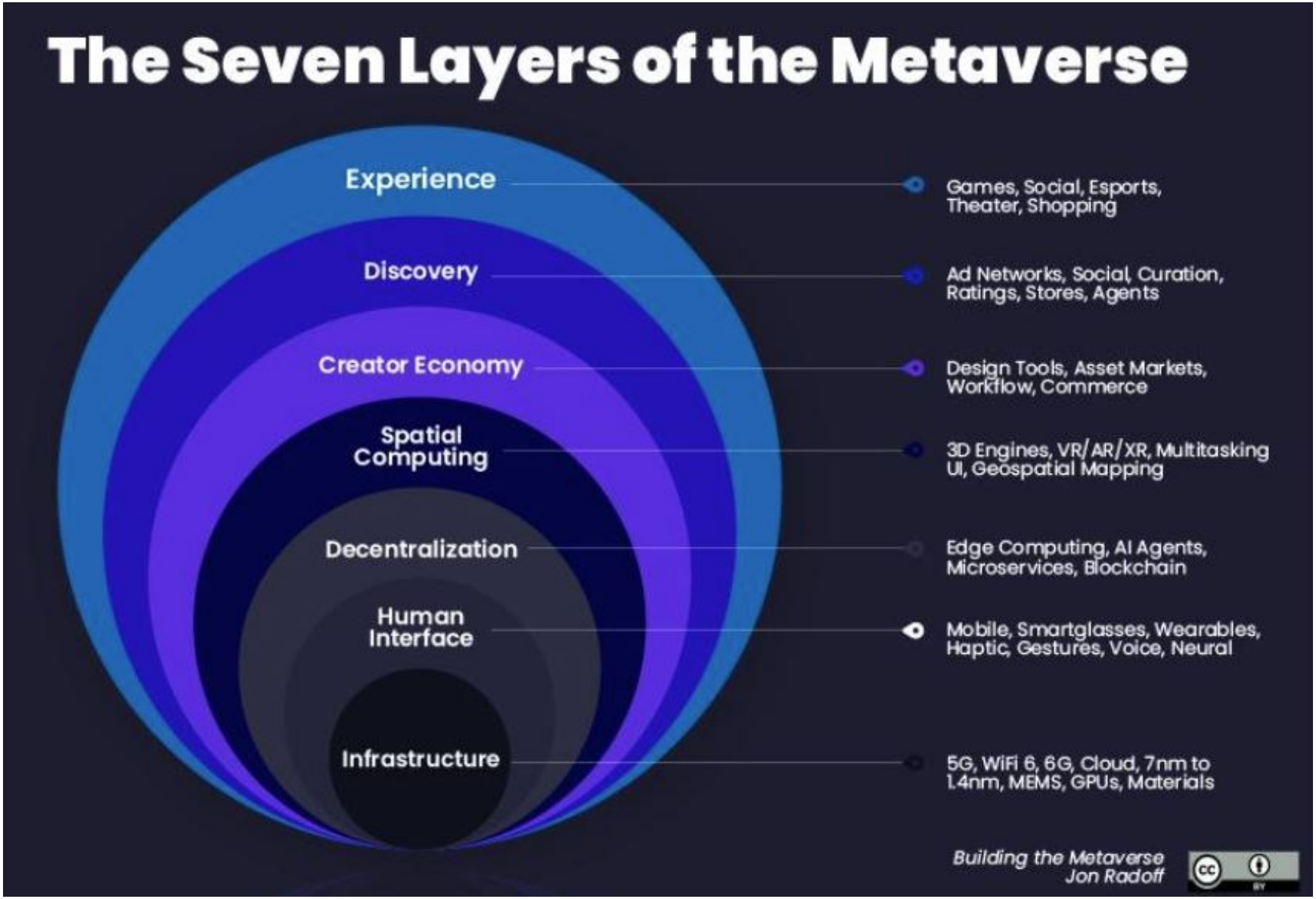
Using Technology to Stimulate Senses

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

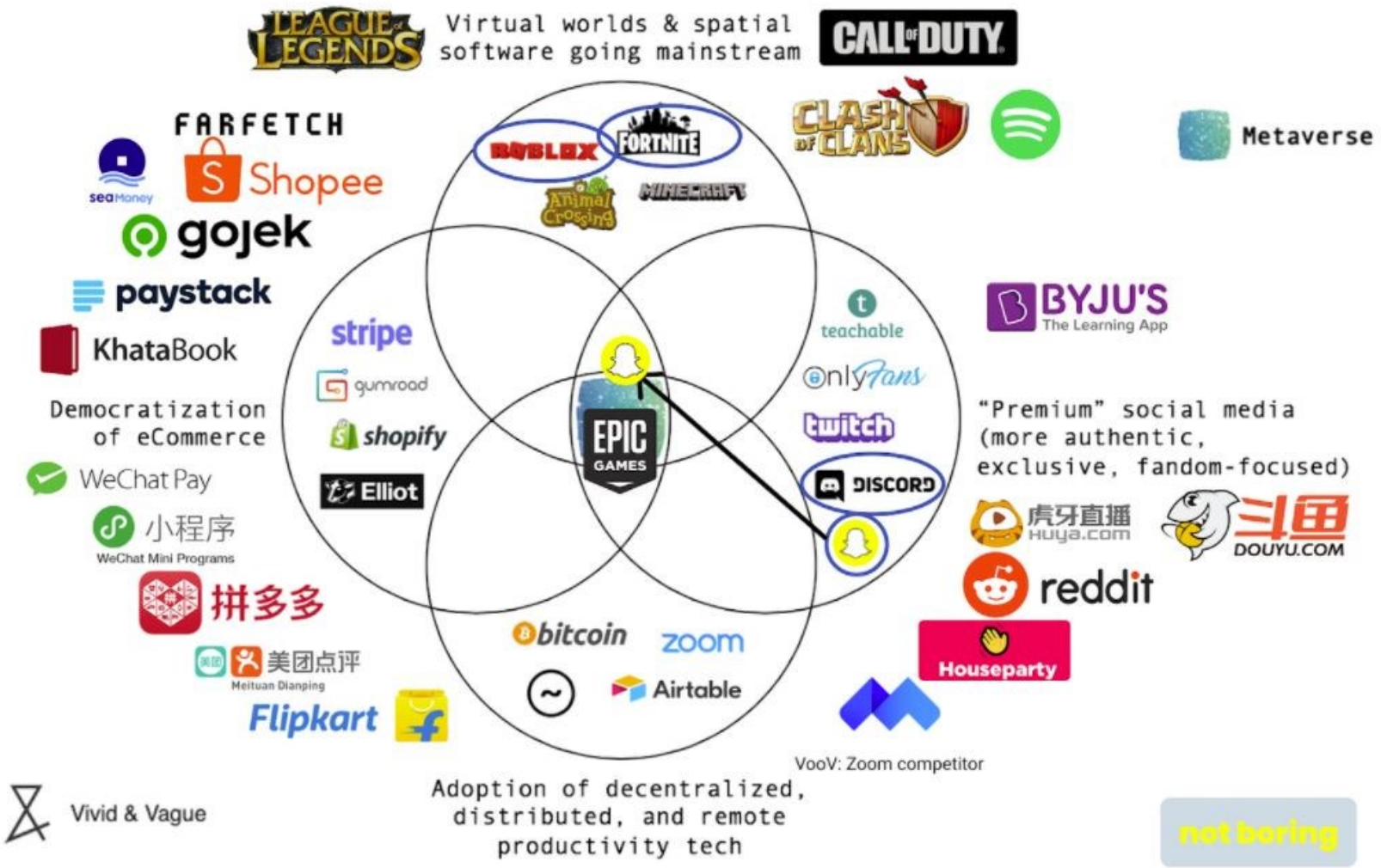


Example: Visual Simulation

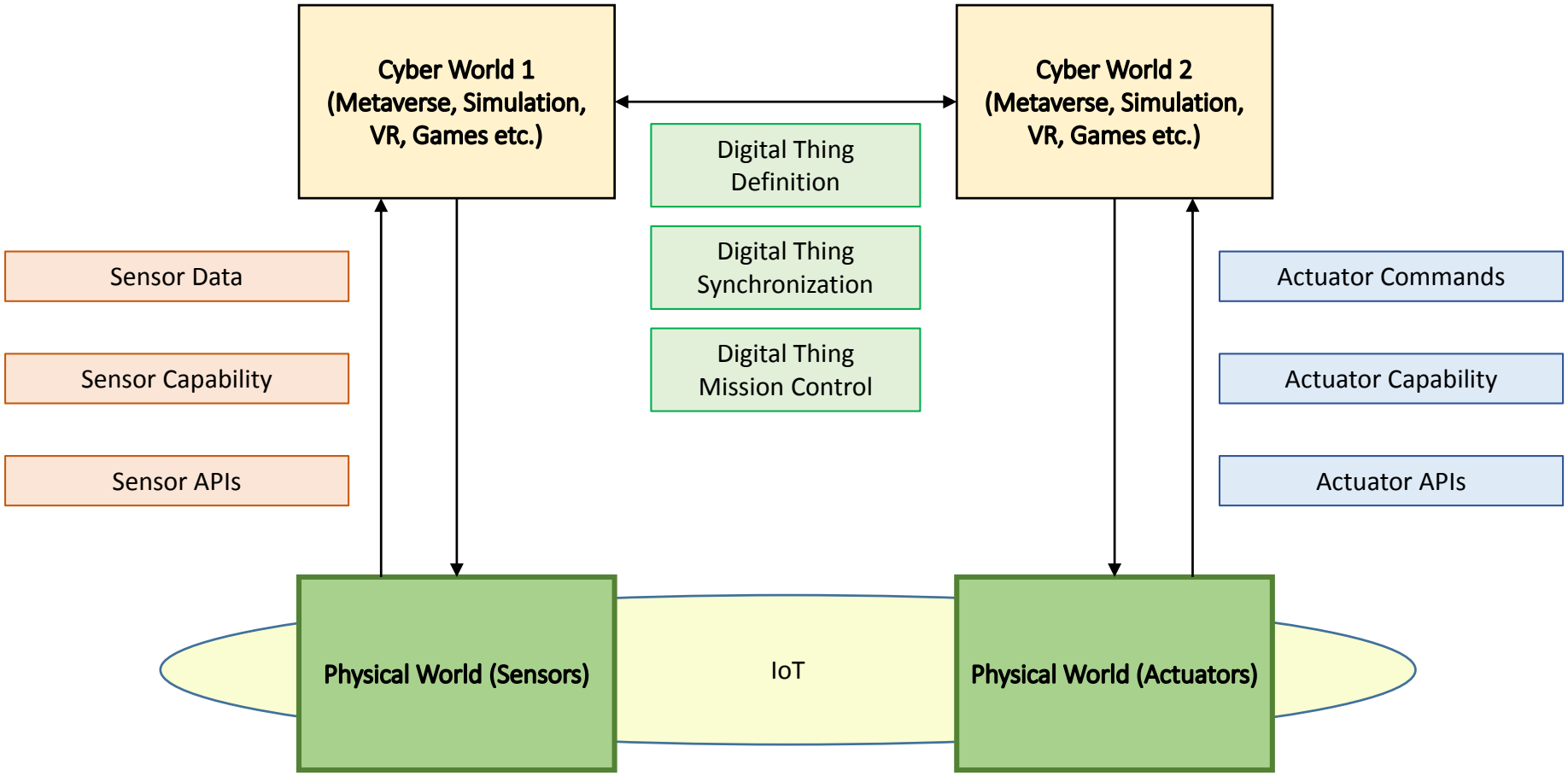



The Seven Layers of the Metaverse
Experience
Games, Social, Esports, Theater, Shopping
Discovery
Ad Networks, Social, Curation, Ratings, Stores, Agents
Creator Economy
Design Tools, Asset Markets, Workflow, Commerce
Spatial Computing
3D Engines, VR/AR/XR, Multitasking UI, Geospatial Mapping
Decentralization
Edge Computing, AI Agents, Microservices, Blockchain
Human Interface
Mobile, Smartglasses, Wearables, Haptic, Gestures, Voice, Neural
Infrastructure
5G, WiFi 6, 6G, Cloud, 7nm to 1.4nm, MEMS, GPUs, Materials
Building the Metaverse
Jon Radoff

Tencent's Metaverse

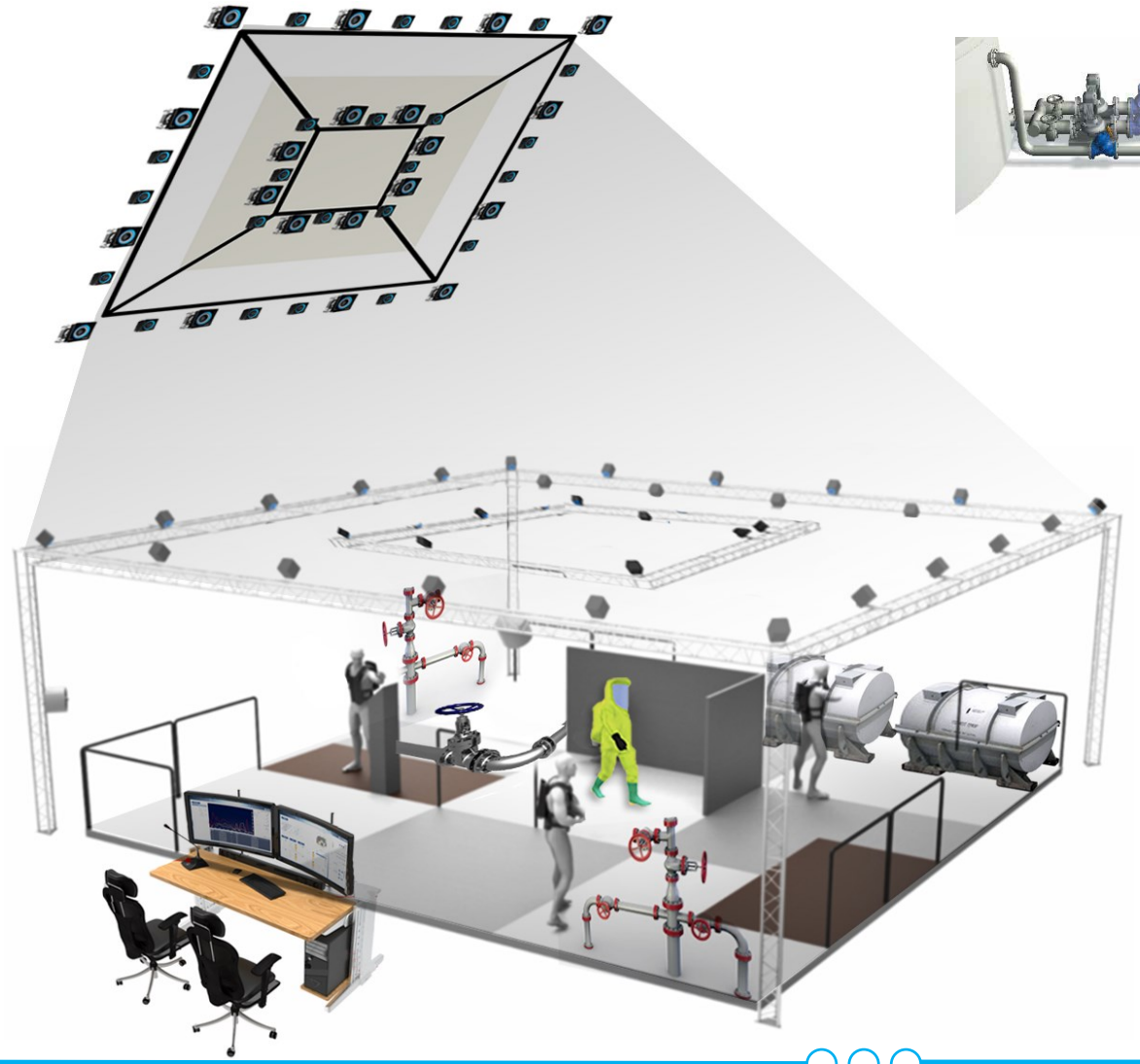


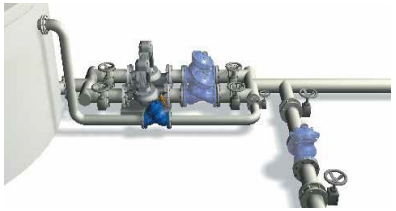
IEEE 2888 Overall Architecture



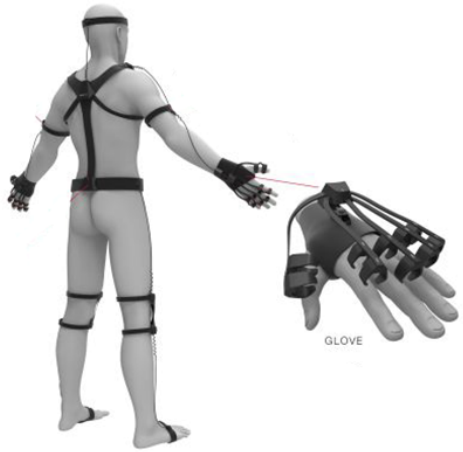
The IEEE 2888 standard: provide common platform for digtial twin space or metaverse plus
https://doi.org/10.1109/ICIR51845.2021.00016

Application support of IEEE 2888





Virtual Objects with
Physical/Virtual Sensors



Physical Sensors

Base Architecture of IEEE 2888.4