LECTURE 2: VR TECHNOLOGY

COMP 4010 - Virtual Reality

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Overview

- Presence in VR
- Perception and VR
- Human Perception
- VR Technology

PRESENCE

Presence ..

"The subjective experience of being in one place or environment even when physically situated in another"

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and virtual environments*, *7*(3), 225-240.

Immersion vs. Presence

- *Immersion:* describes the extent to which technology is capable of delivering 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, defined in technical terms, is capable of producing a sensation of Presence
- Goal of VR: Create a high degree of Presence
  - Make people believe they are really in Virtual Environment

Slater, M., & Wilbur, S. (1997). A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments. *Presence: Teleoperators and virtual environments*, *6*(6), 603-616.

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)

Example: UNC Pit Room

- Key Features
  - Training room and pit room
  - Physical walking
  - Fast, accurate, room scale tracking
  - Haptic feedback – feel edge of pit, walls
  - Strong visual and 3D audio cues
- Task
  - Carry object across pit
    - Walk across or walk around
  - Dropping virtual balls at targets in pit
- http://wwwx.cs.unc.edu/Research/eve/walk_exp/

Typical Subject Behaviour

- Note – from another pit experiment
- https://www.youtube.com/watch?v=VVAO0DkoD-8

Benefits of High Presence

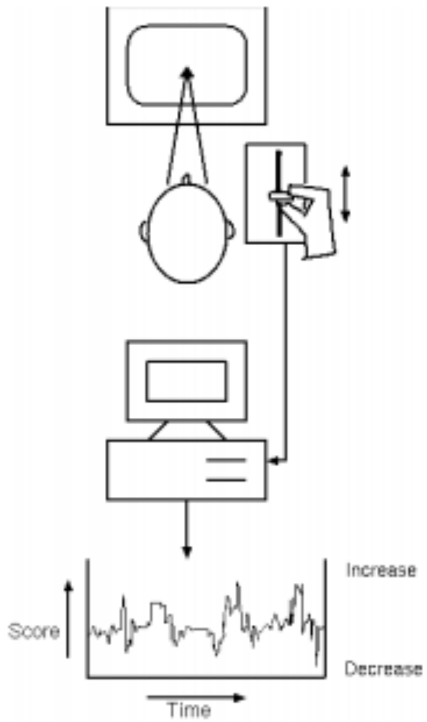
 

- Leads to greater engagement, excitement and satisfaction
  - Increased reaction to actions in VR
- People more likely to behave like in the real world
  - E.g. people scared of heights in real world will be scared in VR
- More natural communication (Social Presence)
  - Use same cues as face to face conversation

- Note: The relationship between Presence and Performance is unclear – still an active area of research

Measuring Presence

- Presence is very subjective so there is a lot of debate among researchers about how to measure it
- Subjective Measures
  - Self report questionnaire
    - University College London Questionnaire (Slater 1999)
    - Witmer and Singer Presence Questionnaire (Witmer 1998)
    - ITC Sense Of Presence Inventory (Lessiter 2000)
  - Continuous measure
    - Person moves slider bar in VE depending on Presence felt
- Objective Measures
  - Behavioural
    - reflex/flinch measure, startle response
  - Physiological measures
    - change in heart rate, skin conductance, skin temperature



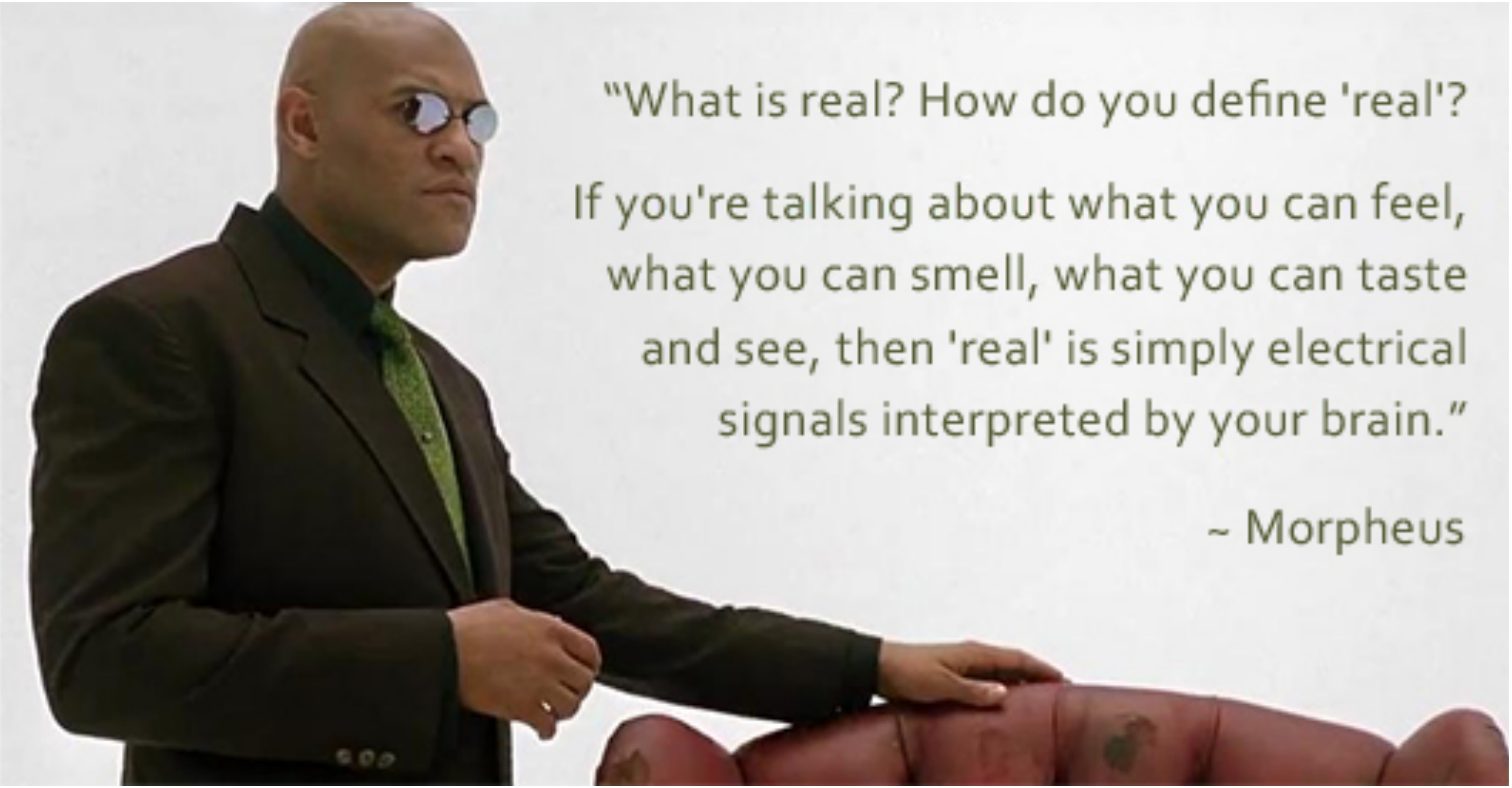
Presence Slider

Relevant Papers

- Slater, M., & Usoh, M. (1993). Representation systems, perceptual positions, and presence in immersive virtual environments. *Presence*, 2:221–233.
- Slater, M. (1999). Measuring presence: A response to the Witmer and Singer Presence Questionnaire. *Presence,* 8:560–565.
- Steuer, J. (1992). Defining virtual reality: Dimensions determining telepresence. *Journal of Communication*, 42(4):72–93.
- Sadowski, W. J. and Stanney, K. M. (2002) Measuring and Managing Presence in Virtual Environments. In: *Handbook of Virtual Environments: Design, implementation, and applications*.http://vehand.engr.ucf.edu/handbook/
- Schuemie, M. J., Van Der Straaten, P., Krijn, M., & Van Der Mast, C. A. (2001). Research on presence in virtual reality: A survey *CyberPsychology & Behavior*, *4*(2), 183-201.
- Lee, K. M. (2004). Presence, explicated. *Communication theory*, *14*(1), 27-50.
- Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and virtual environments*, *7*(3), 225-240.
- Lessiter, J., Freeman, J., Keogh, E., & Davidoff, J. (2000). Development of a new cross-media presence questionnaire: The ITC-Sense of presence. Paper at the *Presence 2000 Workshop*, March 27–28, Delft.

PERCEPTION AND VR

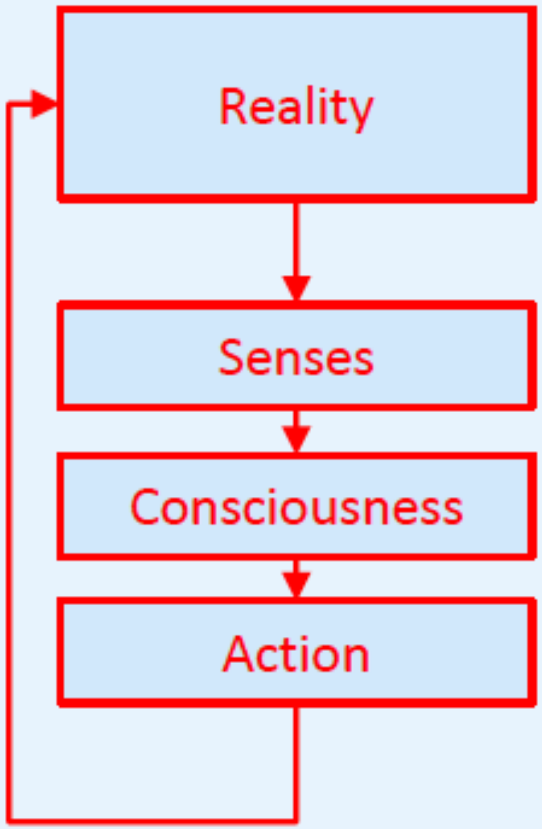
What is Reality?



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



Goal of Virtual Reality

".. to make it feel like you're actually in a place that you are not."

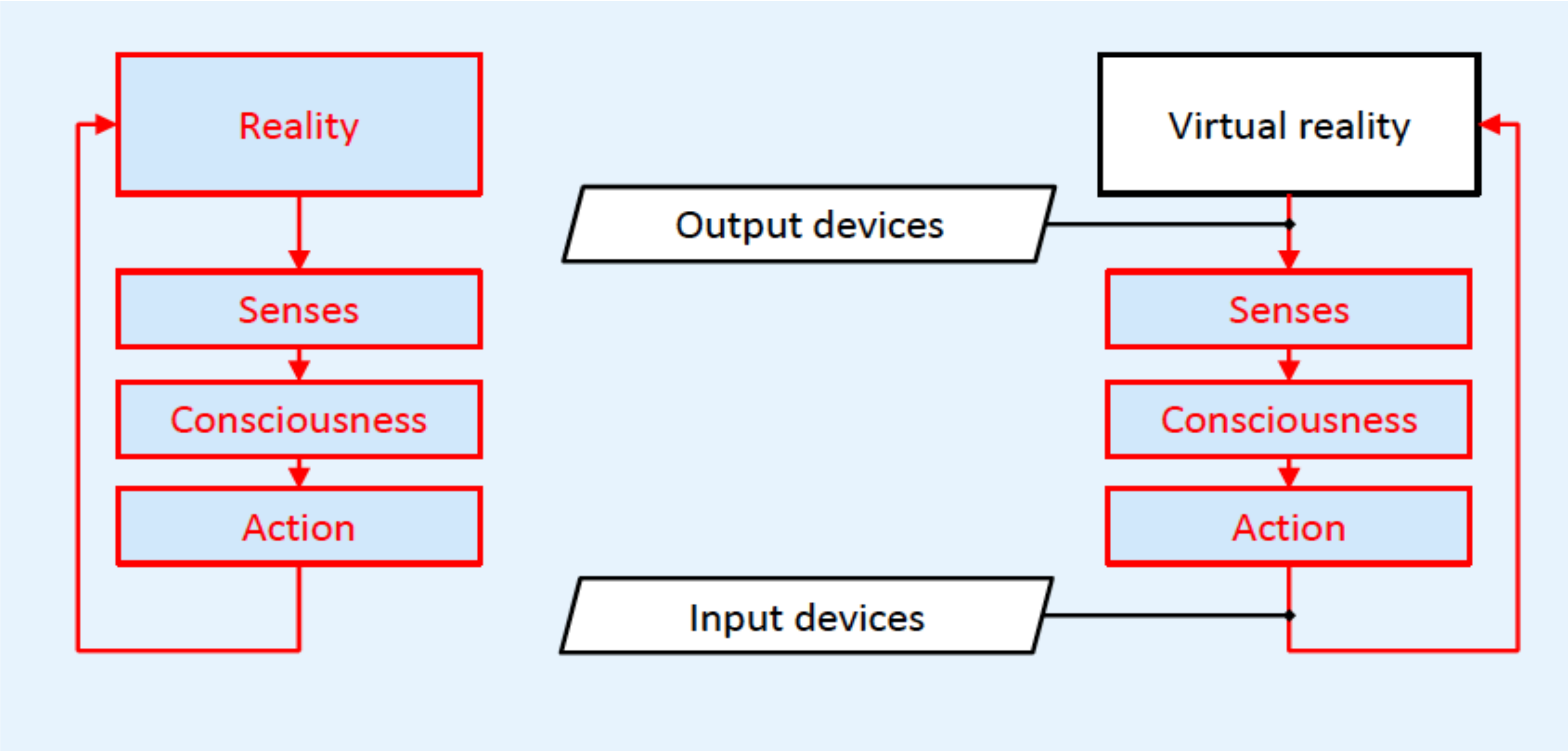
Palmer Luckey

Co-founder, Oculus

Creating the Illusion of Reality

- Fooling human perception by using technology to generate artificial sensations
  - Computer generated sights, sounds, smell, etc

Reality vs. Virtual Reality



- In a VR system there are input and output devices between human perception and action

Example Birdly - http://www.somniacs.co/

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

Birdly Demo

- https://www.youtube.com/watch?v=gHE6H62GHoM

Today

Tomorrow

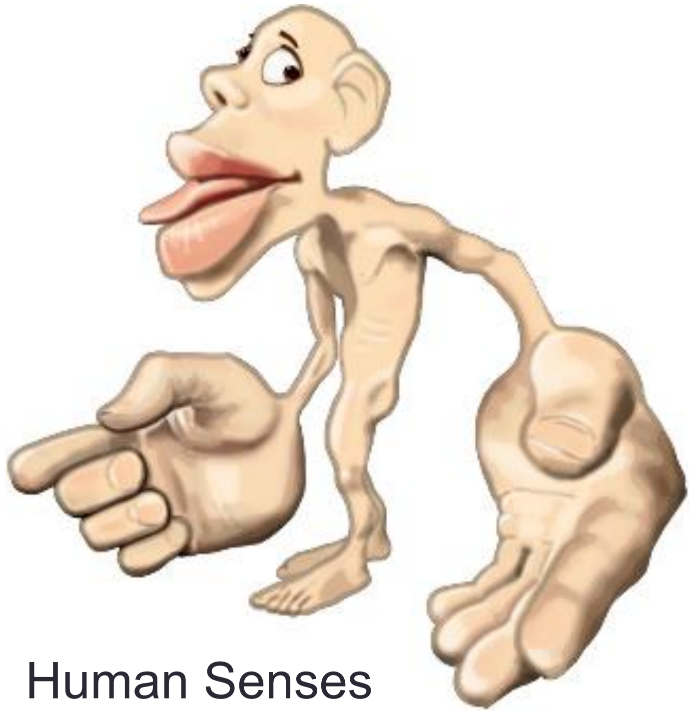
‘Virtual Reality is a synthetic sensory experience which may one day be indistinguishable from the real physical world.”

-Roy Kalawsky (1993)

HUMAN PERCEPTION

Motivation

VR Hardware



Human Senses

- Understand: In order to create a strong sense of Presence we need to understand the Human Perception system
- Stimulate: We need to be able to use technology to provide real world sensory inputs, and create the VR illusion

Senses

- How an organism obtains information for perception:
  - Sensation part of **Somatic Division** of **Peripheral Nervous System**
  - Integration and perception requires the **Central Nervous System**
- Five major senses:
  - Sight (Opthalamoception)
  - Hearing (Audioception)
  - Taste (Gustaoception)
  - Smell (Olfacaoception)
  - Touch (Tactioception)

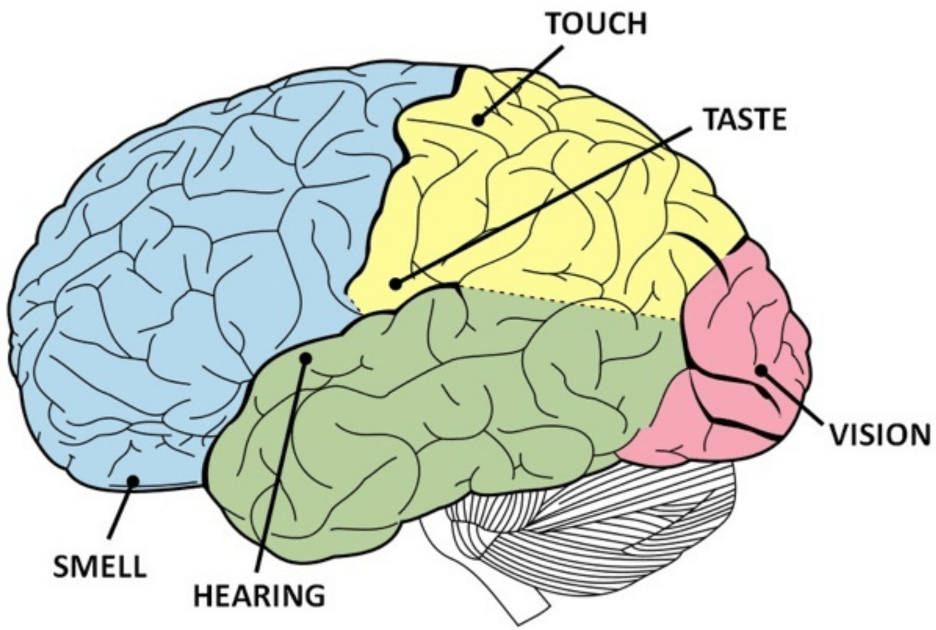
Other Lessor Known Senses..

- Proprioception = sense of body position
  - what is your body doing right now
- Equilibrium = balance
- Acceleration
- Nociception = sense of pain
- Temperature
- Satiety (the quality or state of being fed or gratified to or beyond capacity)
- Thirst
- Micturition
- Amount of CO_2 and Na in blood

Relative Importance of Each Sense

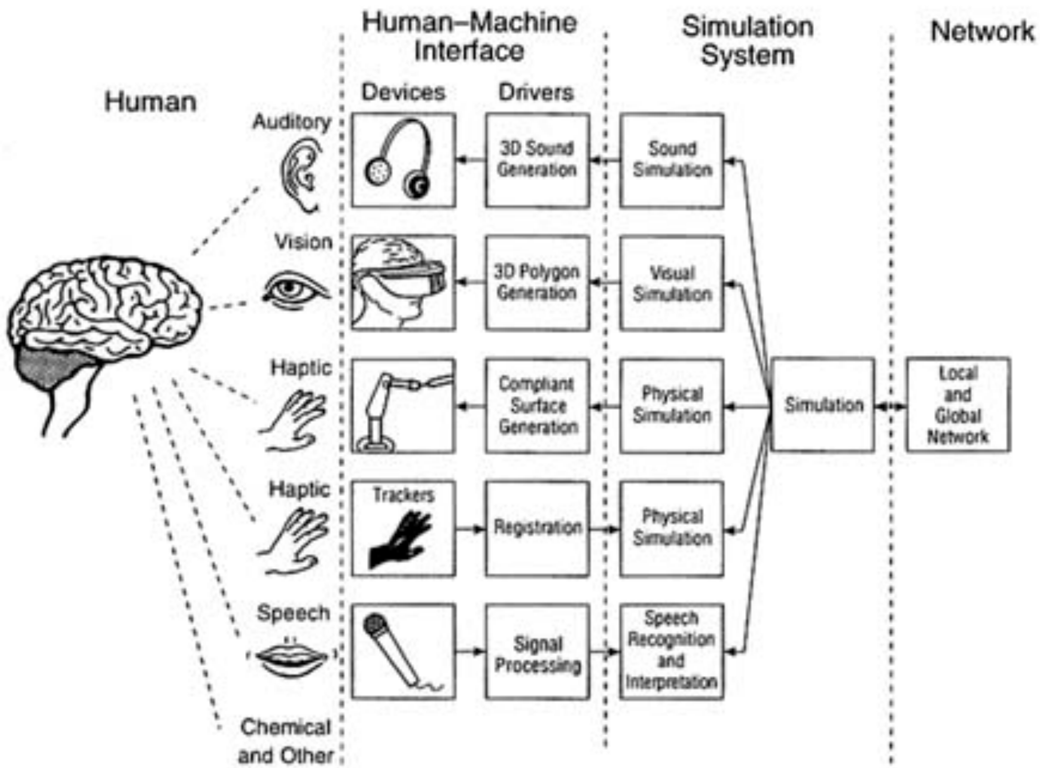
- Percentage of neurons in brain devoted to each sense
  - Sight – 30%
  - Touch – 8%
  - Hearing – 2%
  - Smell - < 1%

- Over 60% of brain involved with vision in some way



VR System Overview

- Simulate output
- Map output to devices
- Use devices to stimulate the senses



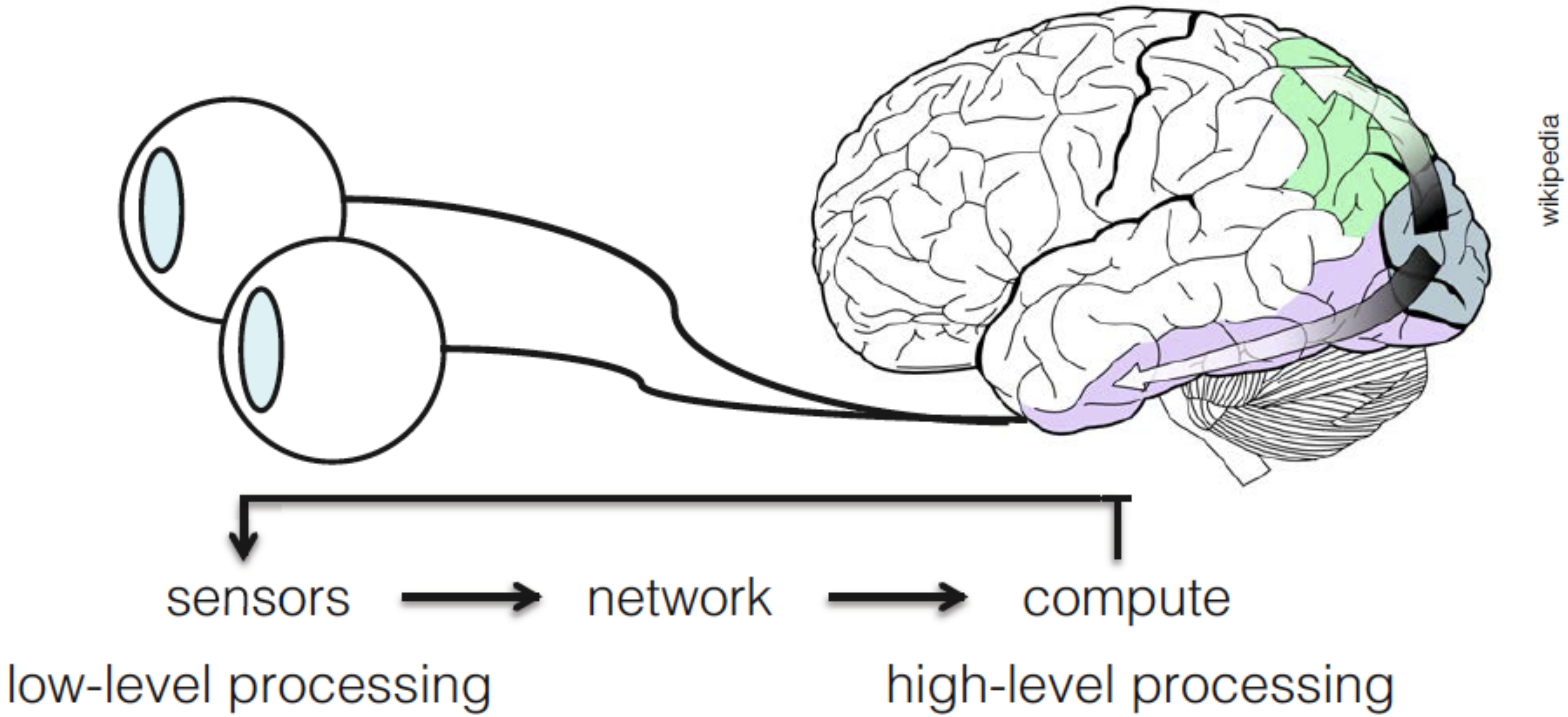
Example: Visual Simulation

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

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

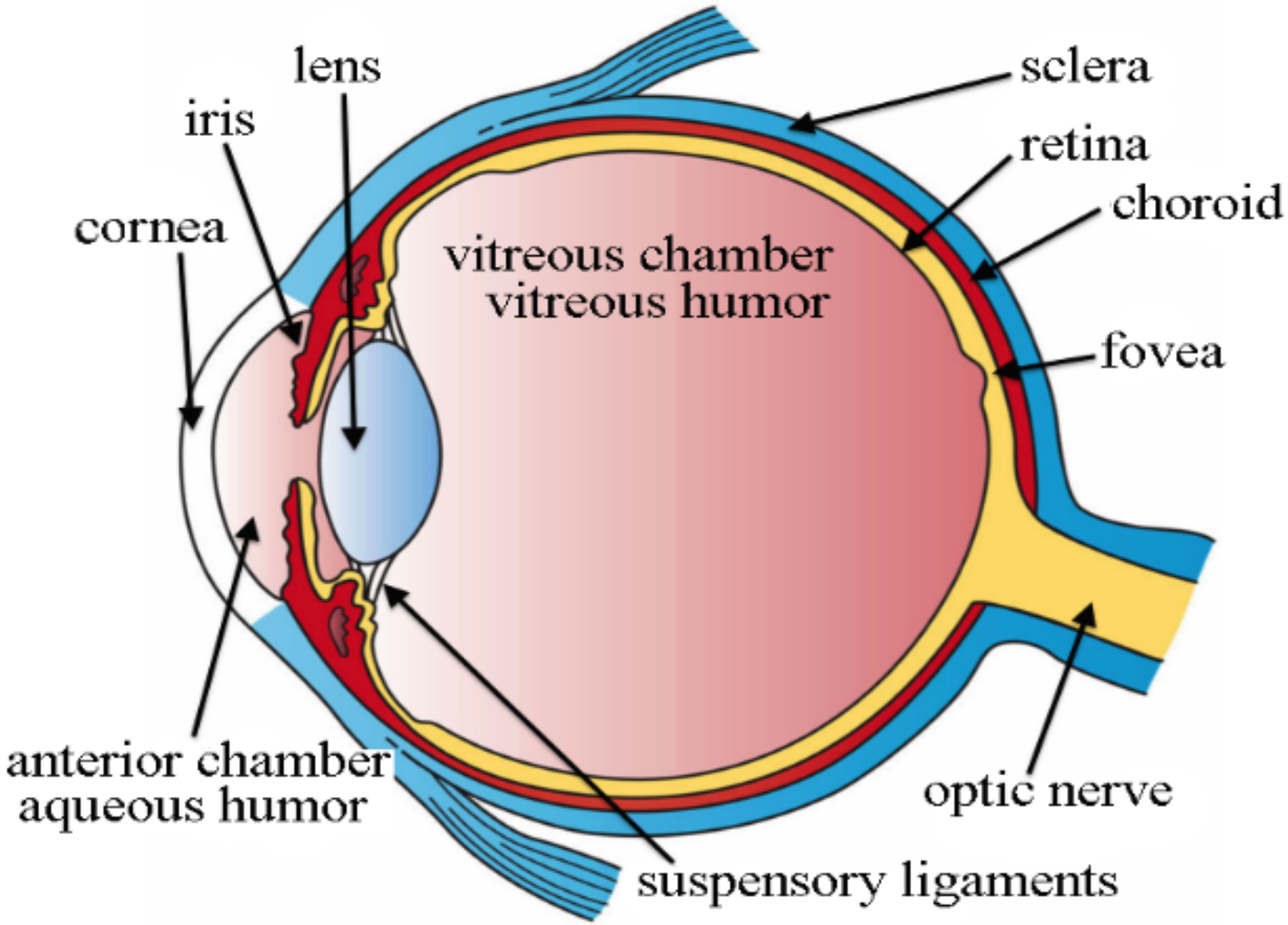

Sight

The Human Visual System



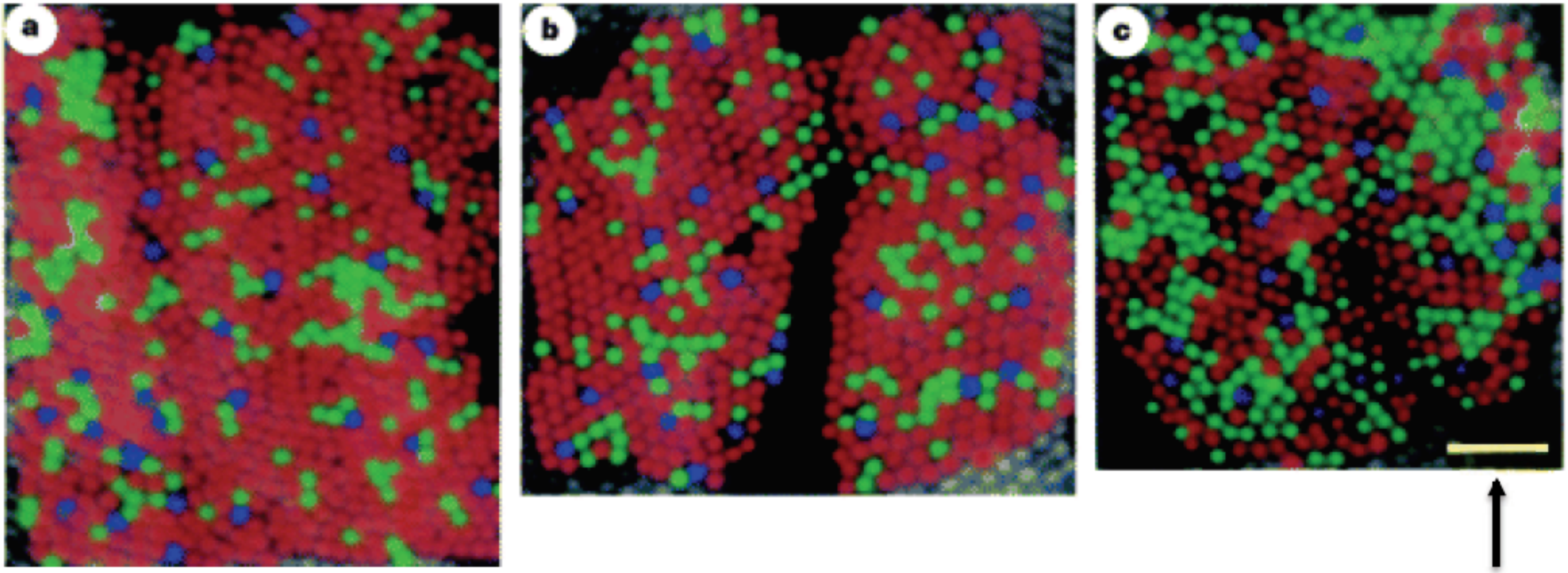
- Purpose is to convert visual input to signals in the brain

The Human Eye



- Light passes through cornea and lens onto retina
- Photoreceptors in retina convert light into electrochemical signals

Photoreceptors – Rods and Cones



Roorda & Williams, 1999, Nature

5 arcmin visual angle

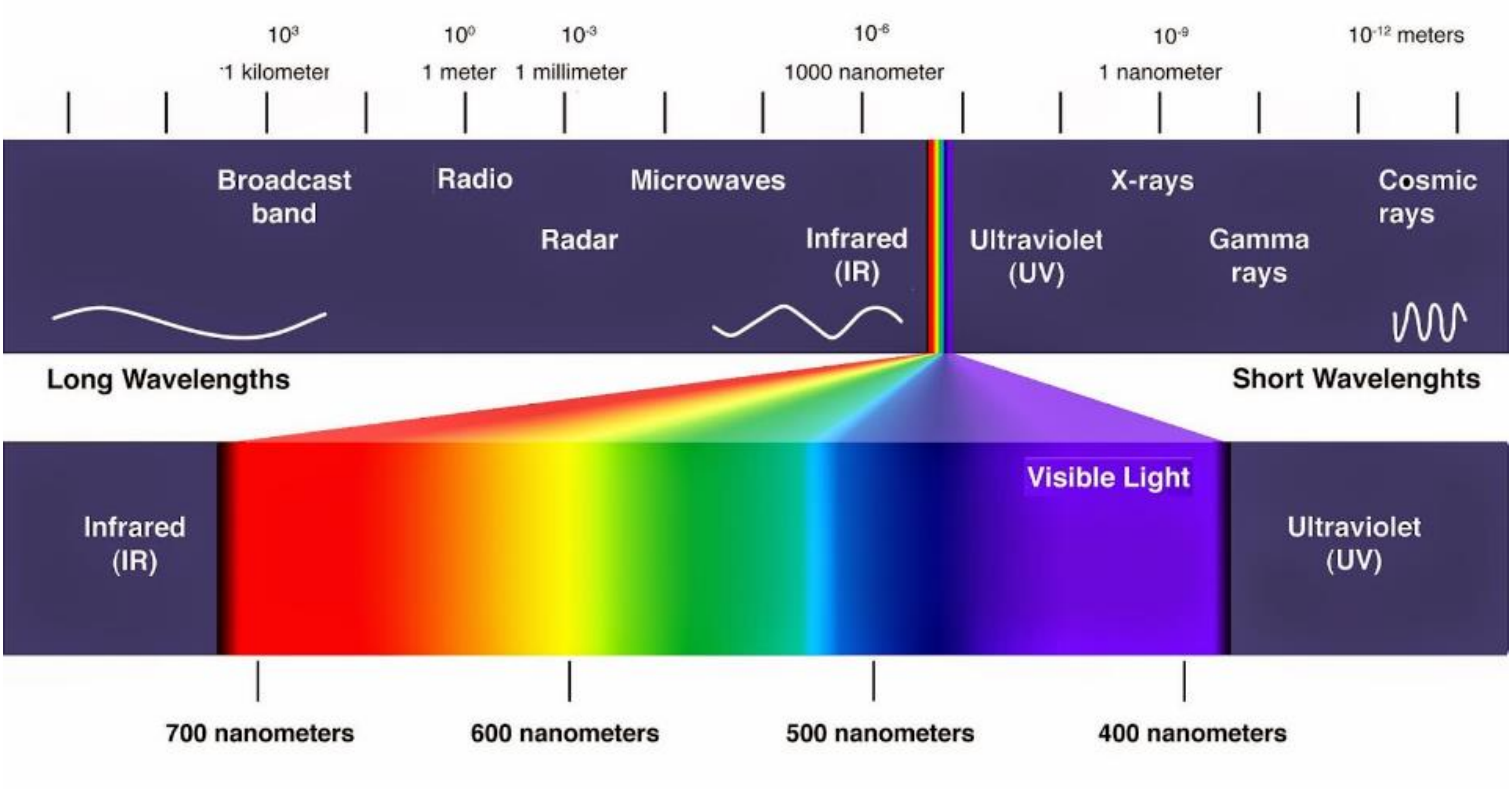
photoreceptors: 3 types of cones (color vision), rods (luminance only, night vision)

- Retina photoreceptors come in two types, Rods and Cones

Rods vs. Cones

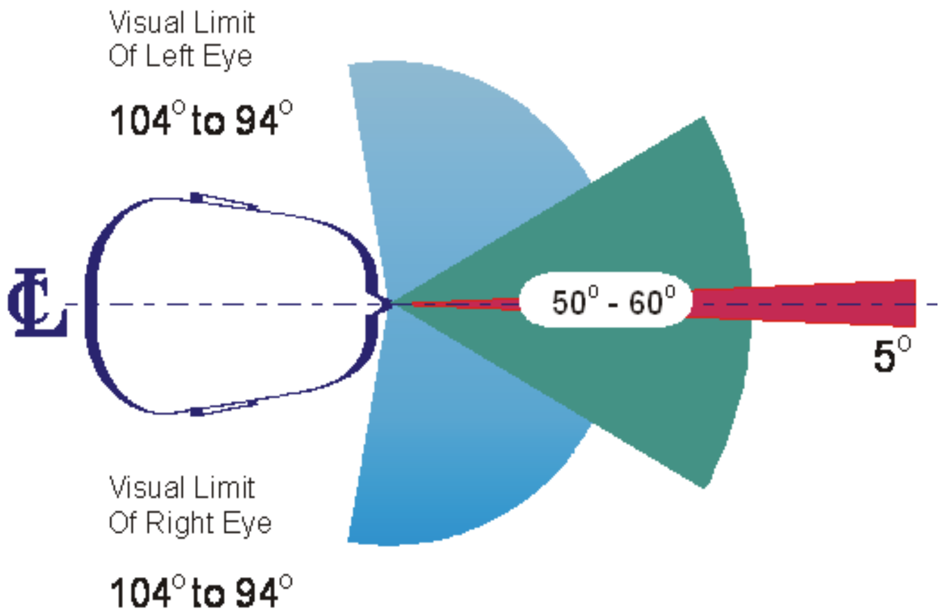
- **RODS**
  - 125 million cells in retina
  - Concentrated on periphery of retina
  - No color detection
  - Most sensitive to light
  - Scotopic (night) vision
  - Provide peripheral vision, motion detection
- **CONES**
  - 4.5-6 million in retina
  - Responsible for color vision
  - Sensitive to red, blue, green light
  - Work best in more intense light

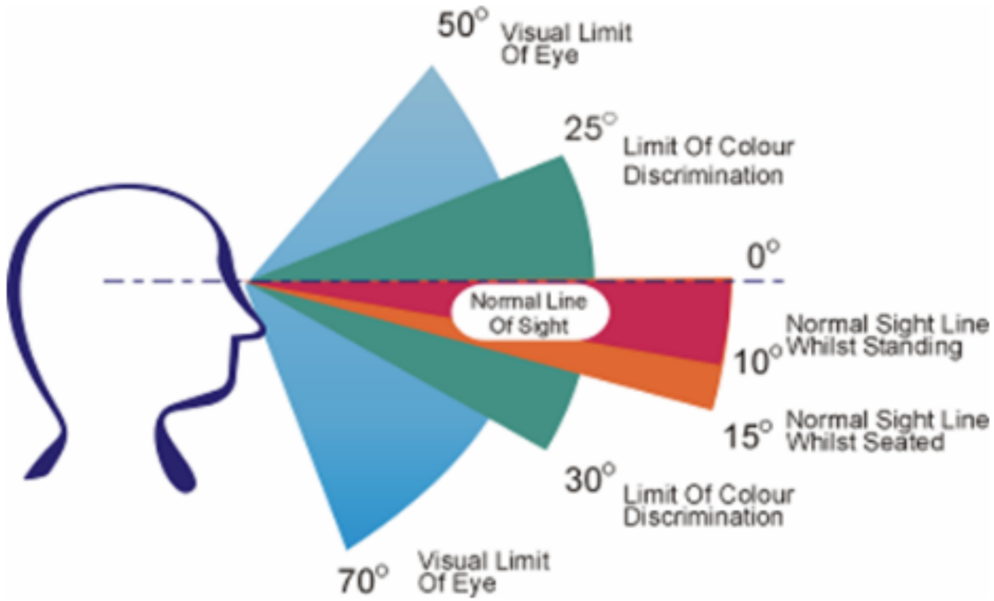
Colour Perception



- Humans only perceive small part of electromagnetic spectrum

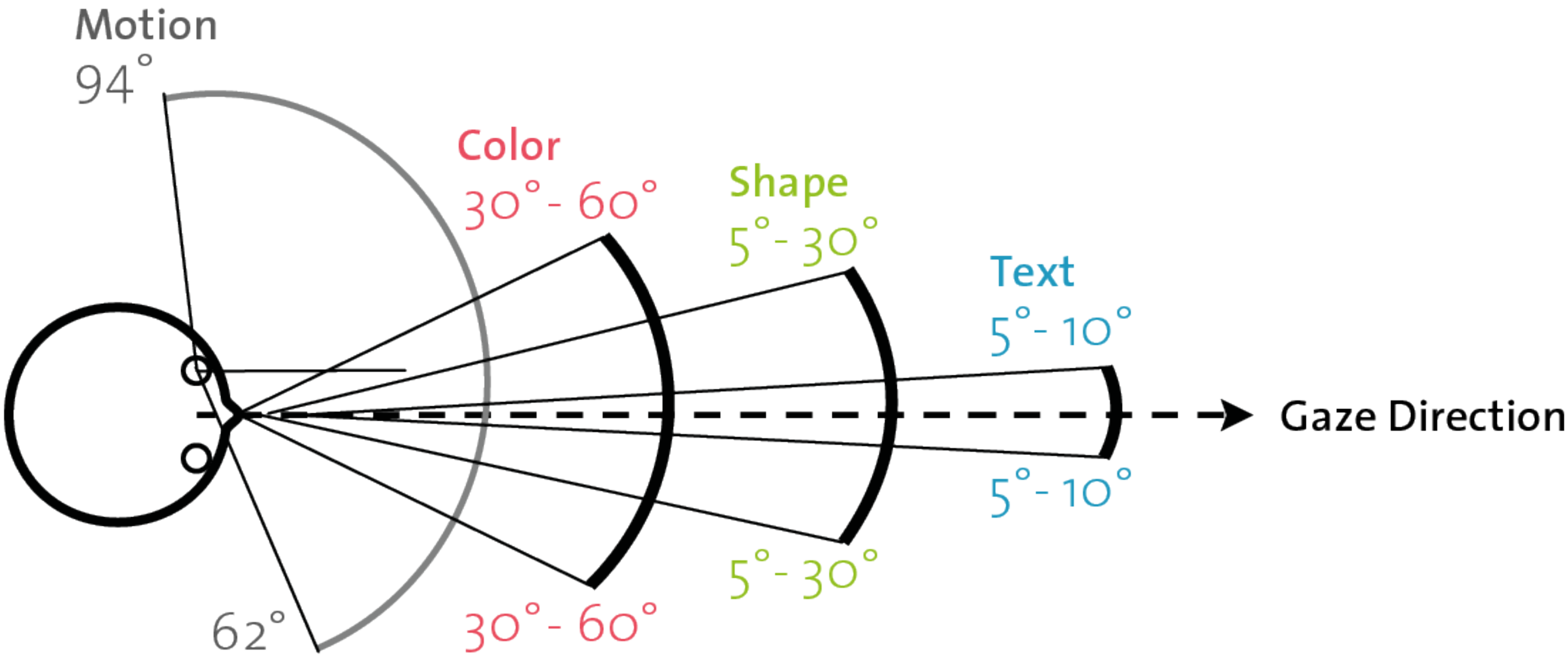
Horizontal and Vertical FOV





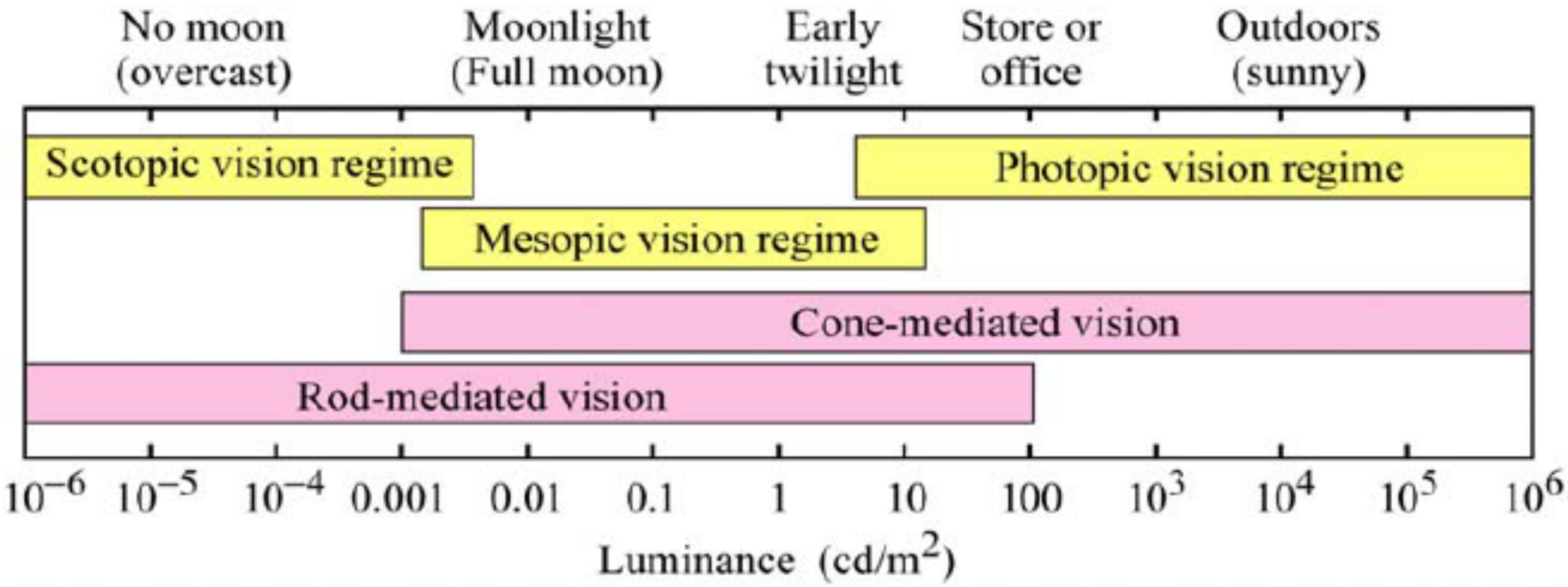
- Humans can see ~135° vertical (60° above, 75° below)
- See up to ~ 210° horizontal FOV, ~ 115° stereo overlap
- Colour/stereo in centre, Black & White/mono in periphery

Types of Visible Perception Possible



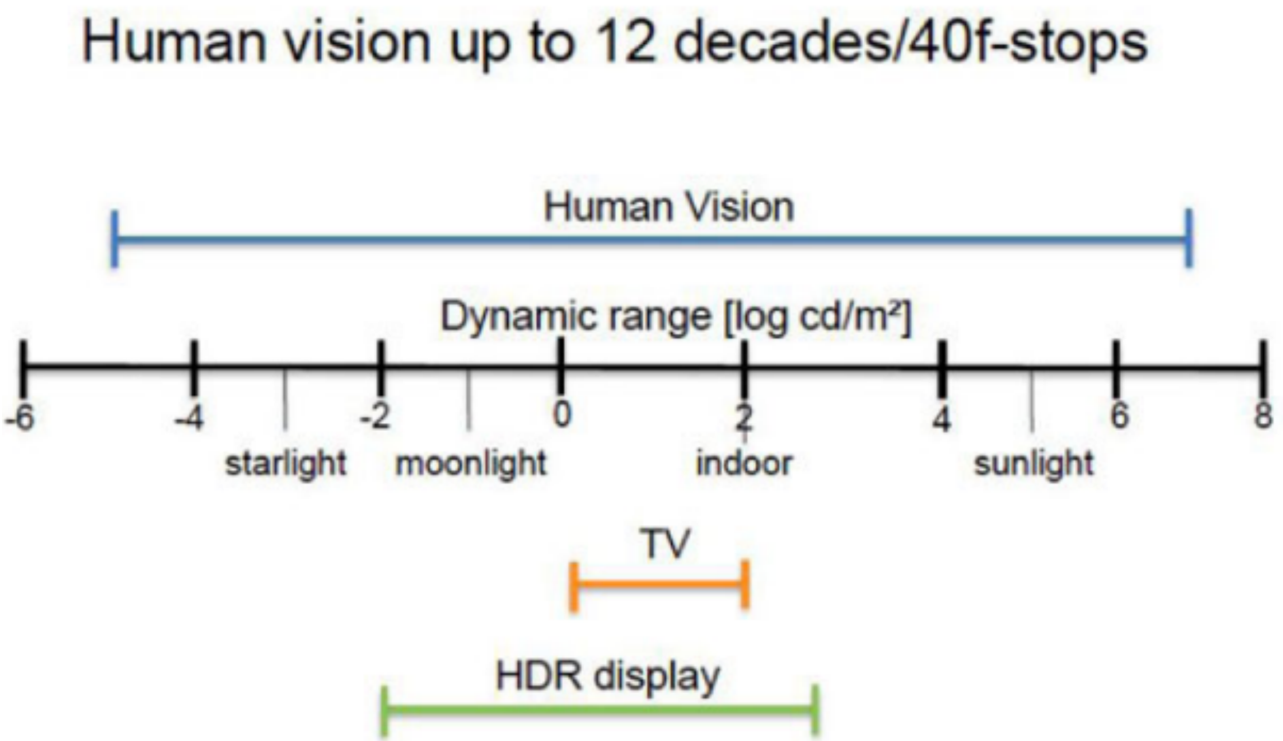
- As move further from fovea, vision becomes more limited

Dynamic Range



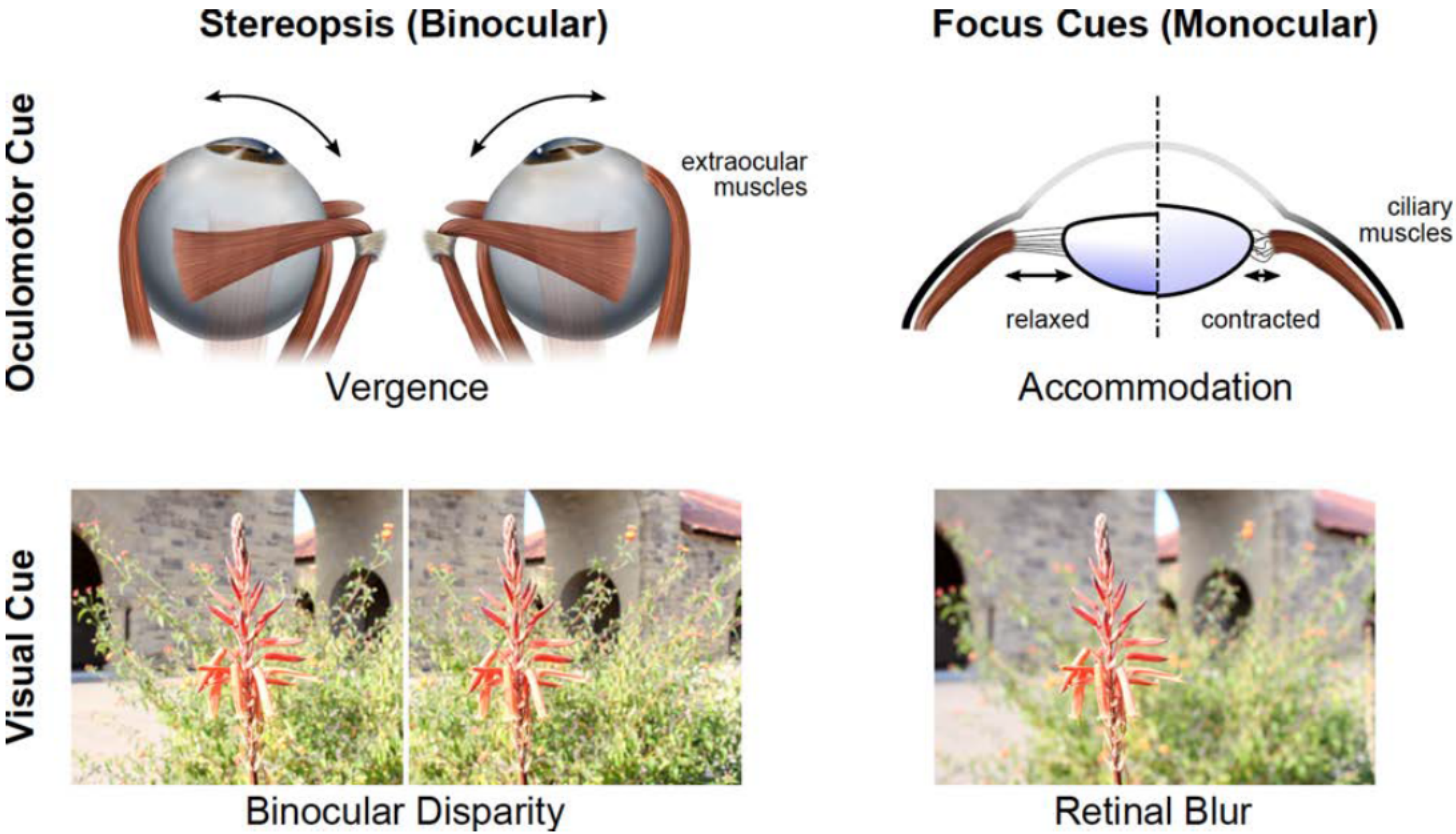
- Rods respond to low Luminance light, Cones to bright light

Comparing to Displays



- Human vision has far higher dynamic range than any available display technology
  - 40 f-stops, cf 17 f-stops for HDR display

Vergence + Accommodation

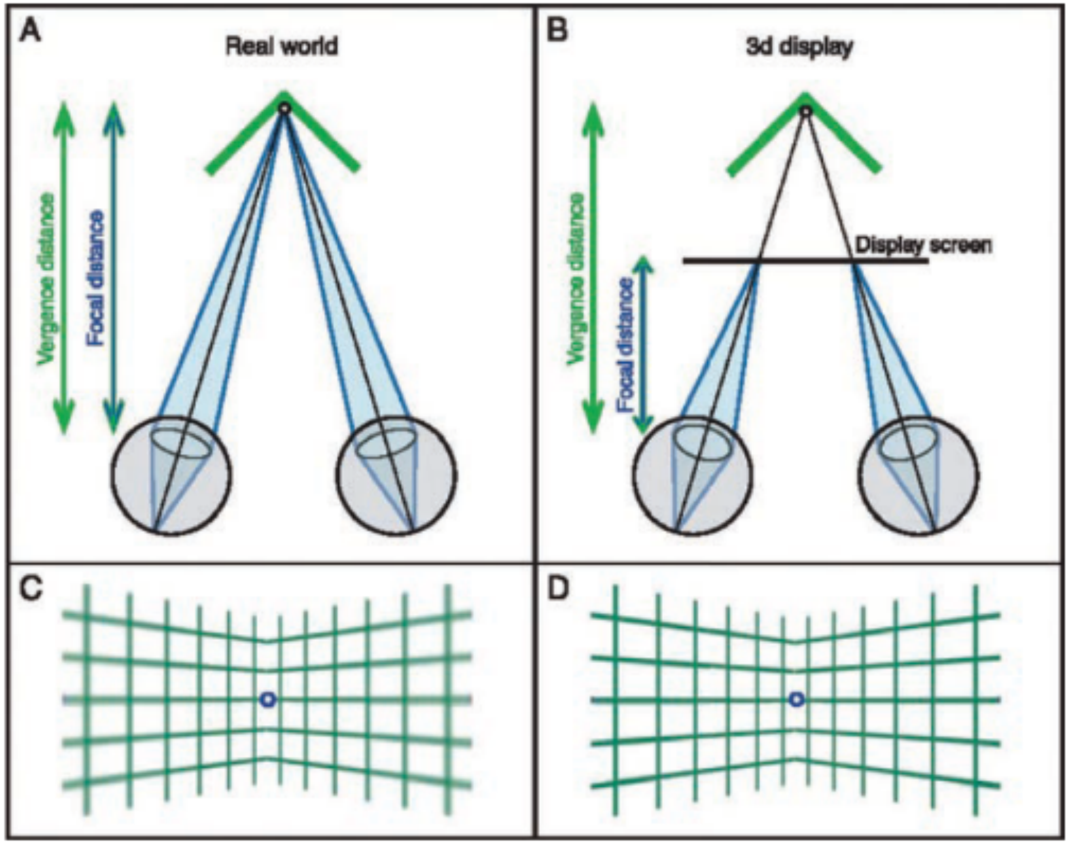


Vergence/Accommodation Demo

- https://www.youtube.com/watch?v=p_xLO7yxgOk

Vergence-Accommodation Conflict

Marty Banks, UC Berkeley

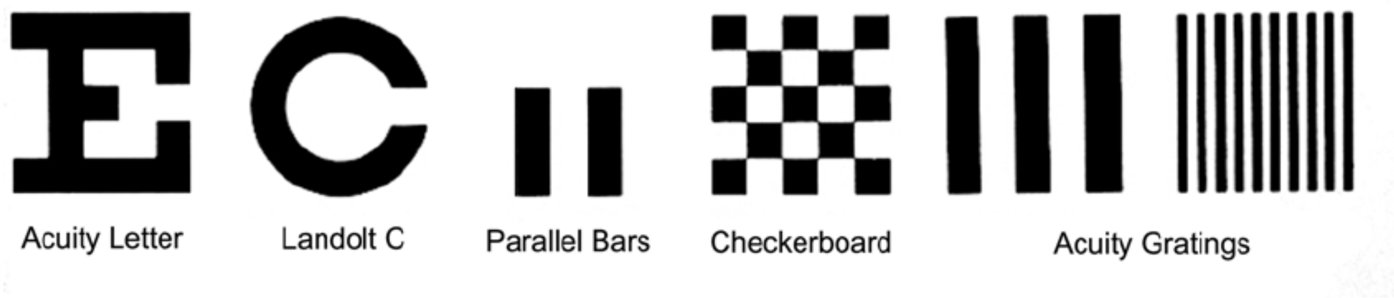


effects

- visual discomfort
- visual fatigue
- nausea
- diplopic vision
- eyestrain
- compromised image quality
- pathologies in developing visual system
- …

- Looking at real objects, vergence and focal distance match
- In Virtual Reality, vergence and accommodation can miss-match
  - Focusing on HMD screen, but accommodating for virtual object behind screen

Visual Acuity

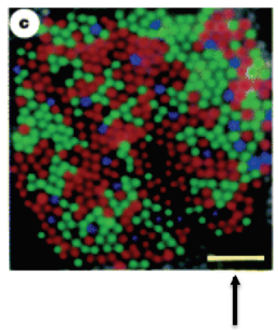


Visual Acuity Test Targets

- Ability to resolve details
- Several types of visual acuity
  - detection, separation, etc
- Normal eyesight can see a 50 cent coin at 80m
  - Corresponds to 1 arc min (1/60th of a degree)
  - Max acuity = 0.4 arc min

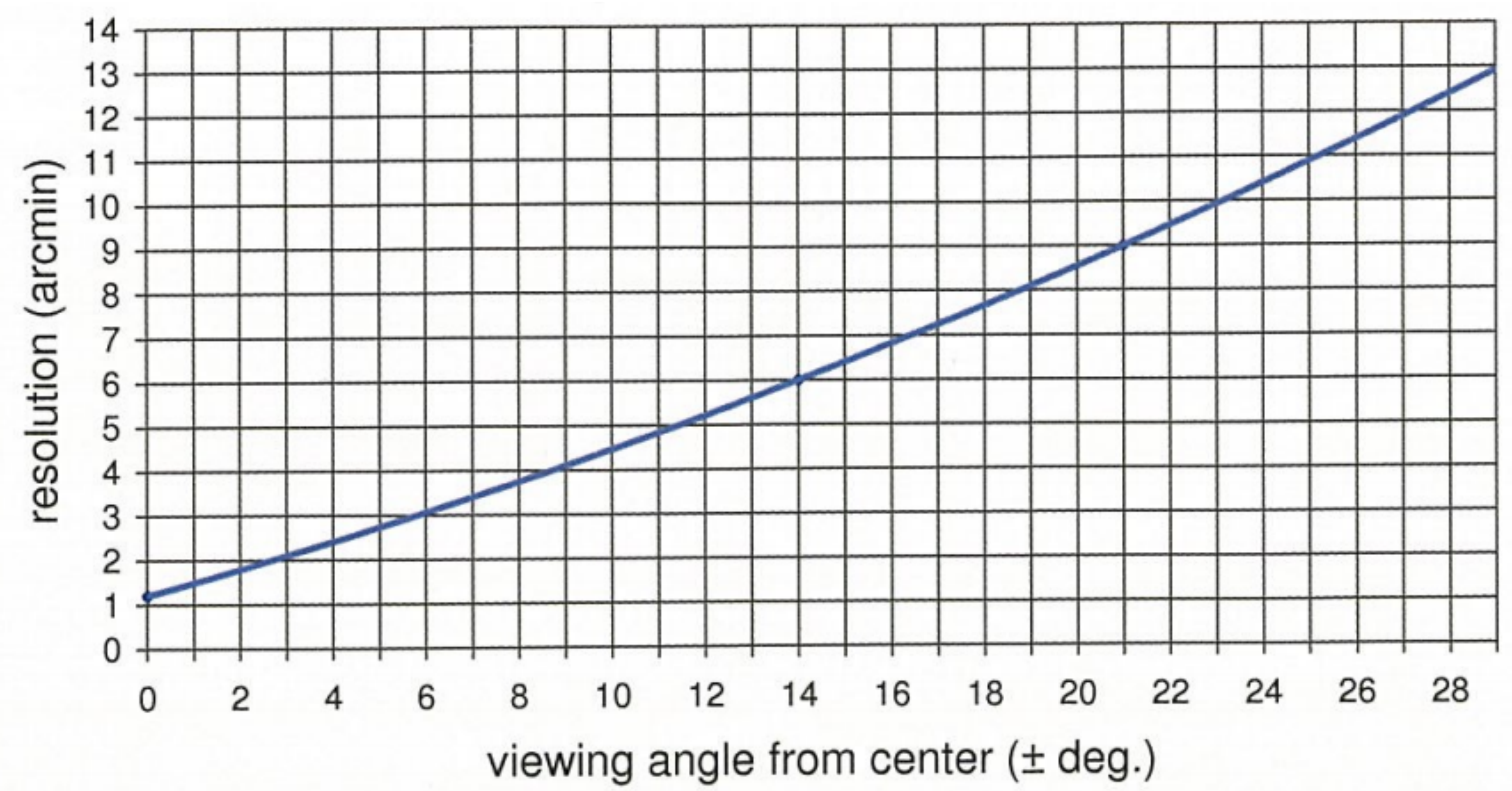
Roorda & Williams, 1999, Nature

each photorecepter
~ 1 arc min (1/60 of a degree)



5 arcmin visual angle

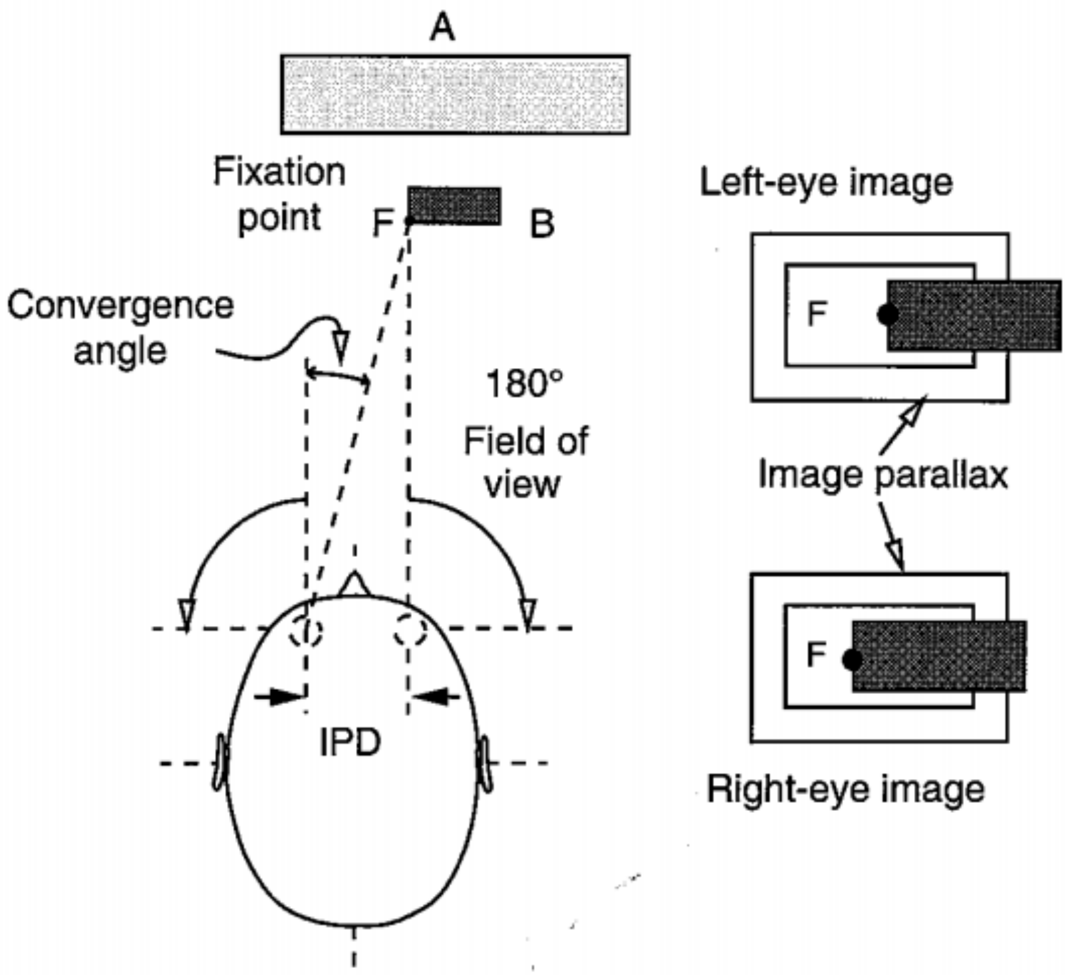
Resolution of the Eye

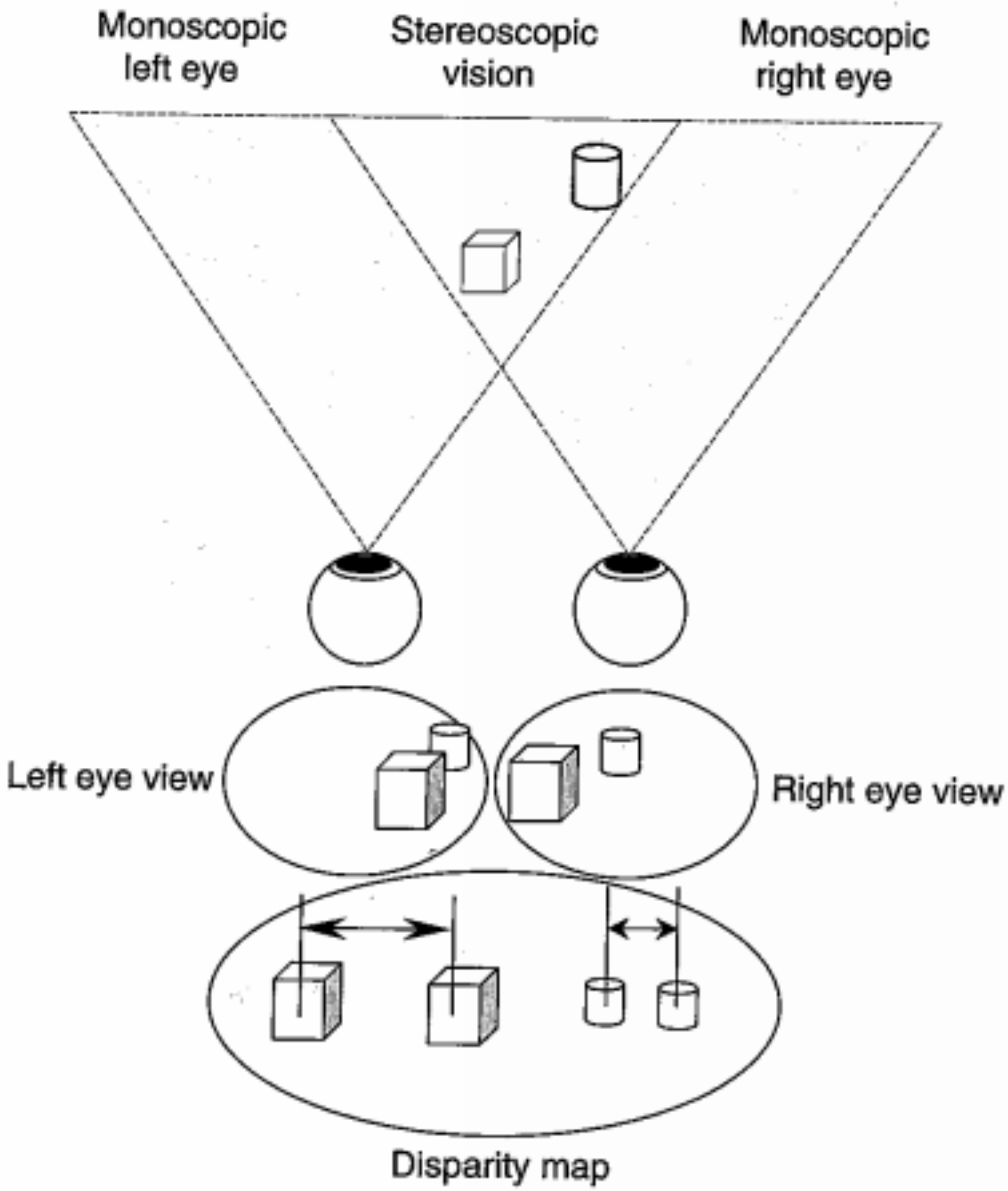


- Decreases away from the fovea
  - Maximum resolution of 1 arcmin – spot of 6×10^{-6} m size on retina

Stereo Perception/Stereopsis

- Eyes separated by IPD
  - Inter pupillary distance
  - 5 – 7.5cm (average. 6.5cm)
- Each eye sees diff. image
  - Separated by image parallax
- Images fused to create 3D stereo view




Monoscopic
left eye
Stereoscopic
vision
Monoscopic
right eye
Left eye view
Right eye view
Disparity map

Depth Perception

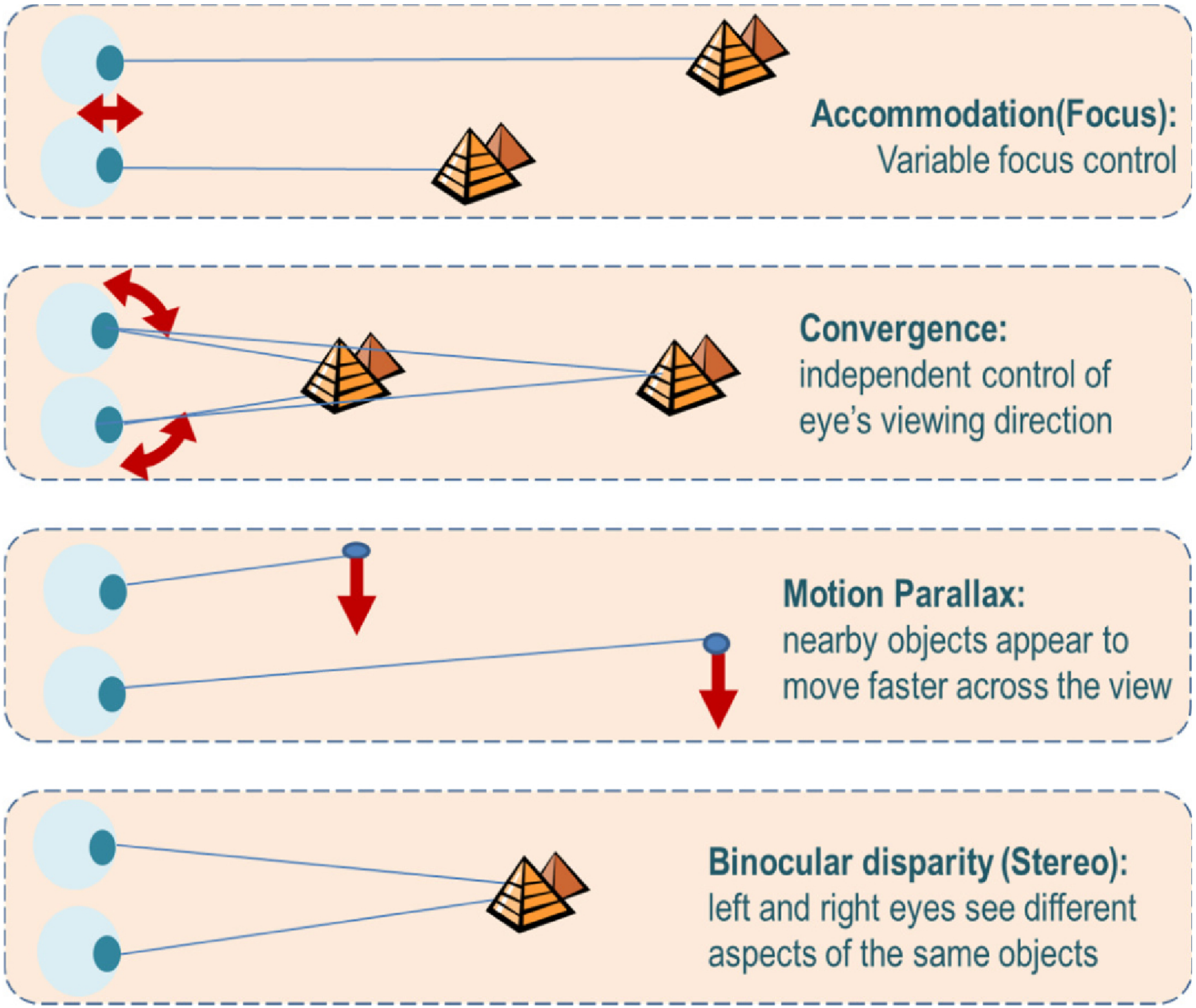
- The visual system uses a range of different Stereoscopic and Monocular cues for depth perception

Stereoscopic	Monocular
eye convergence angle disparity between left and right images diplopia	eye accommodation perspective atmospheric artifacts (fog) relative sizes image blur occlusion motion parallax shadows texture

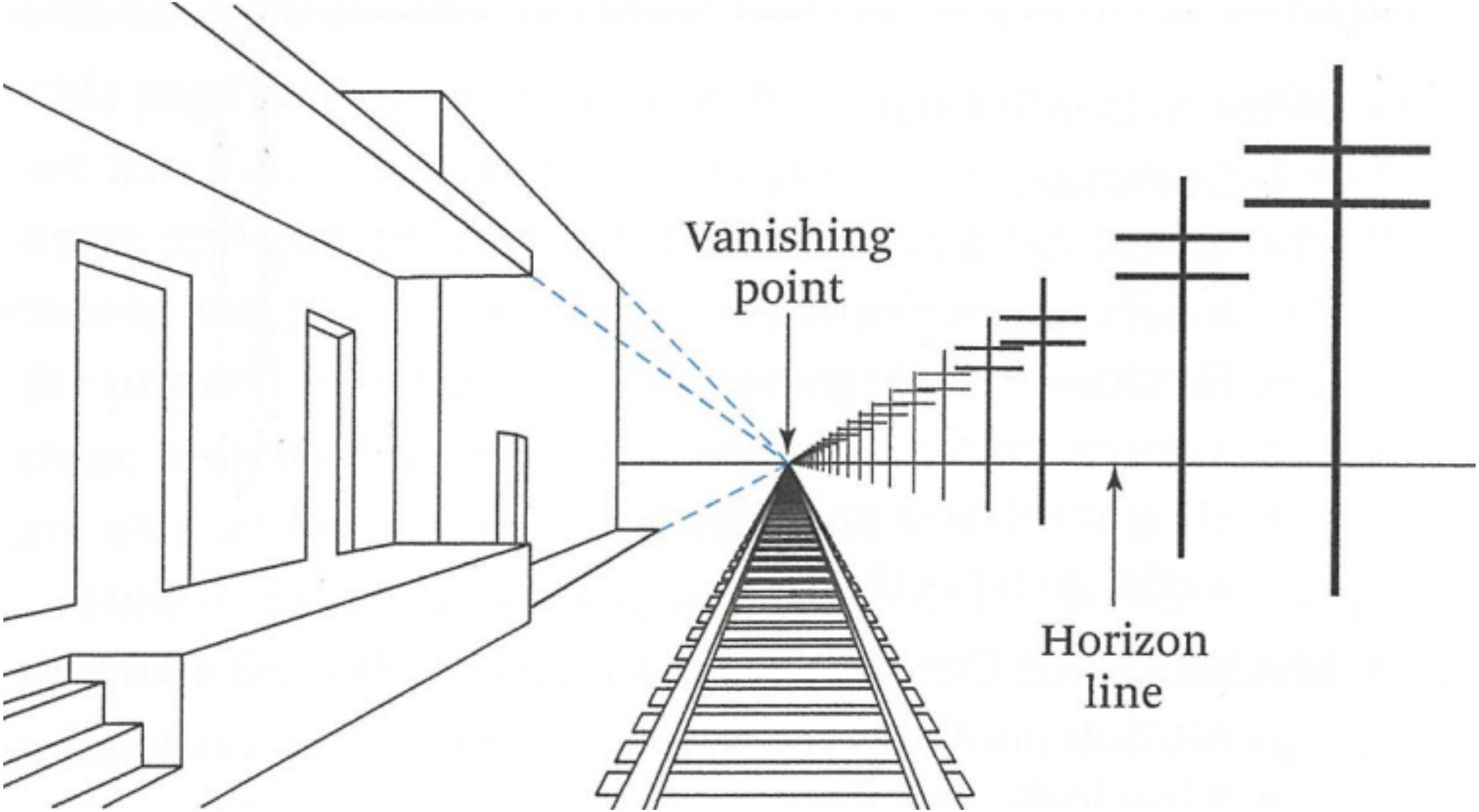
Parallax can be more important for depth perception!

Stereoscopy is important for size and distance evaluation

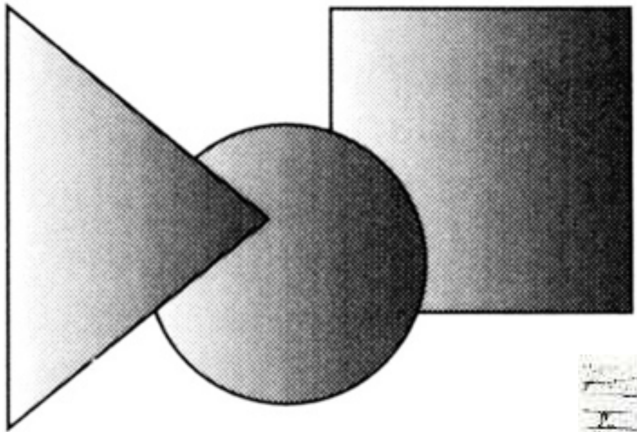
More Depth Cues



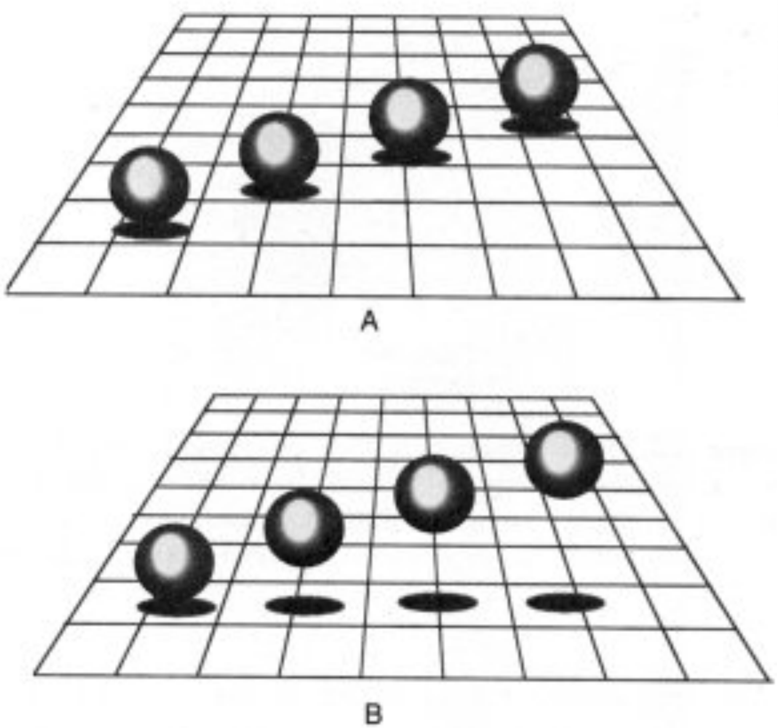
Example: Perspective Cues



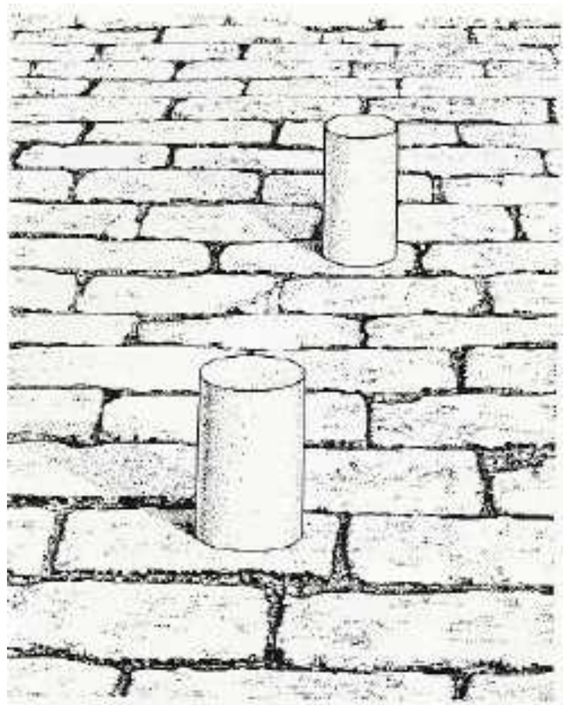
More Examples



Occlusion

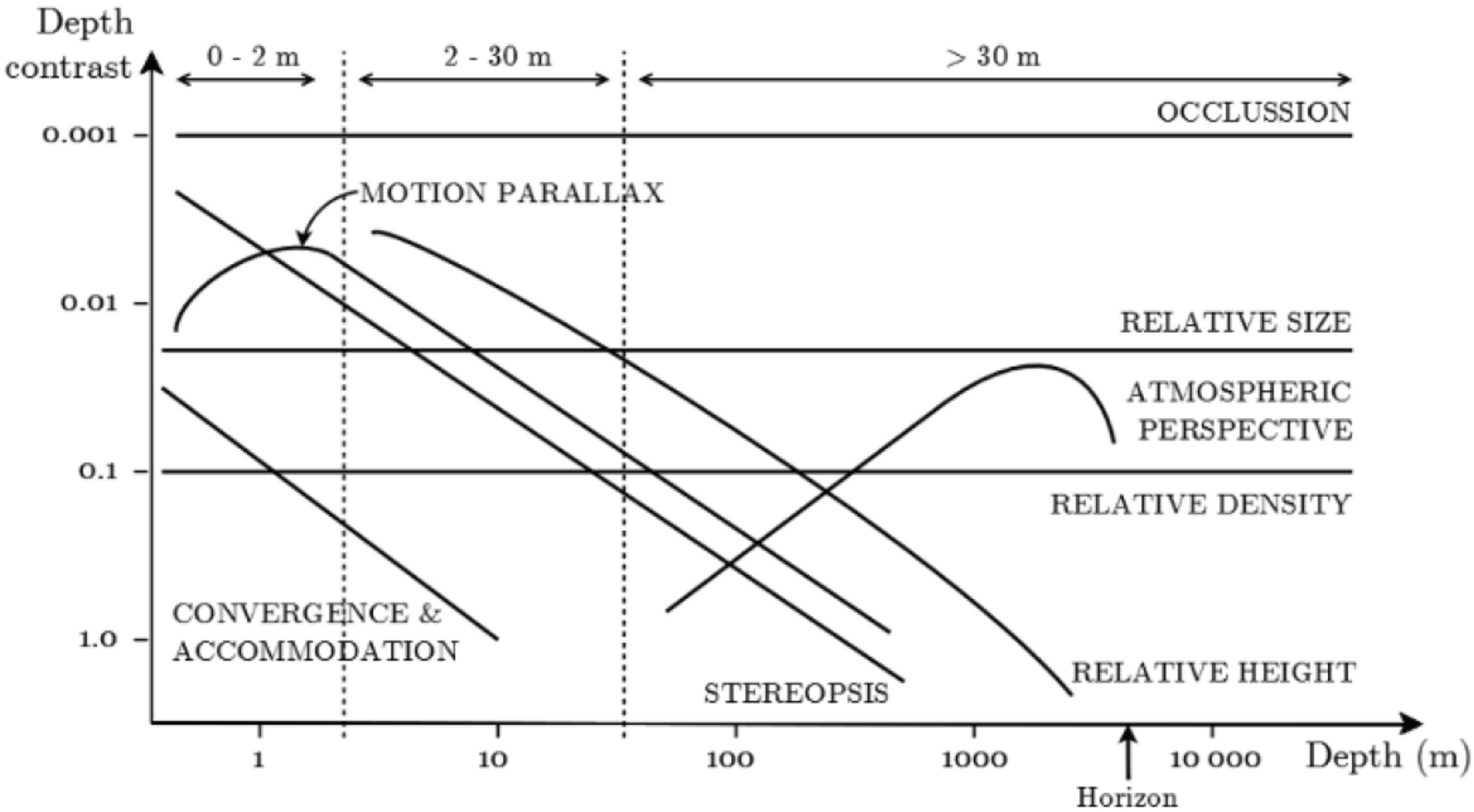


Shadows



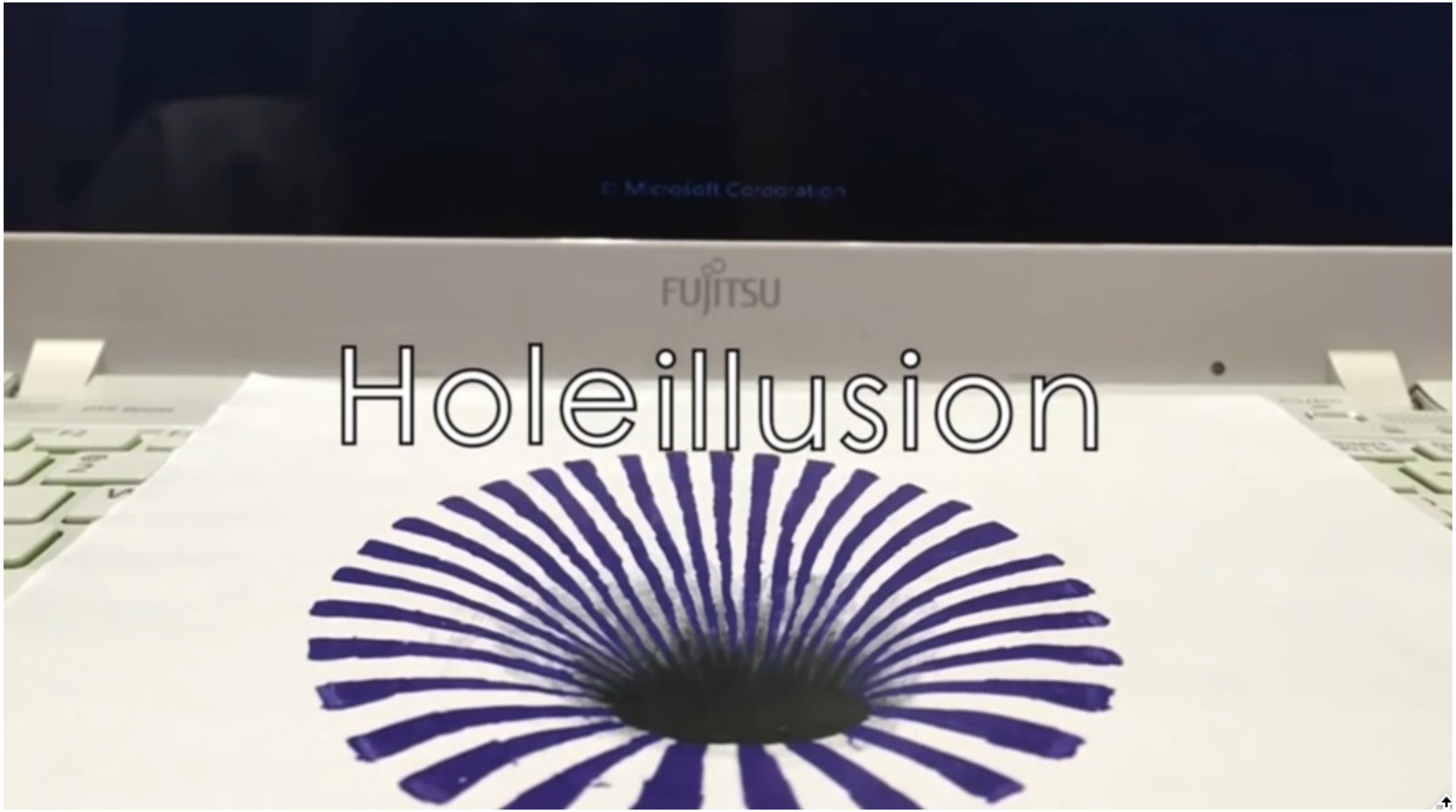
Texture Gradient

Depth Perception Distances



Cutting & Vishton, 1995

Fooling Depth Perception



- https://www.youtube.com/watch?v=p-eZcHPp7Go

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

The Perfect Retina Display

- A HMD capable of creating images indistinguishable from reality would need to match the properties of the eye:
  - FOV: 200-220° x 135° needed (both eyes)
    - 120° stereo overlap
  - Acuity: ~0.4 arc min (1 pixel/0.4 arc min)
  - Pixel Resolution: ~30,000 x 20,000 pixels
    - 200*60°/0.4 = 30,000, 135*60°/0.4 = 20,250
  - Pixels/inch: > 2190 PPI @ 100mm (depends on distance to screen)
  - Update rate: 60 Hz

- The biggest challenge: bandwidth
  - compress and transmit huge amount of data
  - drive and operate display pixels

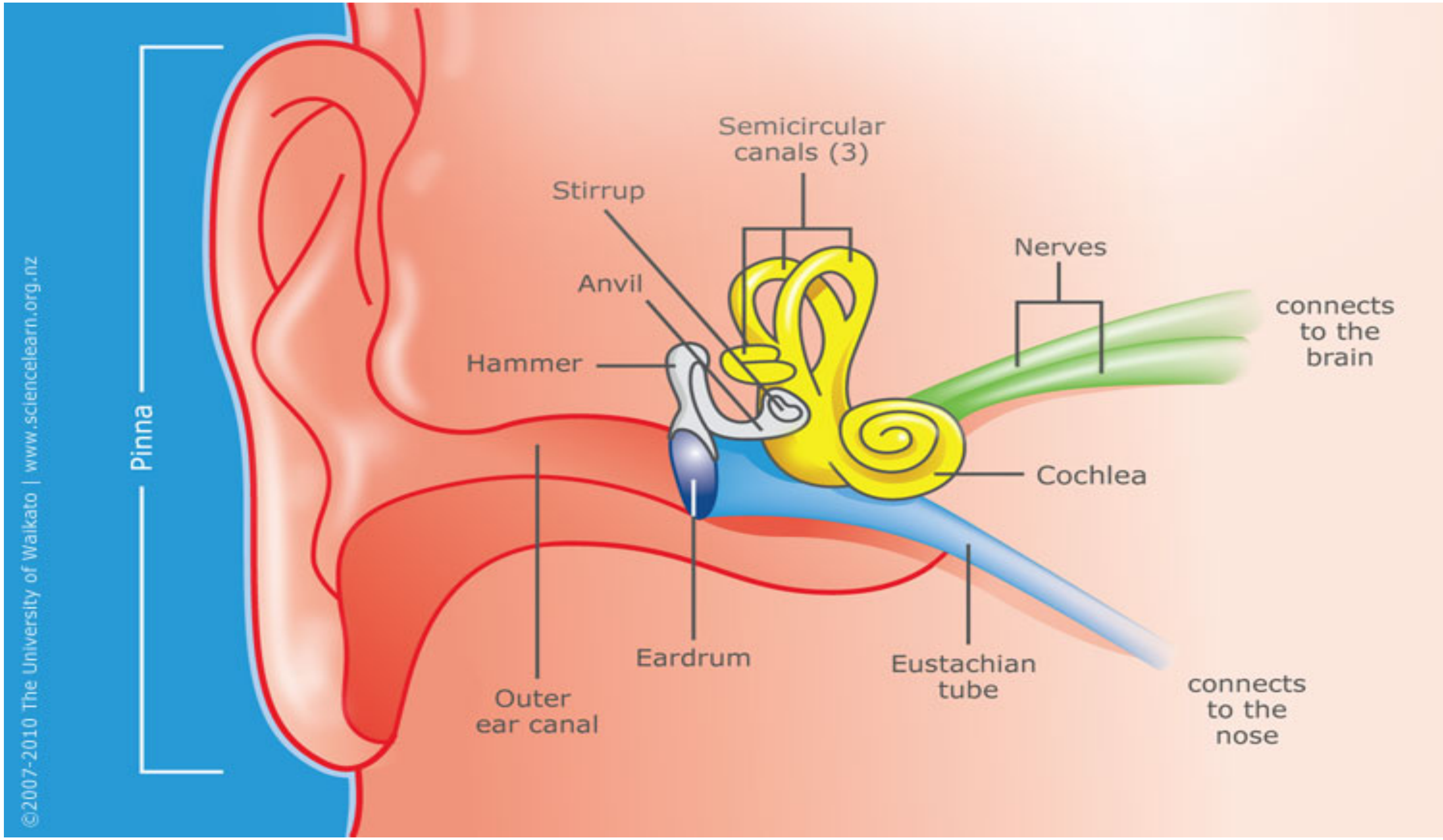
Comparison between Eyes and HMD

	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/


Hearing

Anatomy of the Ear



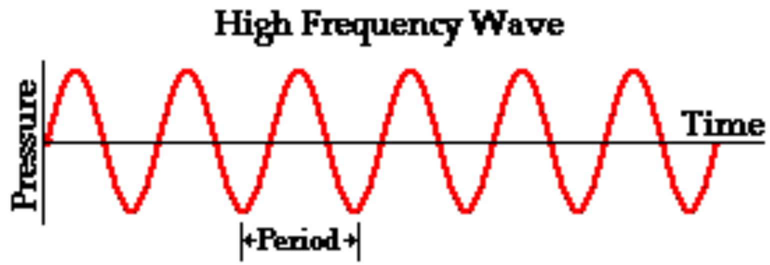
How the Ear Works

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

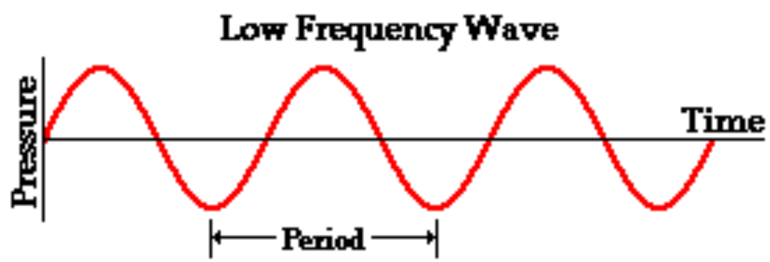
Sound Frequency and Amplitude

- Frequency determines the *pitch* of the sound
- Amplitude relates to intensity of the sound
  - Loudness is a subjective measure of intensity

High frequency = short period



Low frequency = long period

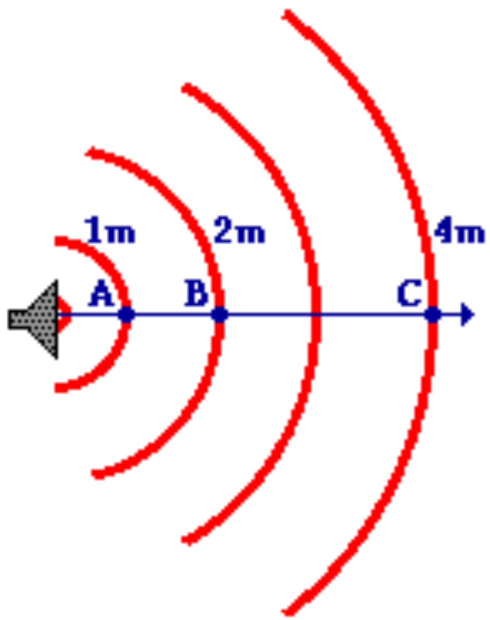


Distance to Listener

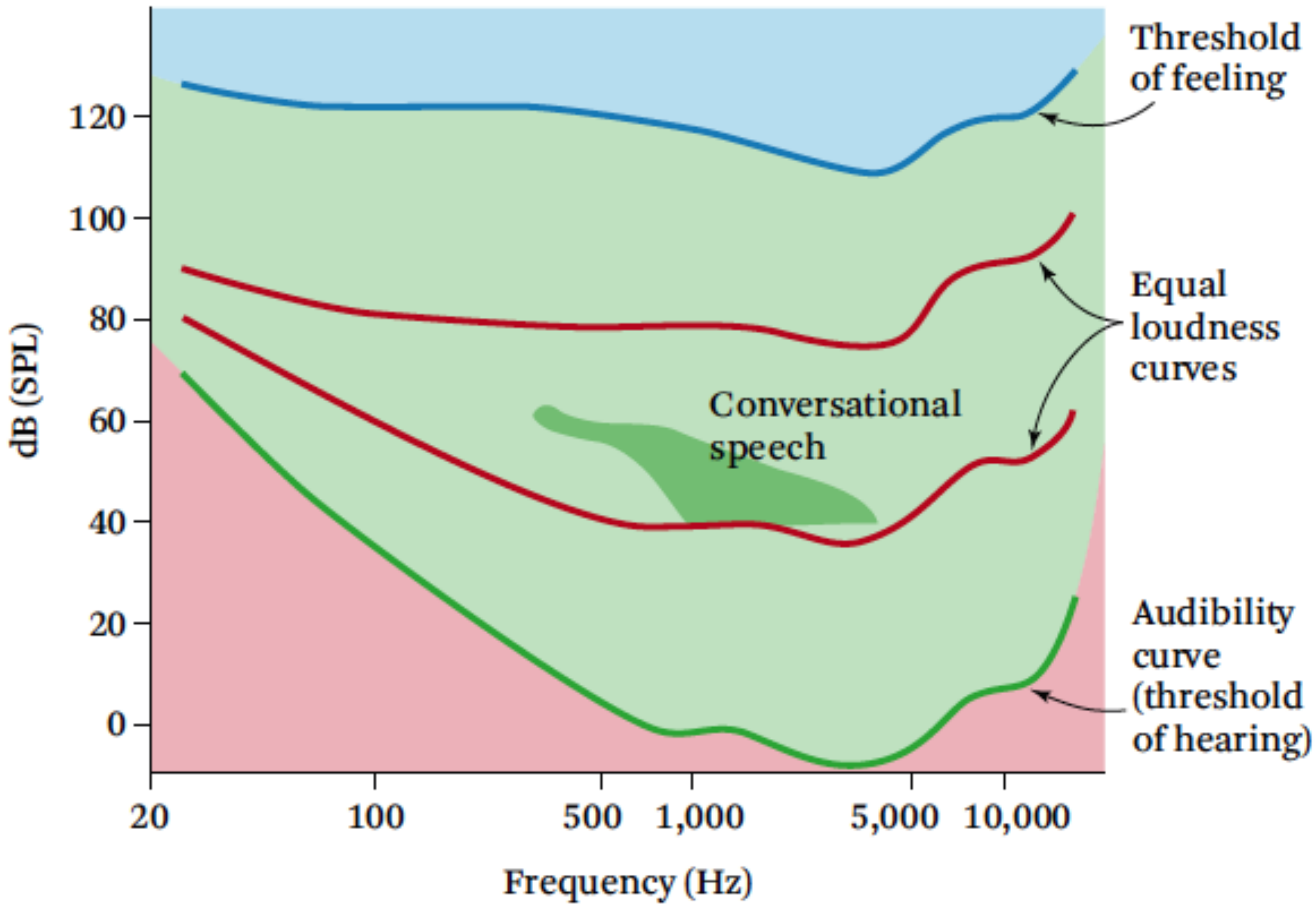
- Relationship between sound intensity and distance to the listener

  Inverse-square law

  - The intensity varies inversely with the square of the distance from the source. So if the distance from the source is doubled (increased by a factor of 2), then the intensity is quartered (decreased by a factor of 4).



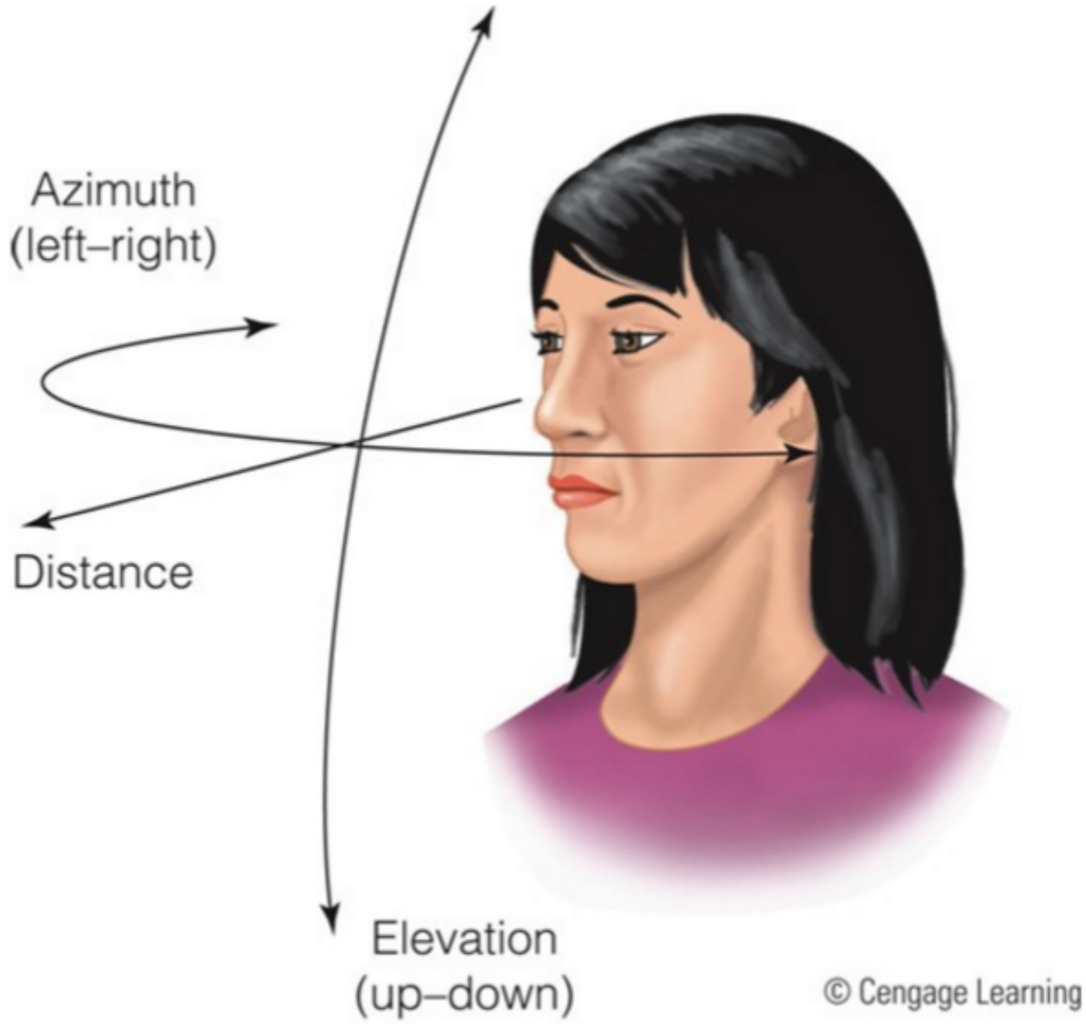
Auditory Thresholds



- Humans hear frequencies from 20 – 22,000 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



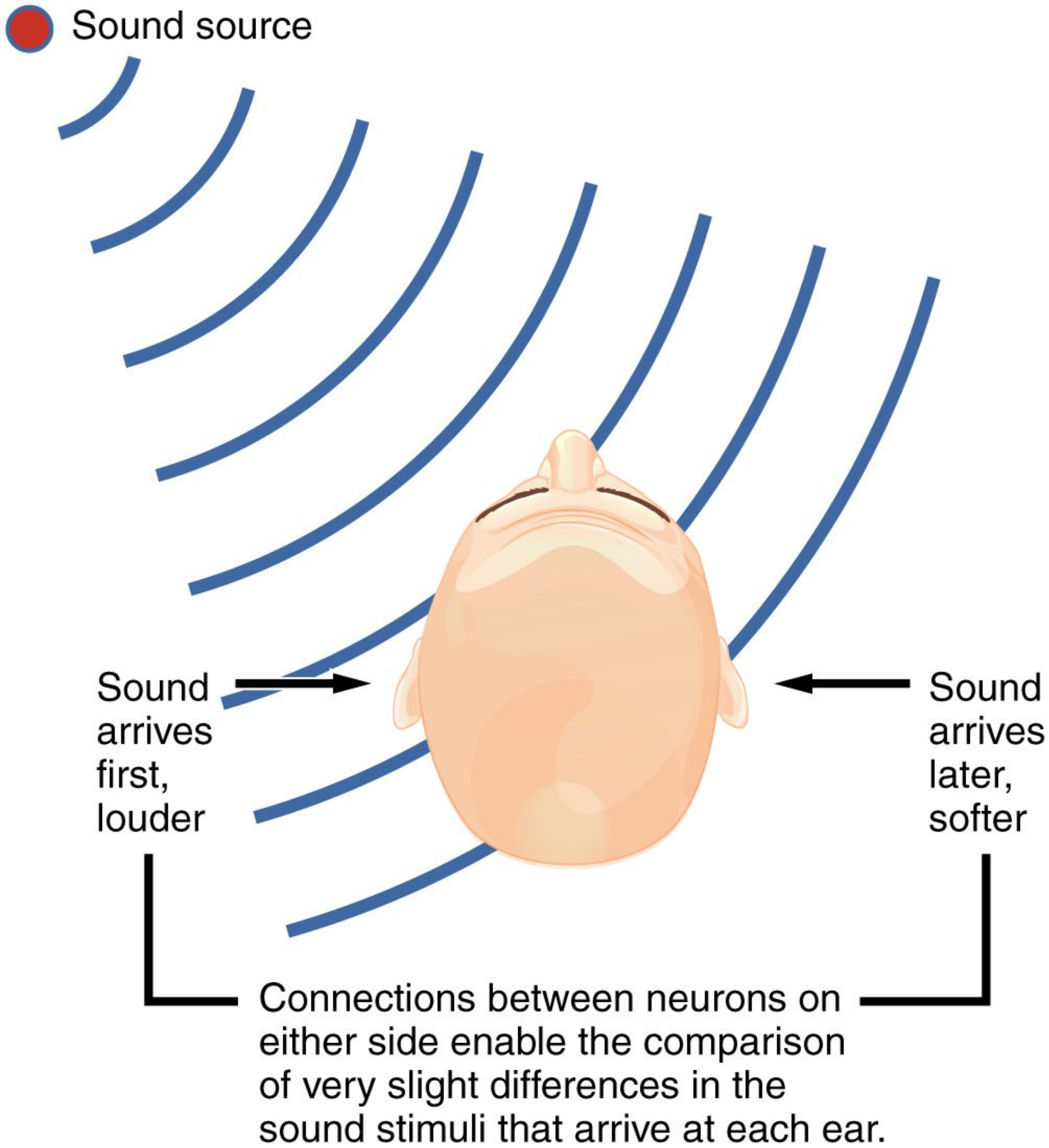
Sound Localization

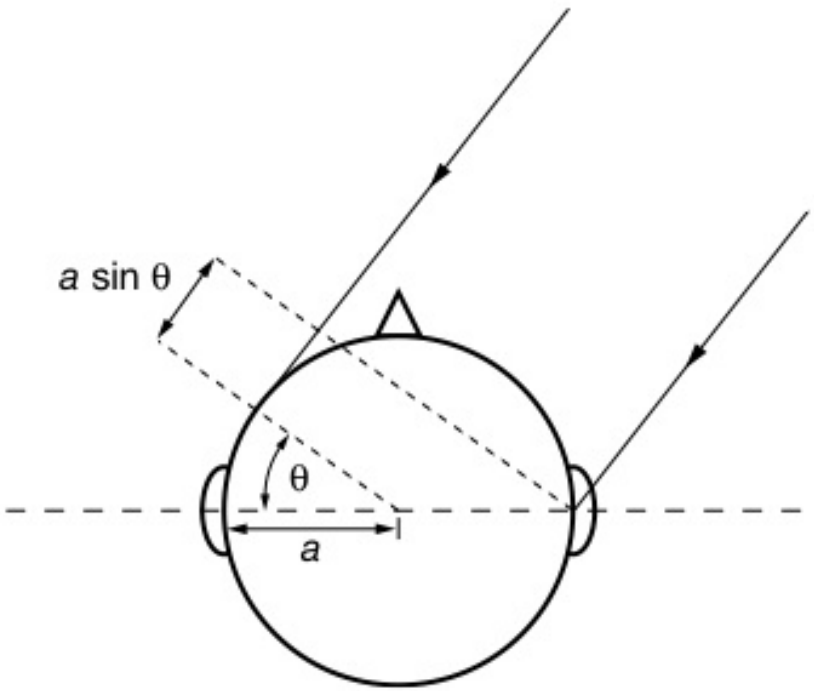
- Azimuth Cues
  - Difference in time of sound reaching two ears
    - Interaural time difference (ITD)
  - Difference in sound intensity reaching two ears
    - Interaural level difference (ILD)
- Elevation Cues
  - Monaural cues derived from the pinna (ear shape)
    - Head related transfer function (HRTF)
- Range Cues
  - Difference in sound relative to range from observer
  - Head movements (otherwise ITD and ILD are same)

Sound Localization

- https://www.youtube.com/watch?v=FIU1bNSIbxk

Sound Localization (Azimuth Cues)

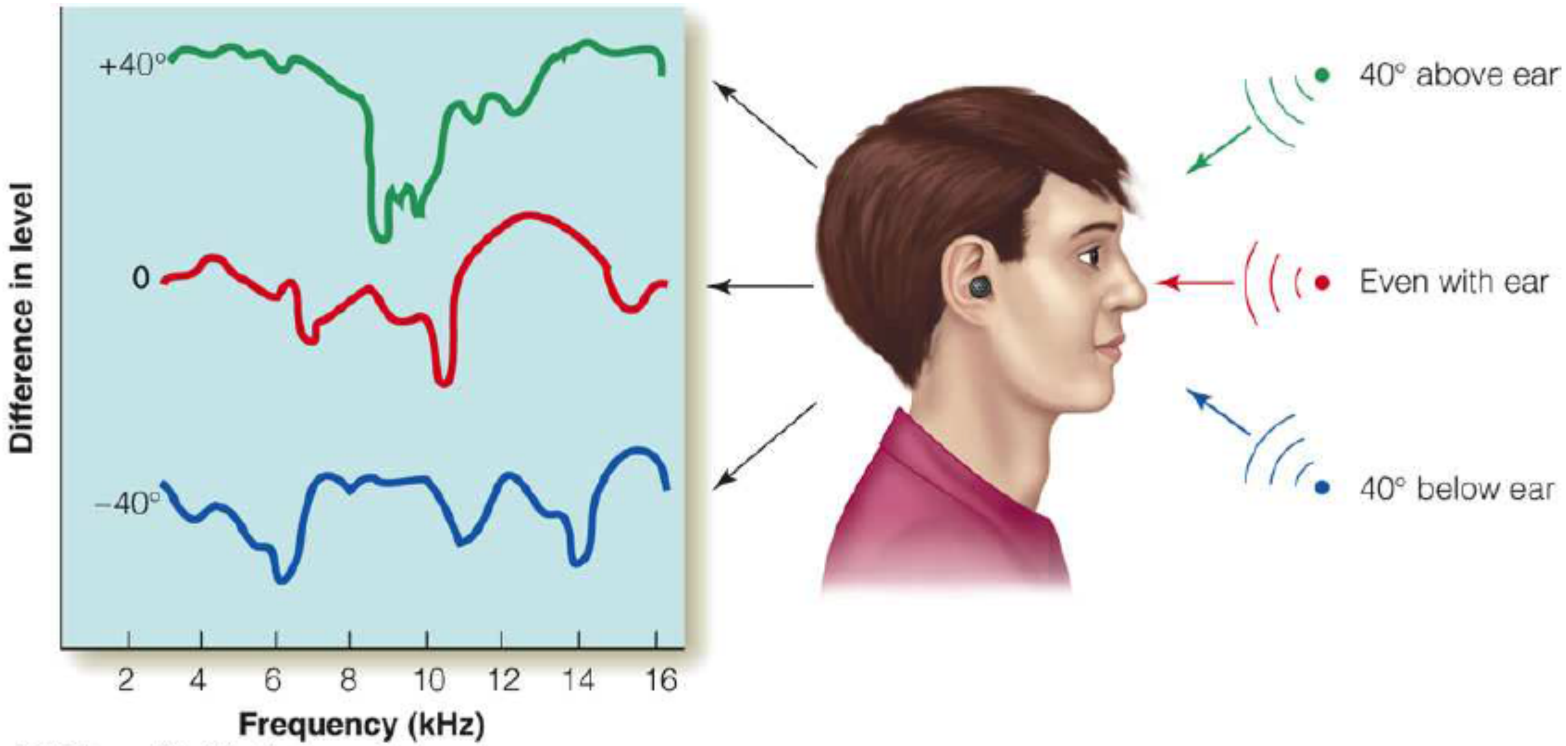




Interaural Time Difference

HRTF (Elevation Cue)

- Pinna and head shape affect frequency intensities
- Sound intensities measured with microphones in ear and compared to intensities at sound source
  - Difference is HRTF, gives clue as to sound source location



Accuracy of Sound Localization

- People can locate sound
  - Most accurately in front of them
    - 2-3° error in front of head
  - Least accurately to sides and behind head
    - Up to 20° error to side of head
    - Largest errors occur above/below elevations and behind head
- Front/back confusion is an issue
  - Up to 10% of sounds presented in the front are perceived coming from behind and vice versa (more in headphones)

BUTEAN, A., Bălan, O., NEGOI, I., Moldoveanu, F., & Moldoveanu, A. (2015). COMPARATIVE RESEARCH ON SOUND LOCALIZATION ACCURACY IN THE FREE-FIELD AND VIRTUAL AUDITORY DISPLAYS. In*Conference proceedings of» eLearning and Software for Education «(eLSE)*(No. 01, pp. 540-548). Universitatea Nationala de Aparare Carol I.

Touch

Touch

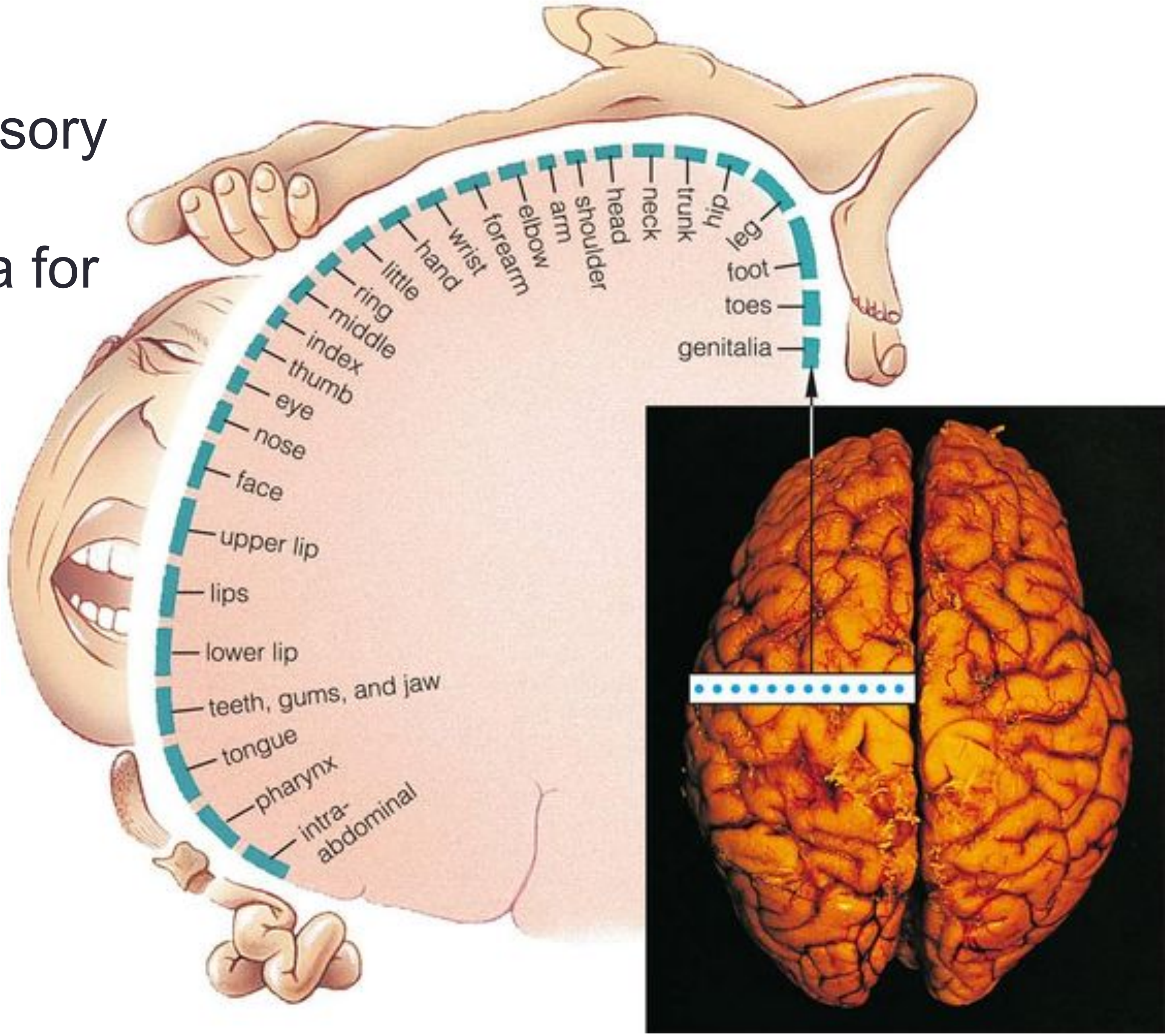
- Mechanical/Temp/Pain stimuli transduced into Action Potentials (AP)
- Transducing structures are specialized nerves:
  - Mechanoreceptors: Detect pressure, vibrations & texture
  - Thermoreceptors: Detect hot/cold
  - Nocireceptors: Detect pain
  - Proprioreceptors: Detect spatial awareness
- This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

Haptic Sensation

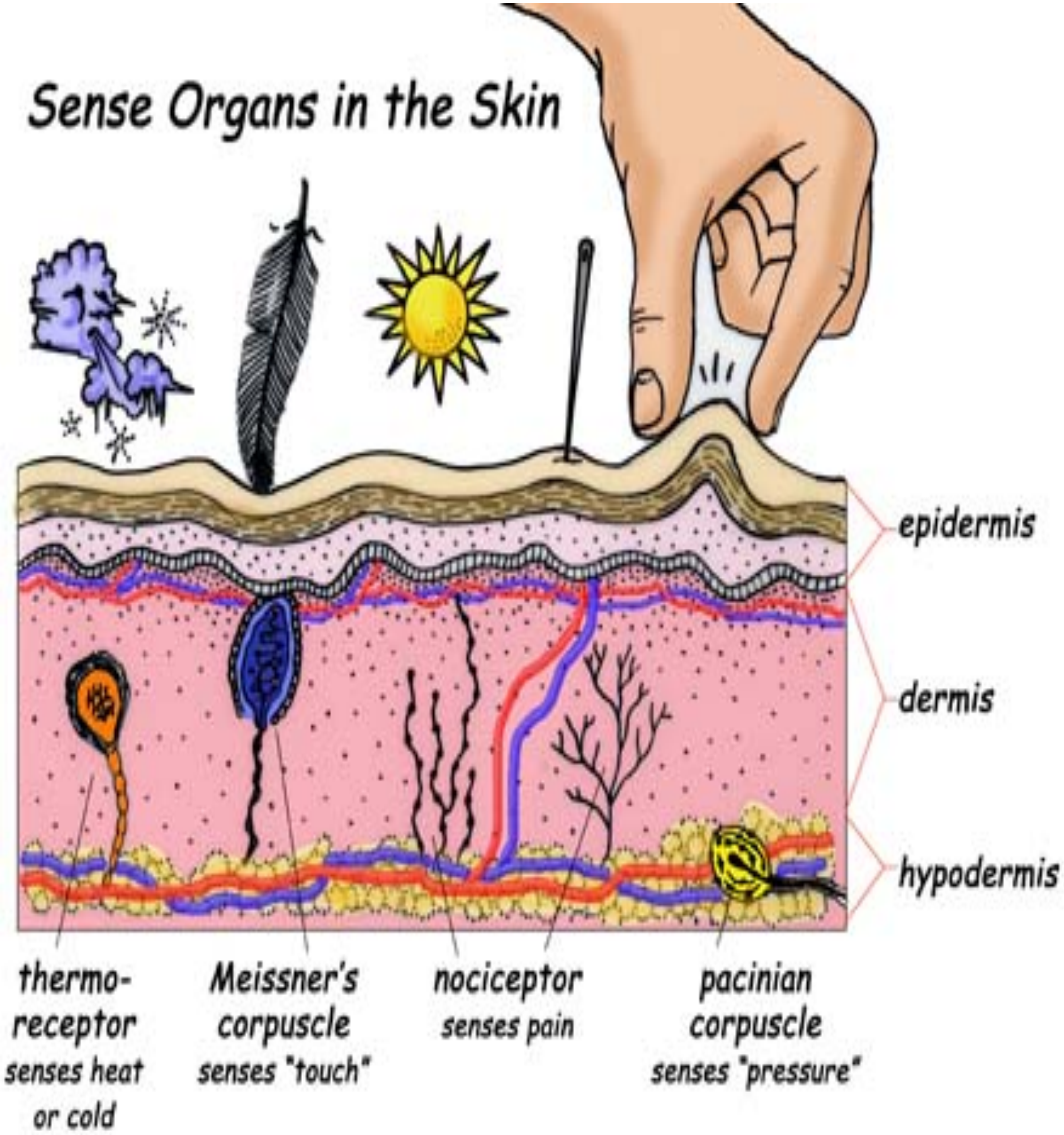
- Somatosensory System
  - complex system of nerve cells that responds to changes to the surface or internal state of the body
- Skin is the largest organ
  - 1.3-1.7 square m in adults
- Tactile: Surface properties
  - Receptors not evenly spread
  - Most densely populated area is the tongue
- Kinesthetic: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

Somatosensory System

- Map of somatosensory areas of the brain, showing more area for regions with more receptors

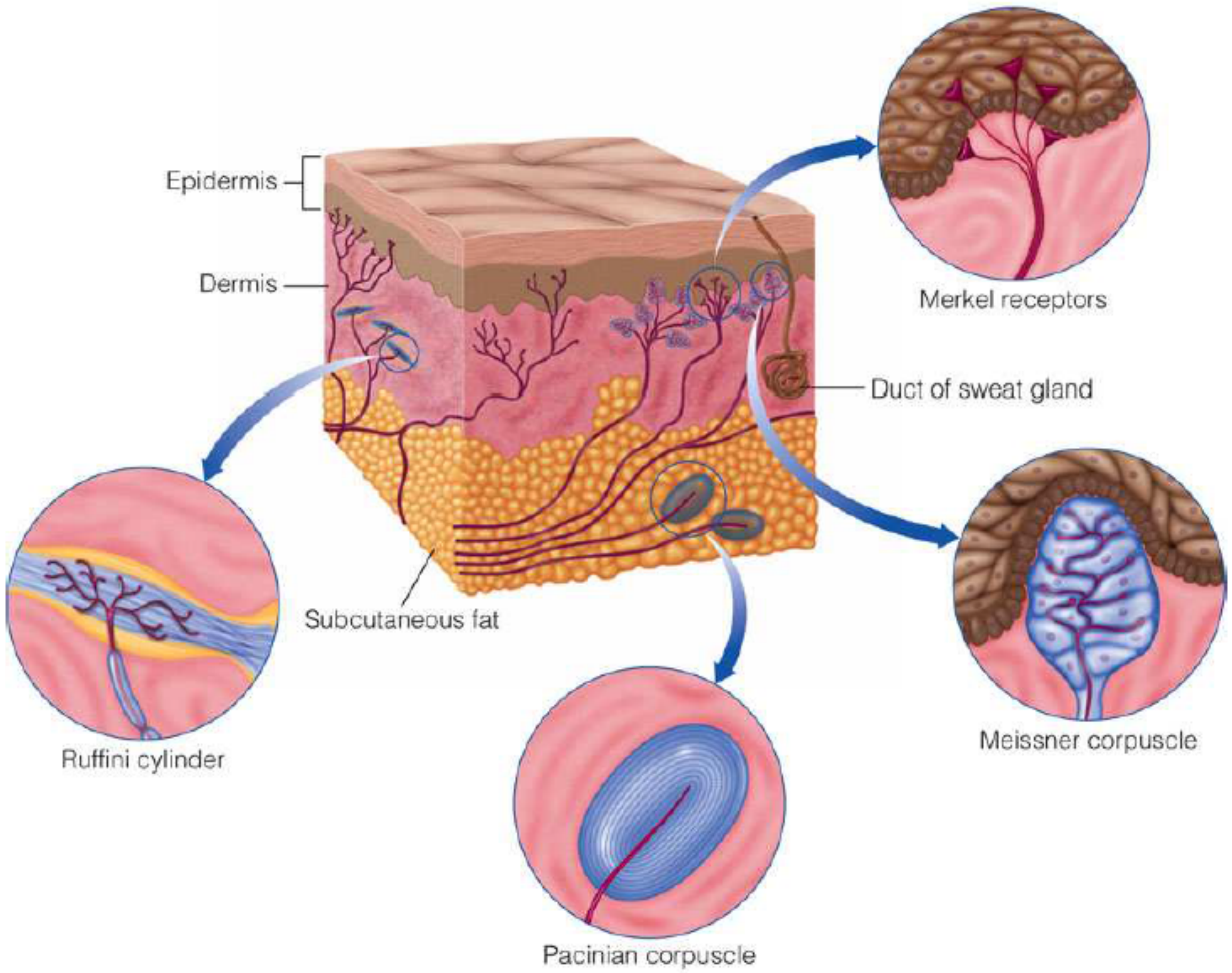


Anatomy of the Skin



Cutaneous System

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



Mechanoreceptors

- Cells that respond to pressure, stretching, and vibration
  - Slow Acting (SA), Rapidly Acting (RA)
  - Type I at surface – light discriminate touch
  - Type II deep in dermis – heavy and continuous touch

Receptor Type	Rate of Acting	Stimulus Frequency	Receptive Field	Detection Function
Merkel Discs	SA-I	0 – 10 Hz	Small, well defined	Edges, intensity
Ruffini corpuscles	SA-II	0 – 10 Hz	Large, indistinct	Static force, skin stretch
Meissner corpuscles	RA-I	20 – 50 Hz	Small, well defined	Velocity, edges
Pacinian corpuscles	RA-II	100 – 300 Hz	Large, indistinct	Acceleration, vibration

Spatial Resolution

- Sensitivity varies greatly
  - Two-point discrimination

Body Site	**Threshold Distance**
Finger	2-3mm
Cheek	6mm
Nose	7mm
Palm	10mm
Forehead	15mm
Foot	20mm
Belly	30mm
Forearm	35mm
Upper Arm	39mm
Back	39mm
Shoulder	41mm
Thigh	42mm
Calf	45mm

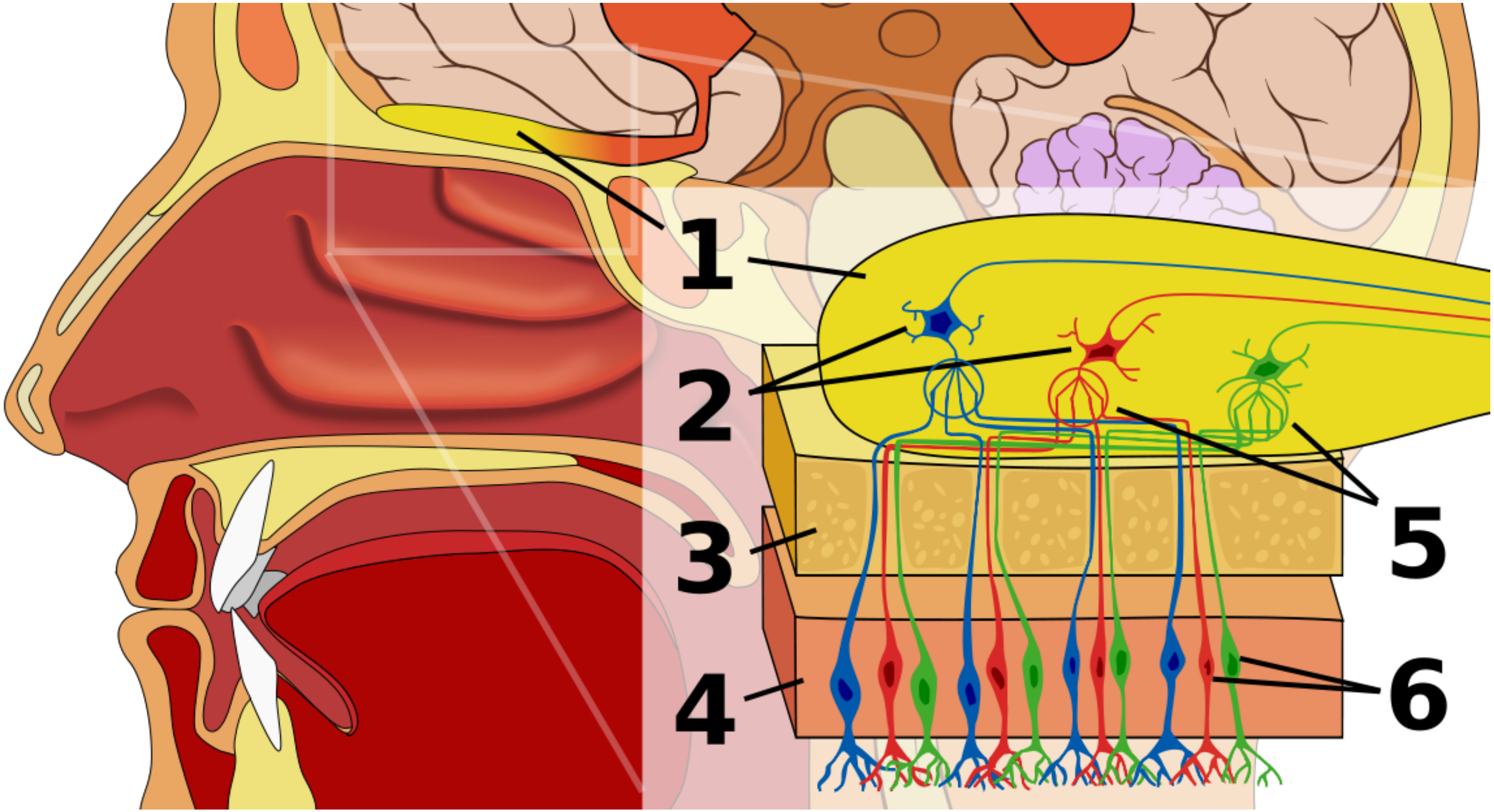
http://faculty.washington.edu/chudler/chsense.html

Proprioception/Kinaesthesia

- Proprioception (joint position sense)
  - Awareness of movement and positions of body parts
    - Due to nerve endings and Pacinian and Ruffini corpuscles at joints
  - Enables us to touch nose with eyes closed
  - Joints closer to body more accurately sensed
  - Users know hand position accurate to 8cm without looking at them
- Kinaesthesia (joint movement sense)
  - Sensing muscle contraction or stretching
    - Cutaneous mechanoreceptors measuring skin stretching
  - Helps with force sensation

Smell

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


Taste

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”

Taste Trivia

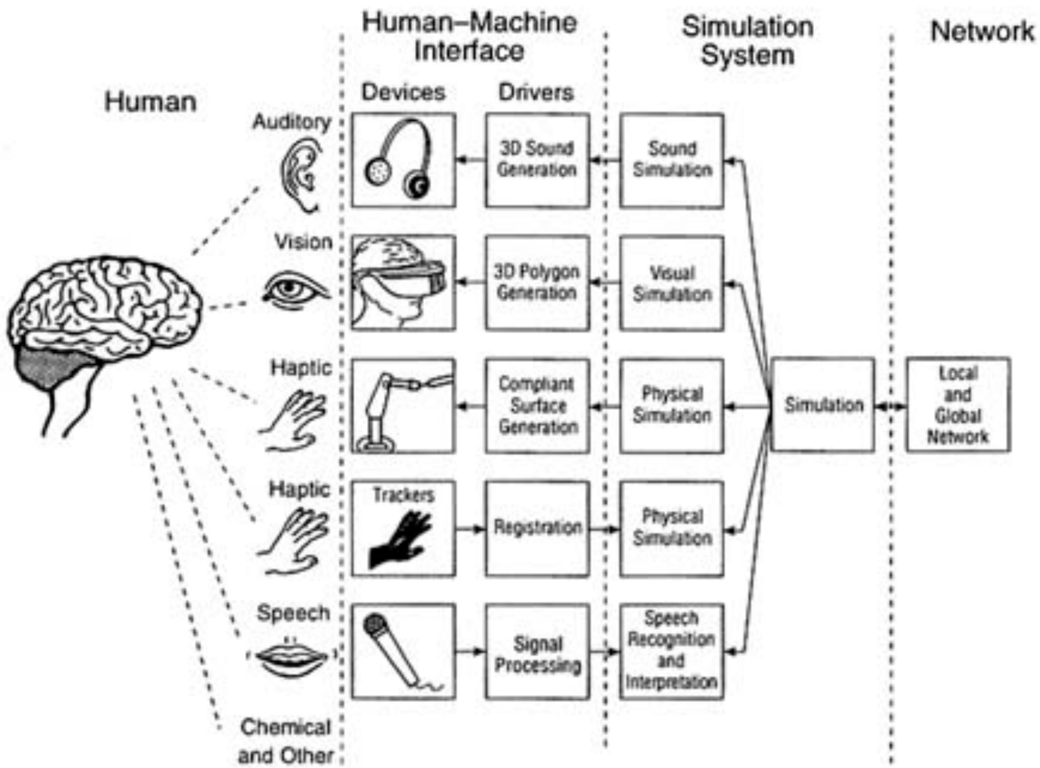
If you hold your nose, all jelly bean flavors taste virtually the same.

Without your sense of smell, you can only detect that a jelly bean is sweet, salty, or sour, not if it's apple or bubblegum flavored.

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**

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

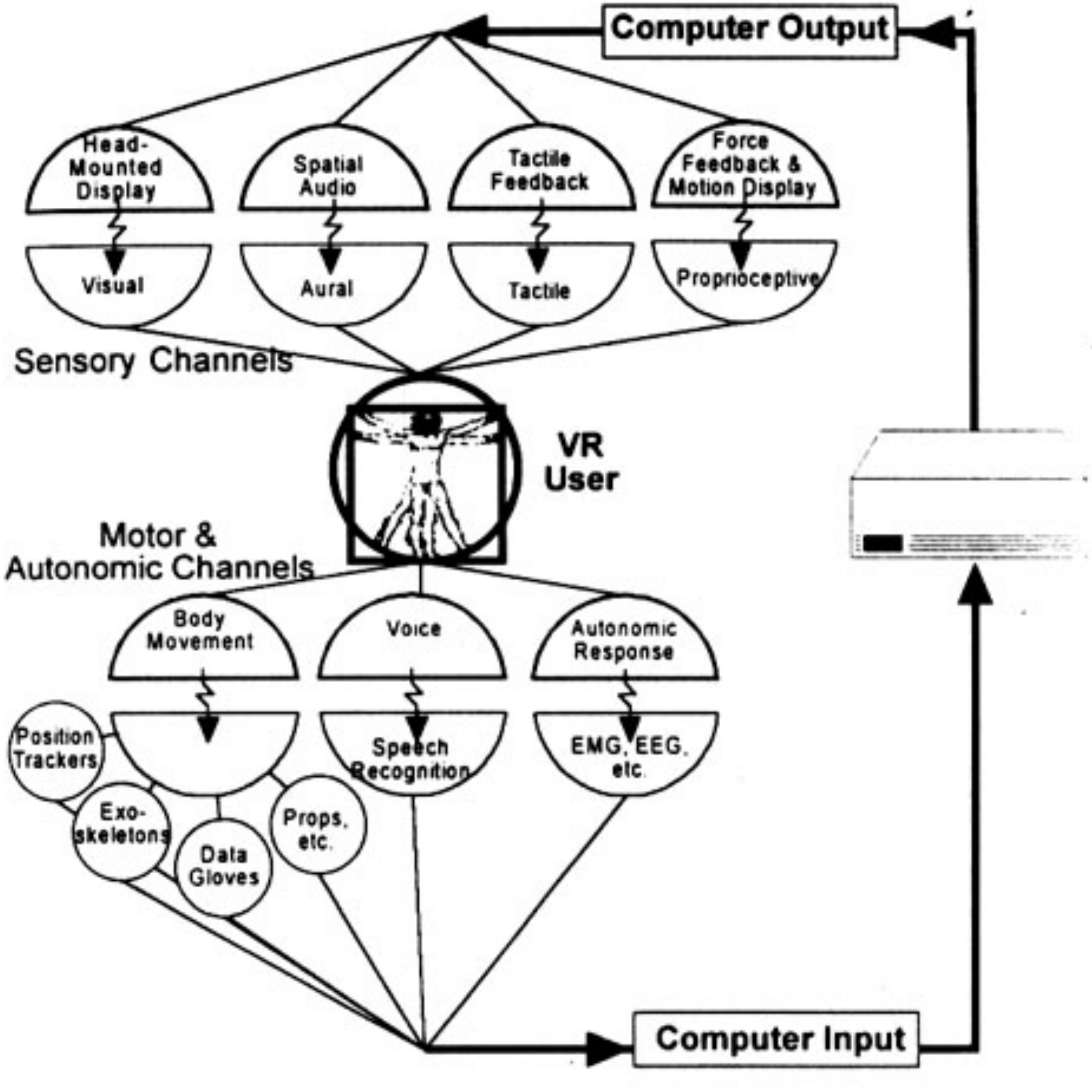
Key Technologies for VR System

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

Mapping Between Input and Output

Input

Output

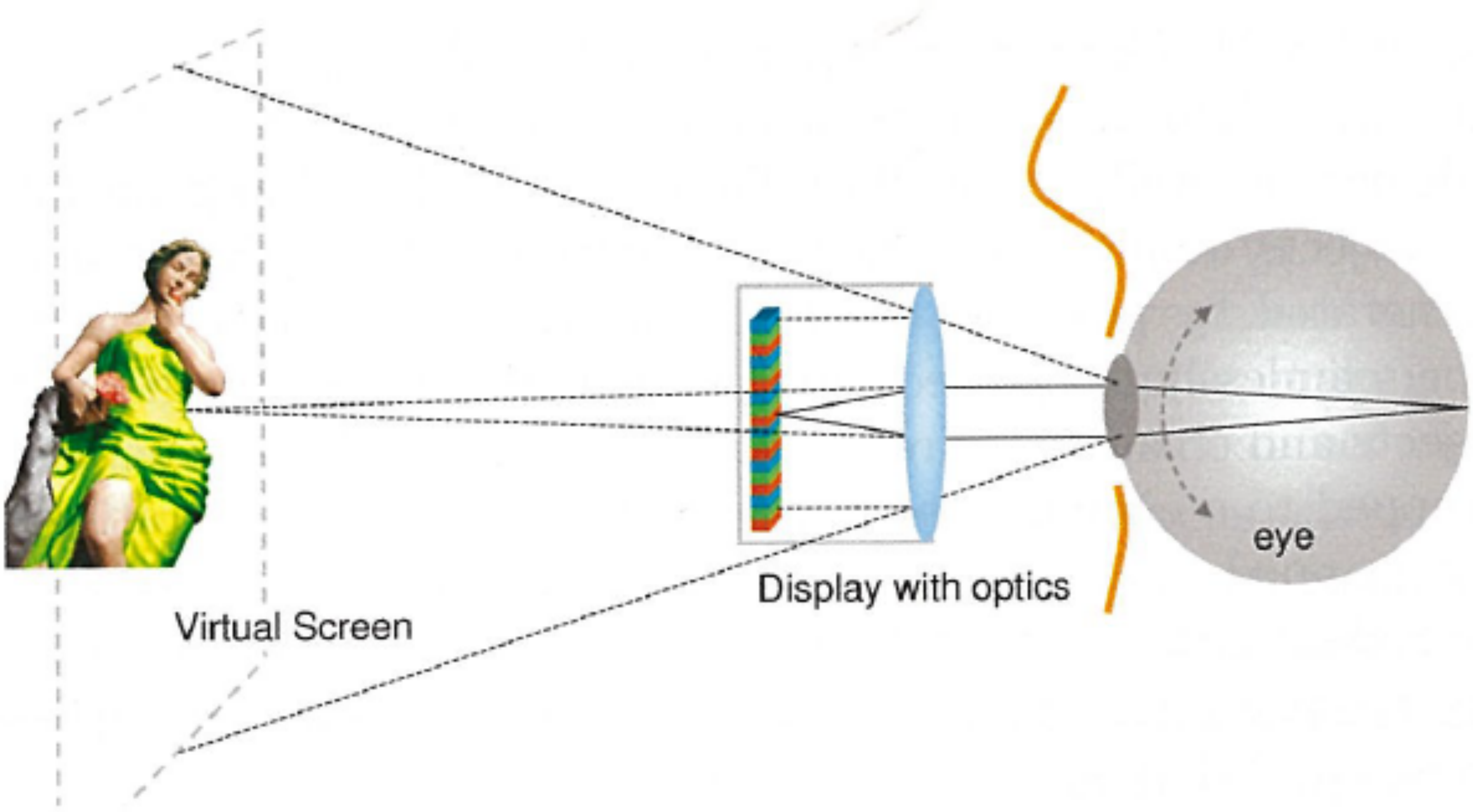


VISUAL DISPLAY

Creating an Immersive Experience

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

HMD Basic Principles

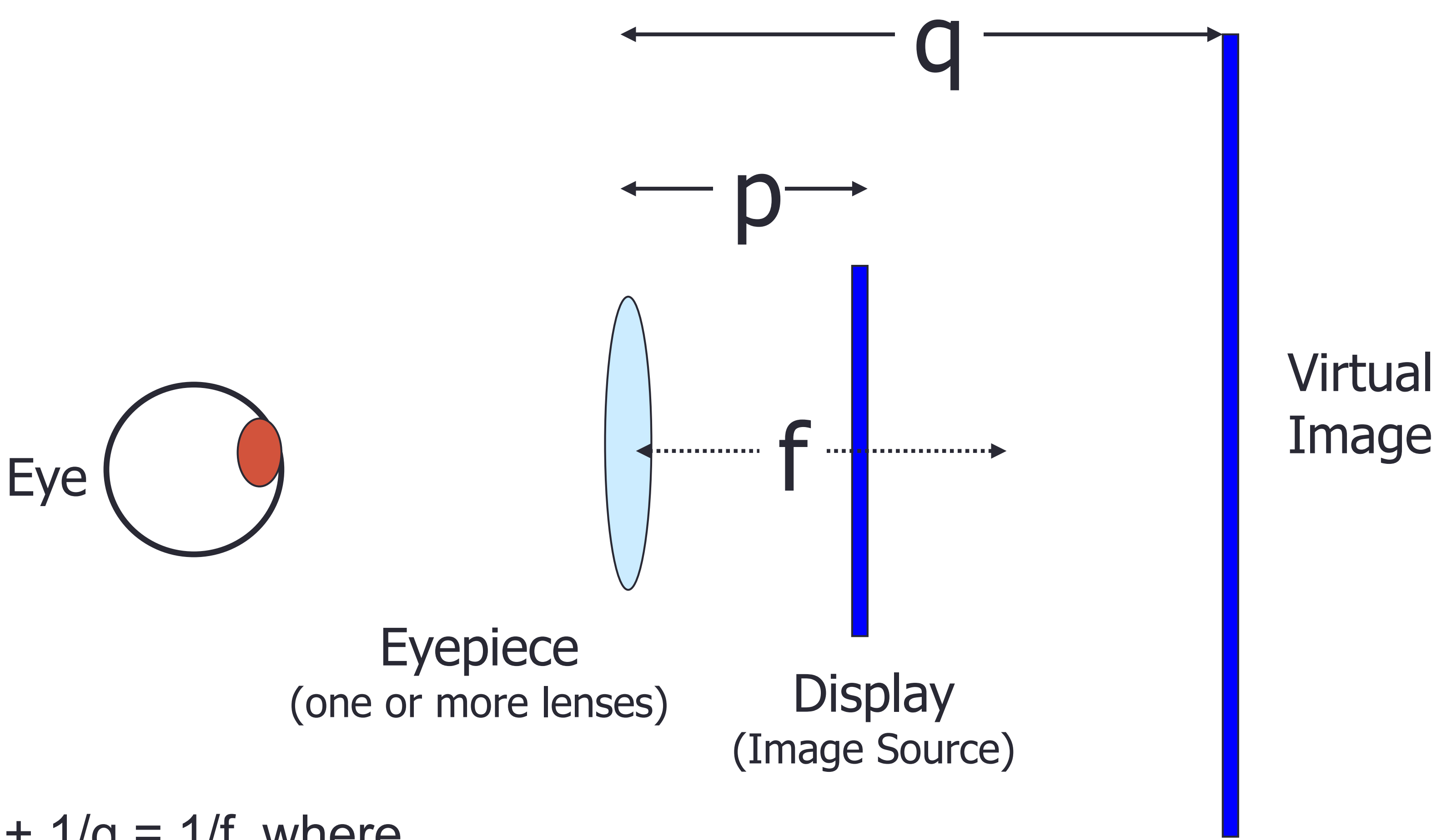


- Use display with optics to create illusion of virtual screen

Key Properties of HMDs

- Lens
  - Focal length, Field of View
  - Occularity, Interpupillary distance
  - Eye relief, Eye box
- Display
  - Resolution, contrast
  - Power, brightness
  - Refresh rate
- Ergonomics
  - Size, weight
  - Wearability

Simple Magnifier HMD Design



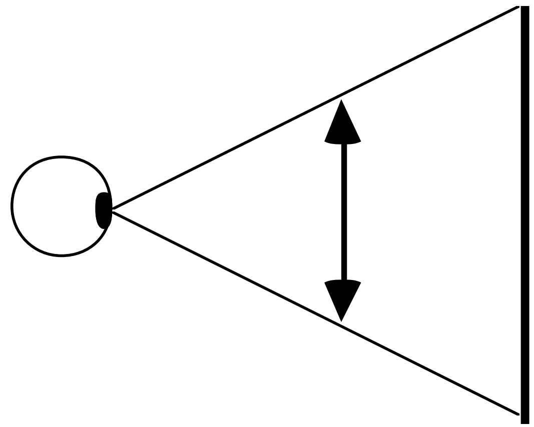
$1/p + 1/q = 1/f$ where

p = object distance (distance from image source to eyepiece)

q = image distance (distance of image from the lens)

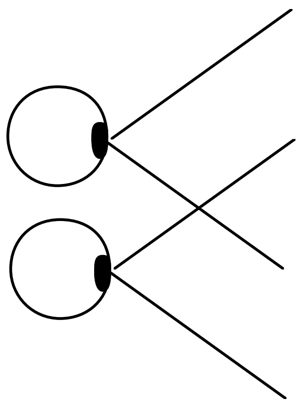
f = focal length of the lens

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.



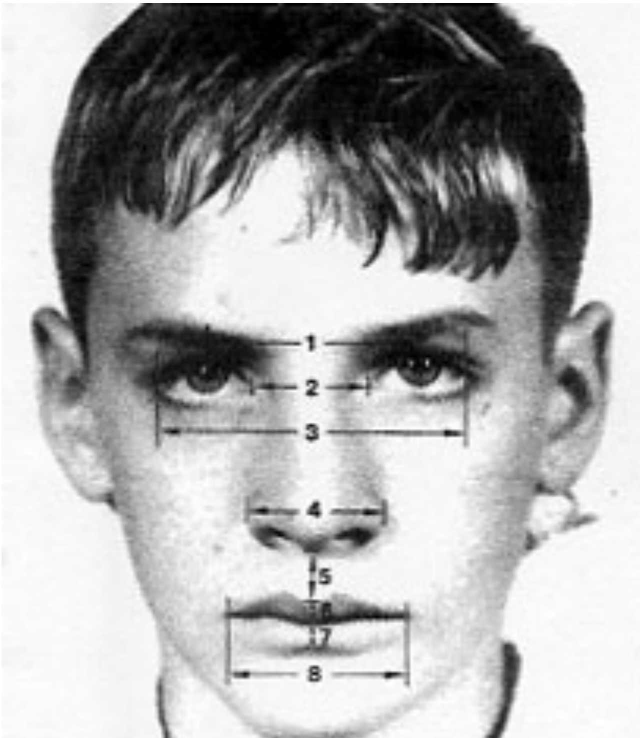
Binocular(or stereoscopic) FOV refers to the part of the displayed image visible to both eyes.

FOV may be measured horizontally, vertically or diagonally.

Ocularity

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

Interpupillary Distance (IPD)

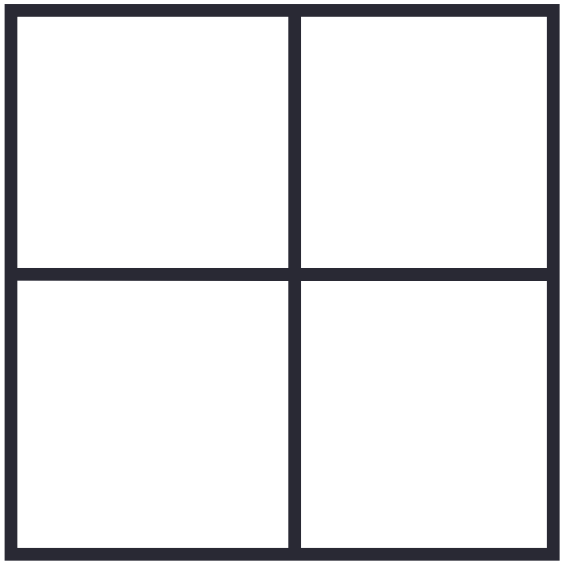


Interpupillary Distance Setting

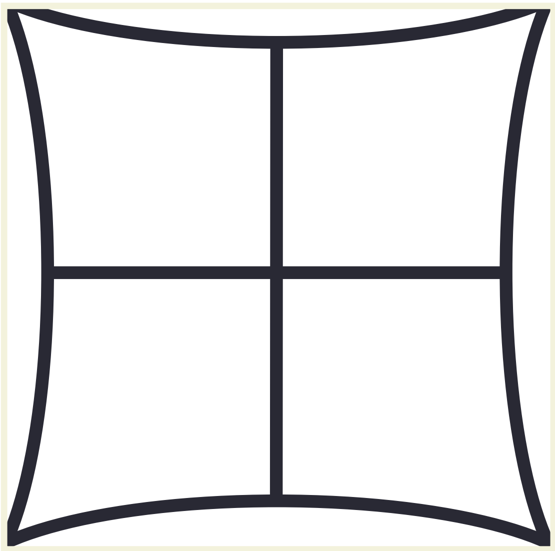
Figure 5

- IPD is the horizontal distance between a user's eyes.
- IPD is the distance between the two optical axes in a binocular view system.

Distortion in Lens Optics

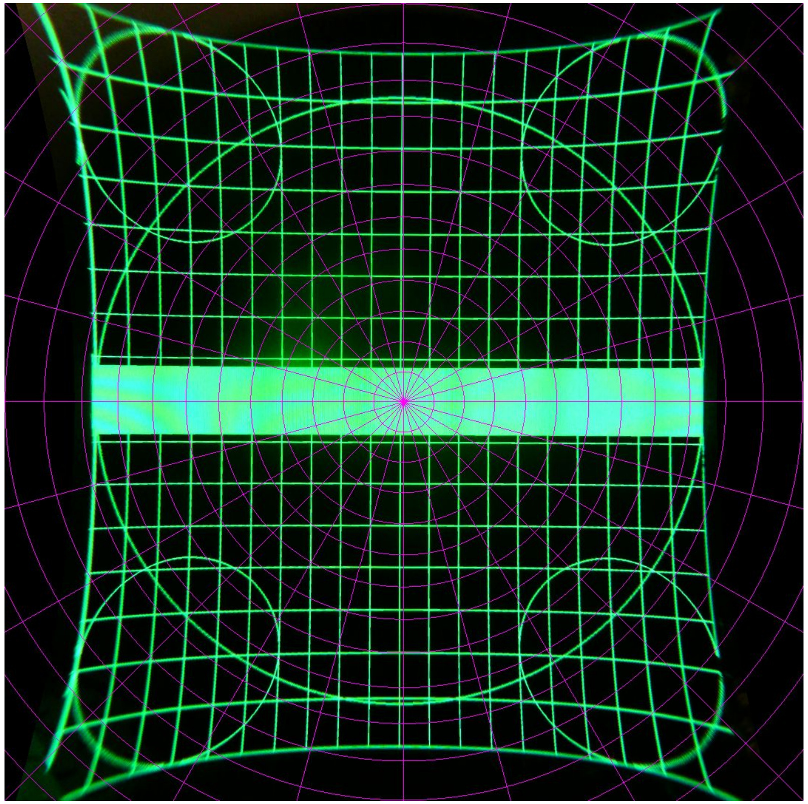


A rectangle

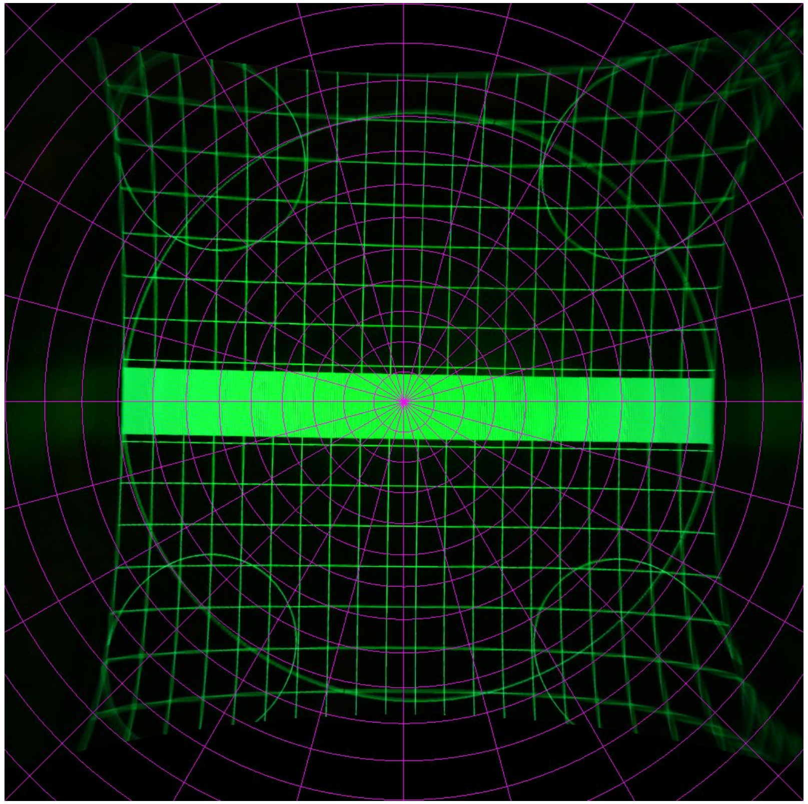


Maps to this

Example Distortion

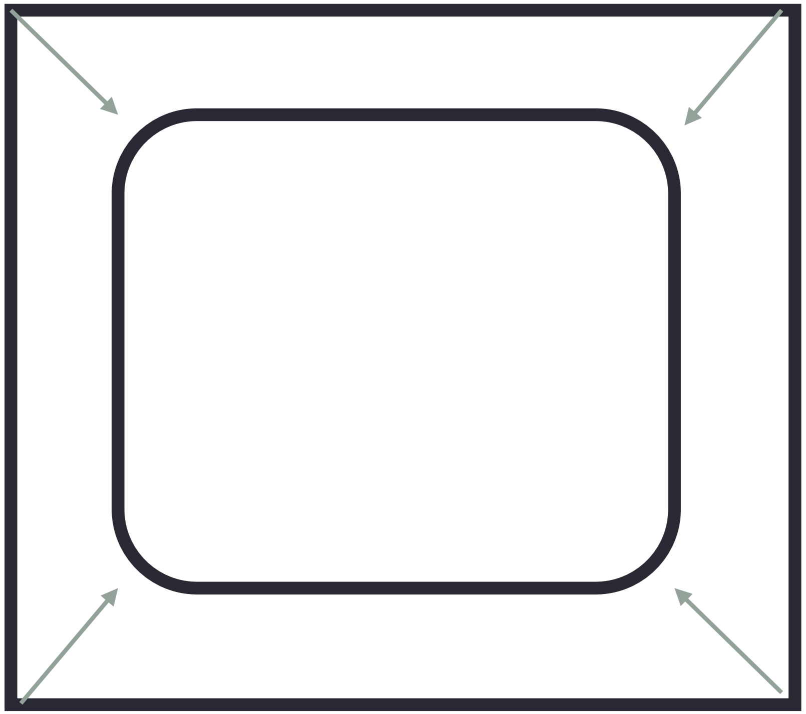


Oculus Rift DK2



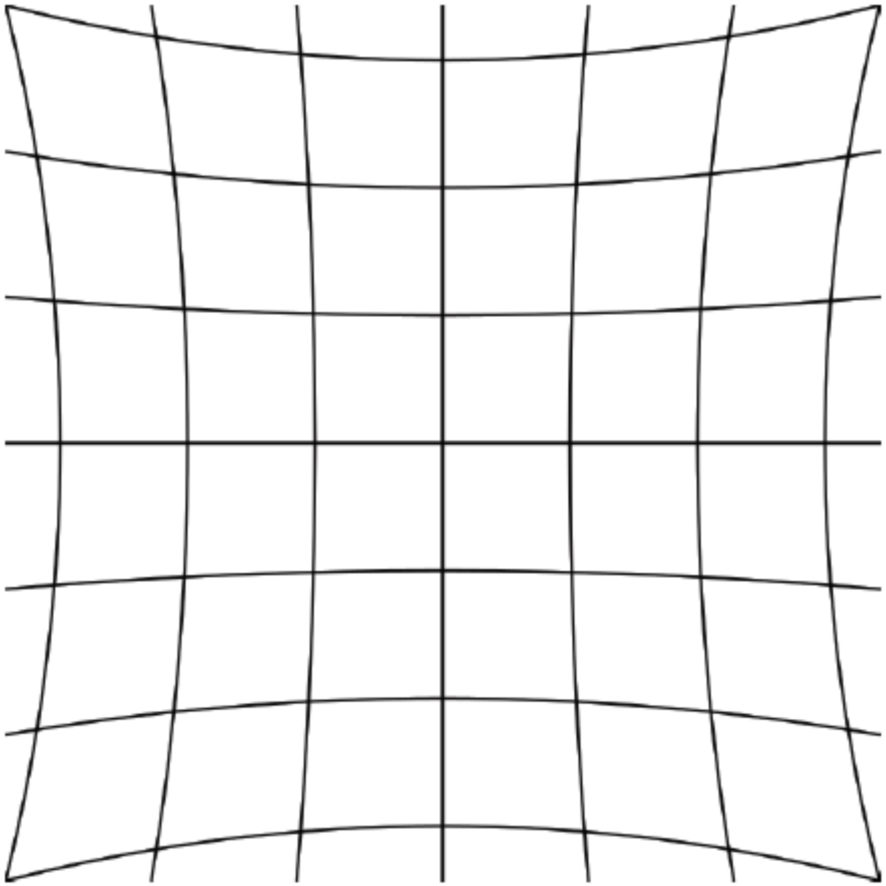
HTC Vive

To Correct for Distortion



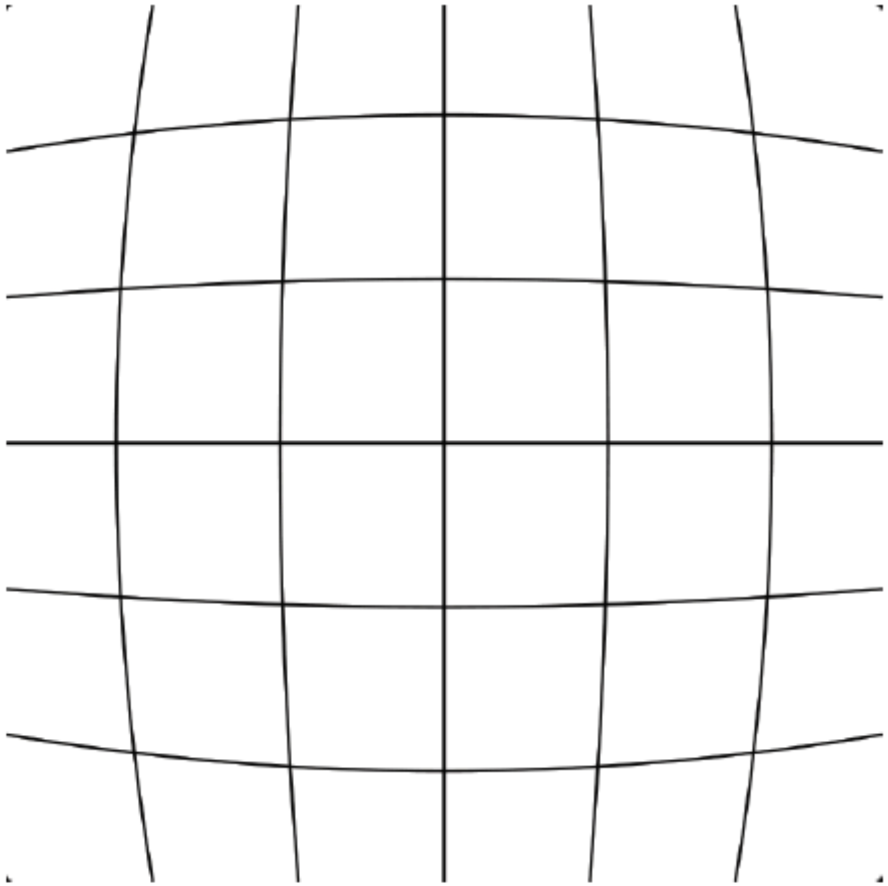
- Must pre-distort image
- This is a pixel-based distortion
- Graphics rendering uses linear interpolation!
- Too slow on most systems
- Use shader programming

Lens Distortion



Pincussion Distortion

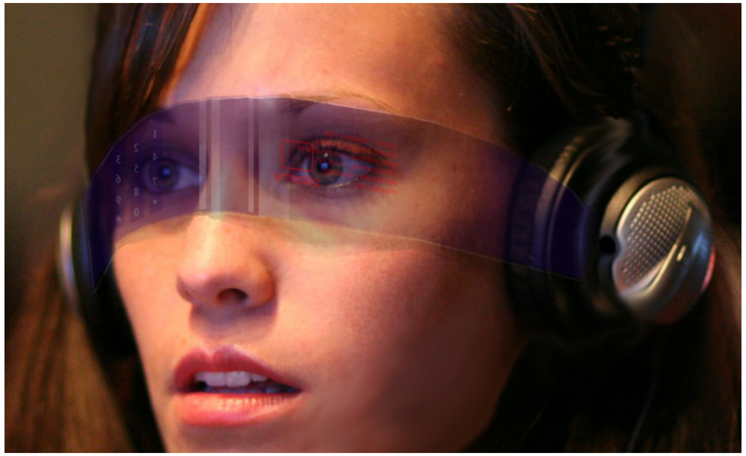
<u>optical</u>



Barrel Distortion

<u>digital correction</u>

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

- Cost: $599 USD
- FOV: 110^{o} Horizontal
- Refresh rate: 90 Hz
- Resolution 1080x1200/eye
- 3 DOF orientation tracking
- 3 axis positional tracking

Inside an Oculus Rift

Oculus DK2 Teardown

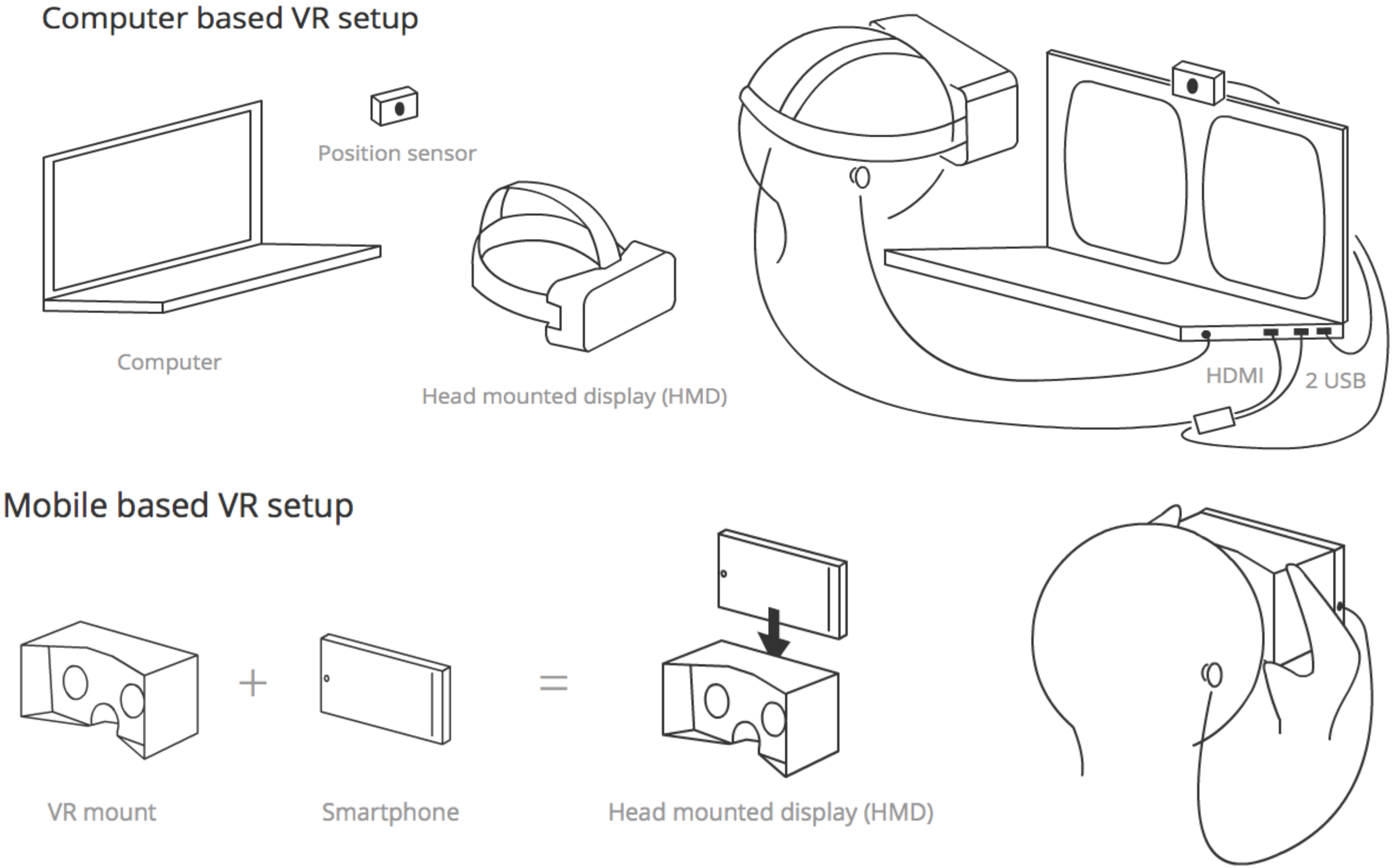
- Samsung 5.7" AMOLED: 1920x1080px, 75Hz
- 2 sets of lenses (for different prescriptions)
- InvenSense 6-axis IMU
- ARM Cortex-M3 MCU
- …

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

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	-	-

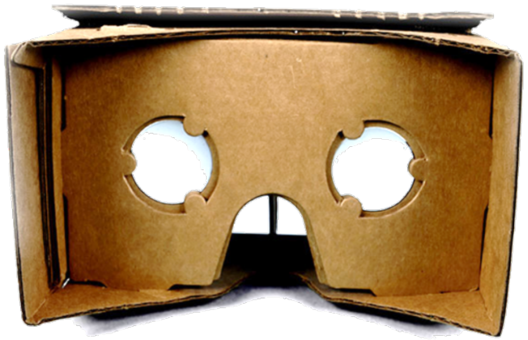
Computer Based vs. Mobile VR Displays




Google Cardboard

Google Cardboard

+



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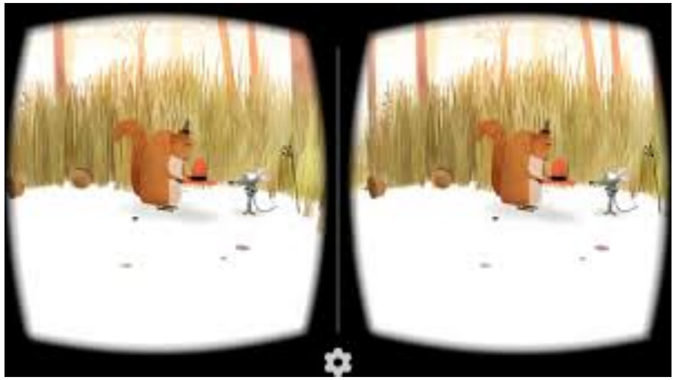


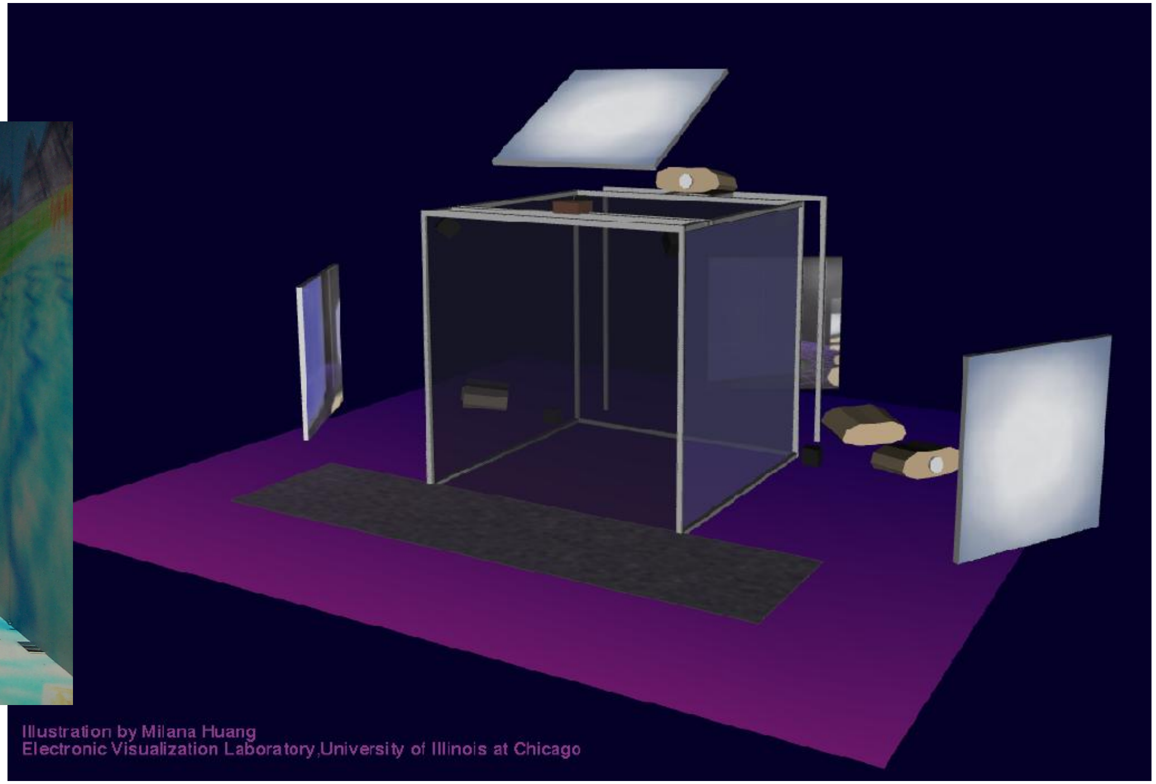
- Released 2014 (Google 20% project)
- >5 million shipped/given away
- Easy to use developer tools

Multiple Mobile VR Viewers Available

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

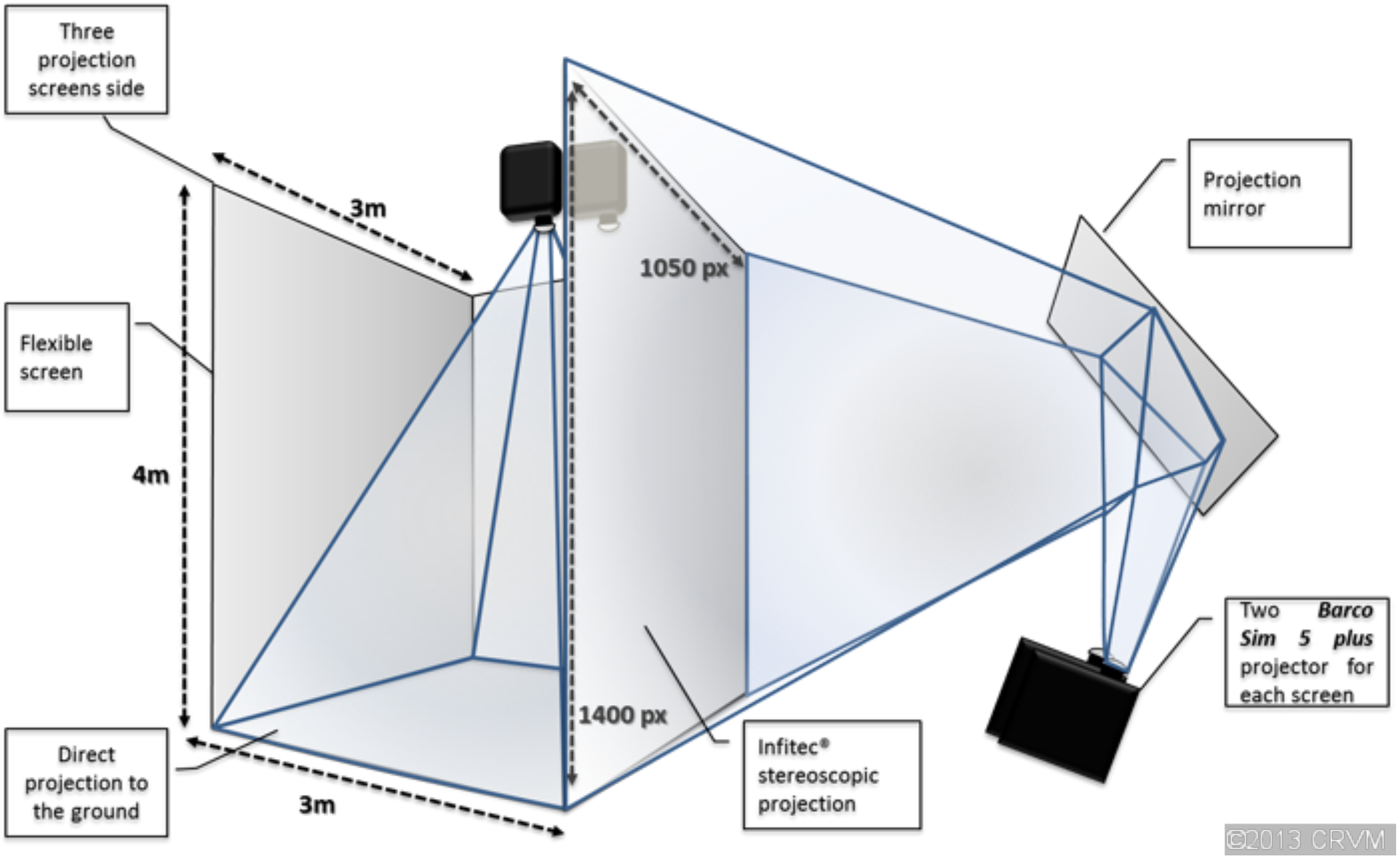
CAVE



- 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

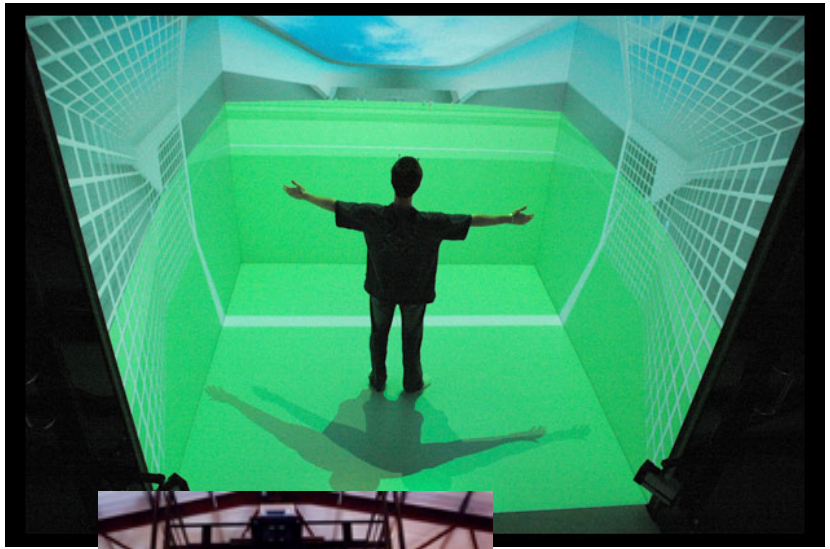


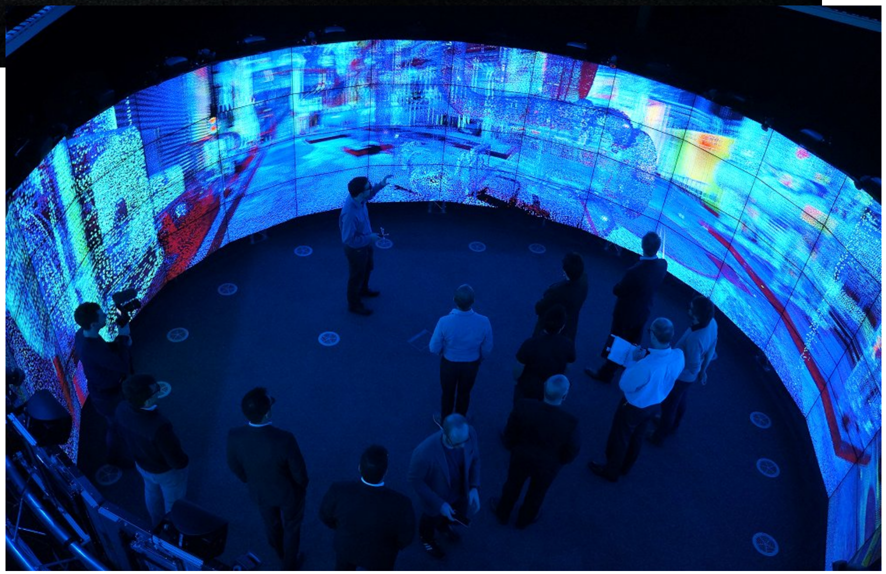
- 4 sides, rear projected stereo images

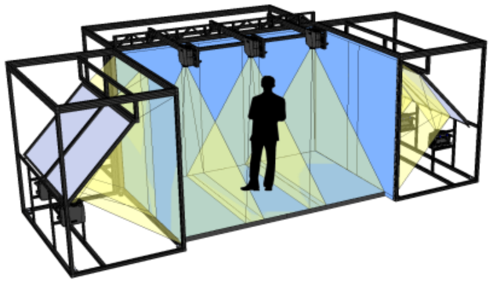
Demo Video – Wisconsin CAVE

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

CAVE Variations

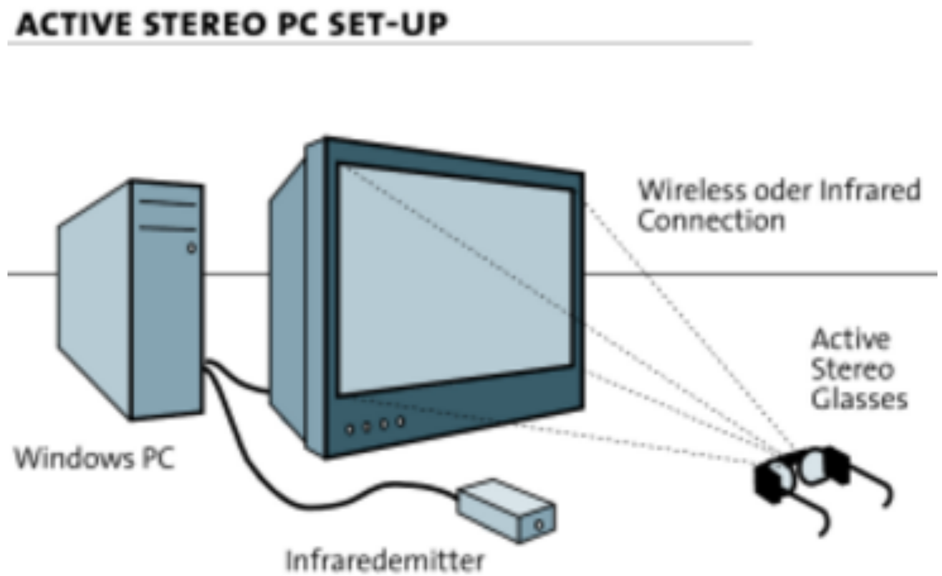


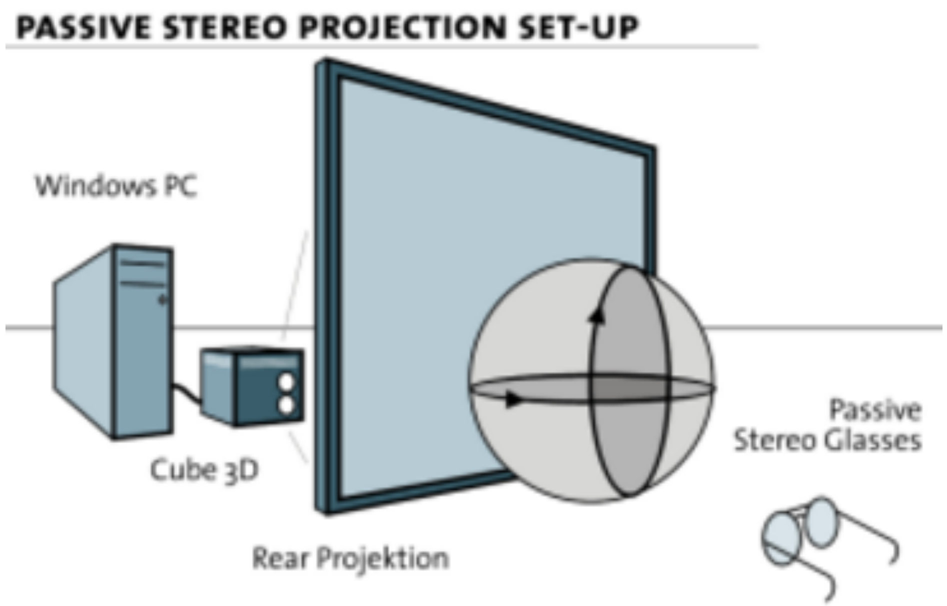




Stereo Projection

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



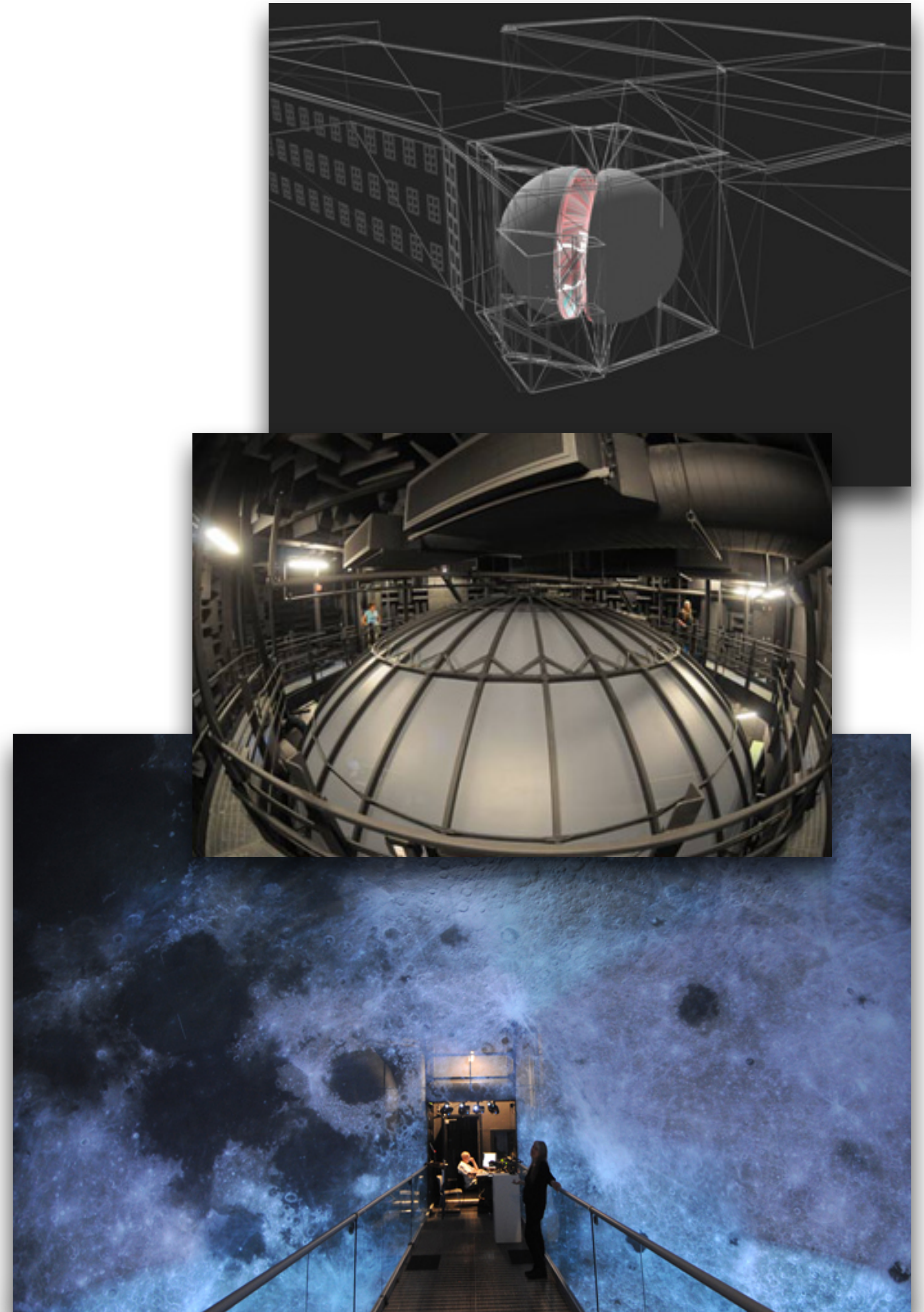


Caterpillar Demo

- https://www.youtube.com/watch?v=r9N1w8PmD1E

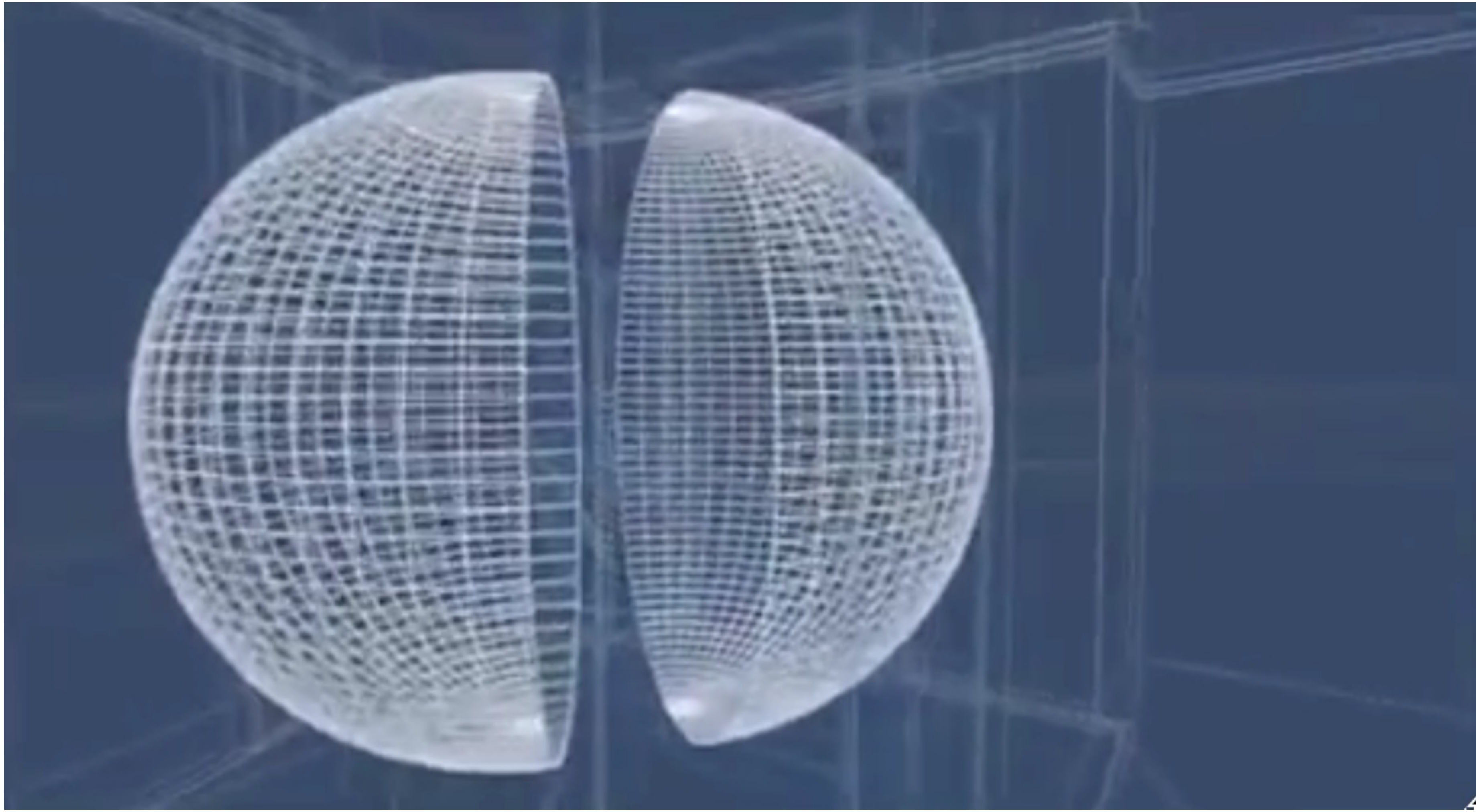
Allosphere

- Univ. California Santa Barbara
  - One of a kind facility
- Immersive Spherical display
  - 10 m diameter
  - Inside 3 story anechoic cube
  - Passive stereoscopic projection
  - 26 projectors
  - Visual tracking system for input
- See http://www.allosphere.ucsb.edu/



Kuchera-Morin, J., Wright, M., Wakefield, G., Roberts, C., Adderton, D., Sajadi, B., ... & Majumder, A. (2014). Immersive full-surround multi-user system design. *Computers & Graphics*, *40*, 10-21.

Allosphere Demo



- https://www.youtube.com/watch?v=25Ch8eE0vJg

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
- When is it needed?
  - Other cues occluded/obstructed
  - Required for task performance
  - High bandwidth!
- 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

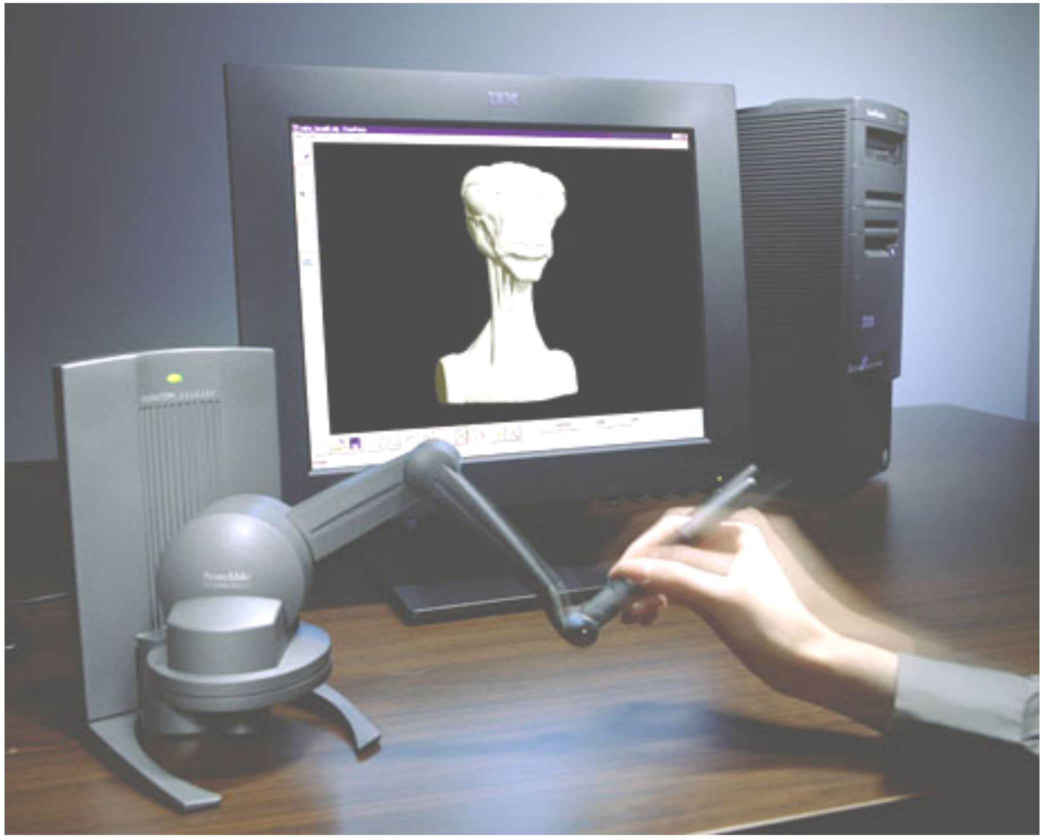
Haptic Devices

- Pin arrays for the finger(s)
- Force-feedback "arms"
- "Pager" motors
- Particle brakes
- Passive haptics
- Many devices are application specific
    - Like surgical devices

Active Haptics

- Actively resists contact motion
- Dimensions
  - Force resistance
  - Frequency Response
  - Degrees of Freedom
  - Latency
  - Intrusiveness
  - Safety
  - Comfort
  - Portability

Example: Phantom Omni



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

Phantom Omni Demo

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

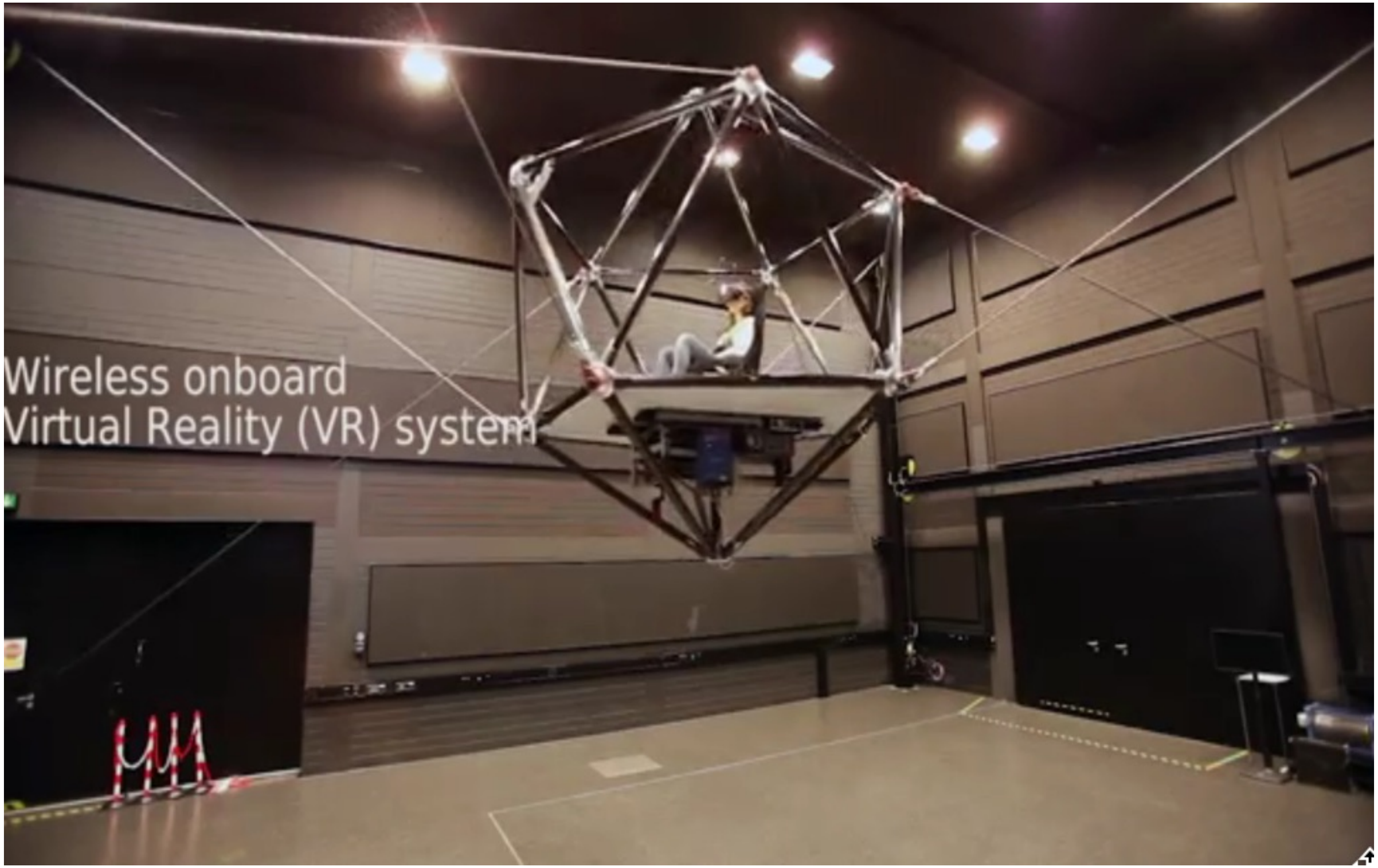
Immersion Cybergrasp

- Haptic feedback on Glove
- Combined with glove input

CyberMotion (MPI Tübingen)

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

CableRobot (MPI Tübingen)

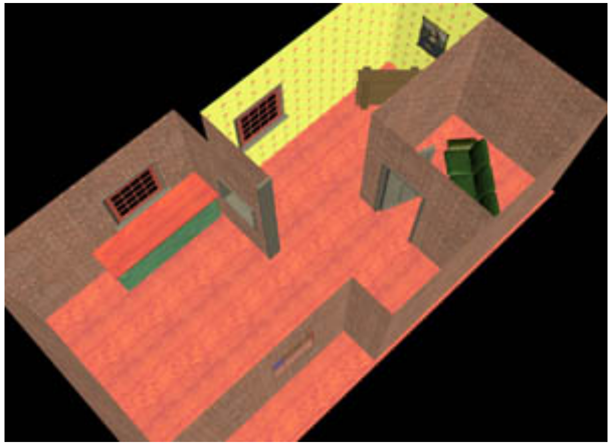
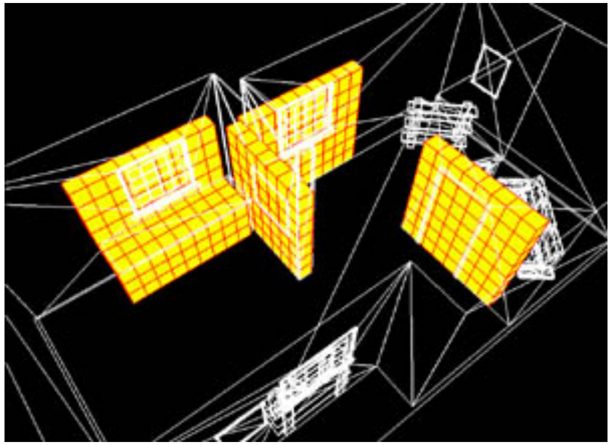
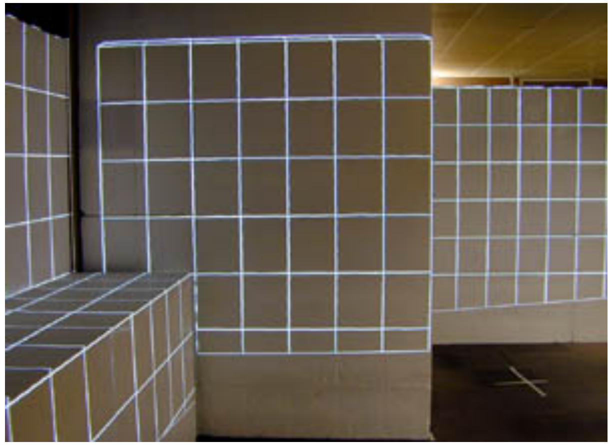


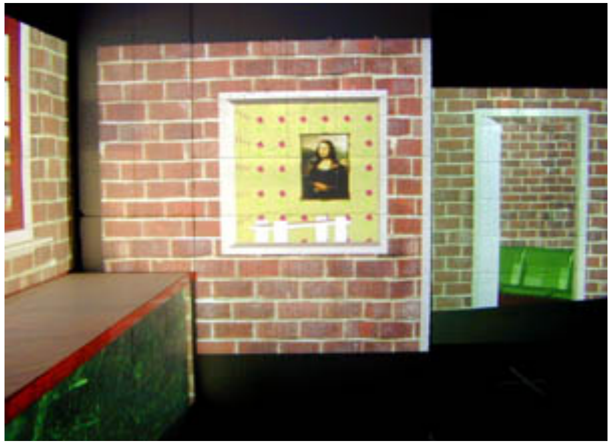
https://www.youtube.com/watch?v=cJCsomGwdk0&t=3s

Passive Haptics

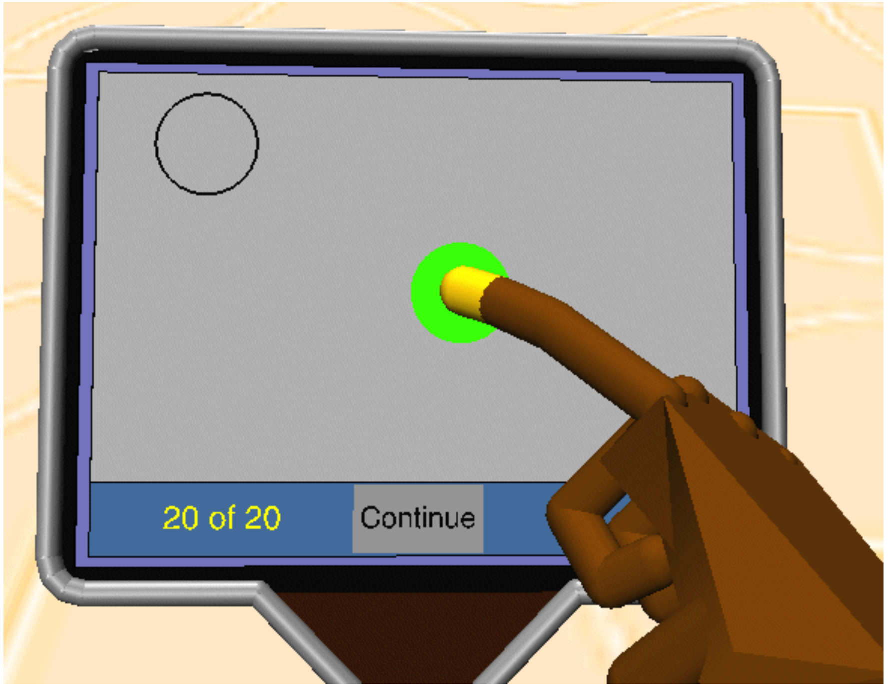
- Not controlled by system
- Pros
  - Cheap
  - Large scale
  - Accurate
- Cons
  - Not dynamic
  - Limited use

UNC Being There Project



Passive Haptic Paddle



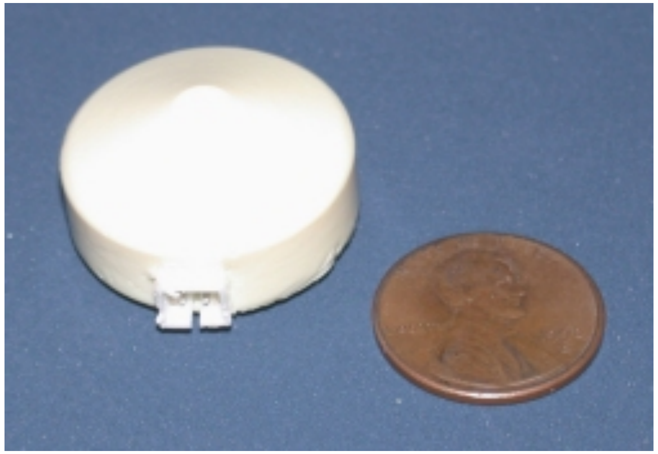
- Using physical props to provide haptic feedback
- http://www.cs.wpi.edu/~gogo/hive/

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

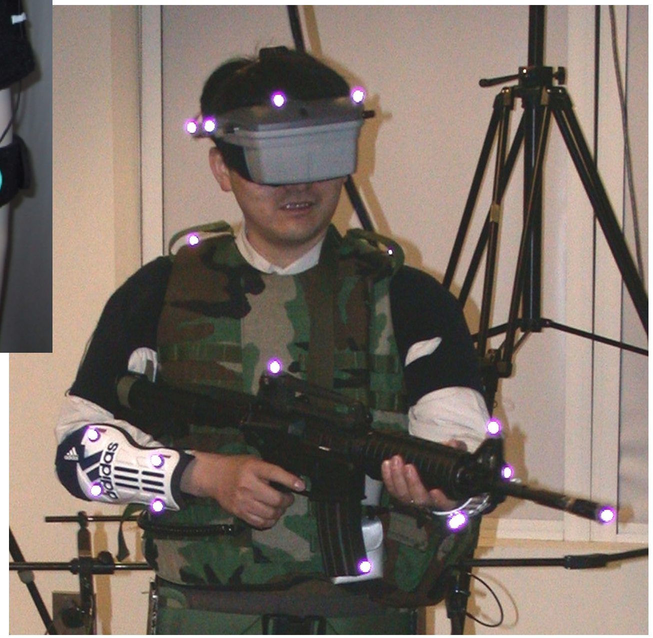
- Vibrotactile feedback has been incorporated into many devices
- Can we use this technology to provide scalable, wearable touch cues?



Vibrotactile Feedback Projects

Navy TSAS Project

TactaBoard and TactaVest



Example: CyberTouch Glove

- Immersion Corporation
  - Expensive - $15000
- Six Vibrotactile actuators
  - Back of finger
  - Palm
- Off-centered actuator motor
  - Rotation speed=frequency of vibration (0-125 Hz)
- When tracked virtual hand intersects with virtual object, send signal to glove to vibrate

http://www.cyberglovesystems.com/cybertouch/

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
- Localization
- Masking
- Amplification

Logistical Properties

- Noise pollution
- User mobility
- Interface with tracking
- Environmental requirements
- Integration
- Portability
- Throughput
- Cumber
- Safety
- Cost

Channels & Masking

- Number of channels
  - Stereo vs. mono vs. quadrophonic
  - 2.1, 5.1, 7.1
- Two kinds of masking
  - Louder sounds mask softer ones
    - We have too many things vying for our audio attention these days!
  - Physical objects mask sound signals
    - Happens with speakers, but not with headphones

Audio Displays: Head-worn

Ear Buds

On Ear

Open Back

Closed

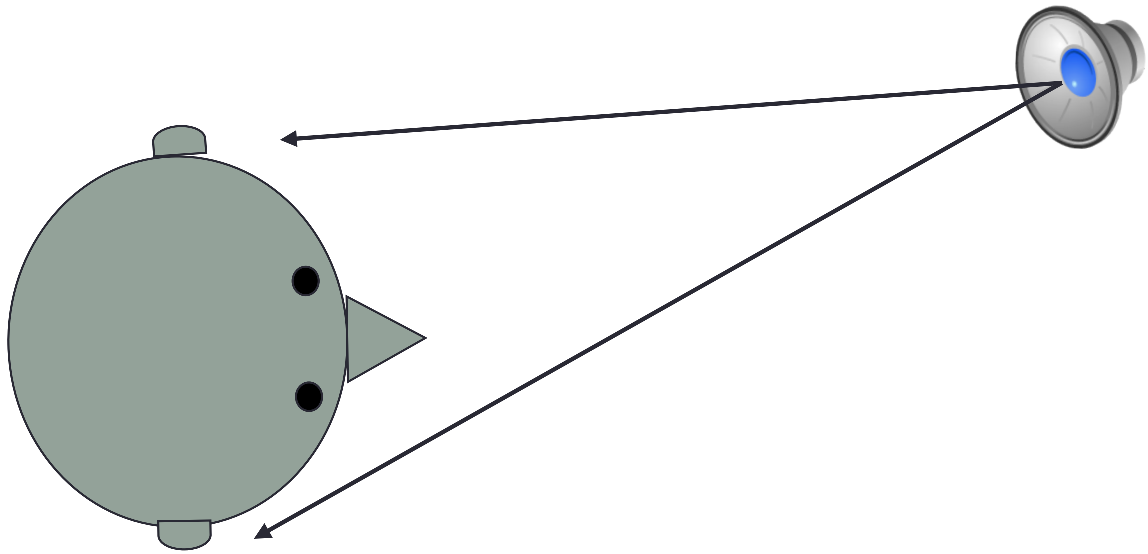
Bone Conduction

Spatialized Audio Effects

- Naïve approach
  - Simple left/right shift for lateral position
  - Amplitude adjustment for distance
- Easy to produce using consumer hardware/software
- Does not give us "true" realism in sound
  - No up/down or front/back cues
- We can use multiple speakers for this
  - Surround the user with speakers
  - Send different sound signals to each one

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



Constructing HRTFs

- Small microphones placed into ear canals
- Subject sits in an anechoic chamber
  - Can use a mannequin's head instead
- Sounds played from a large number of known locations around the chamber
- Functions are constructed for this data
- Sound signal is filtered through inverse functions to place the sound at the desired source

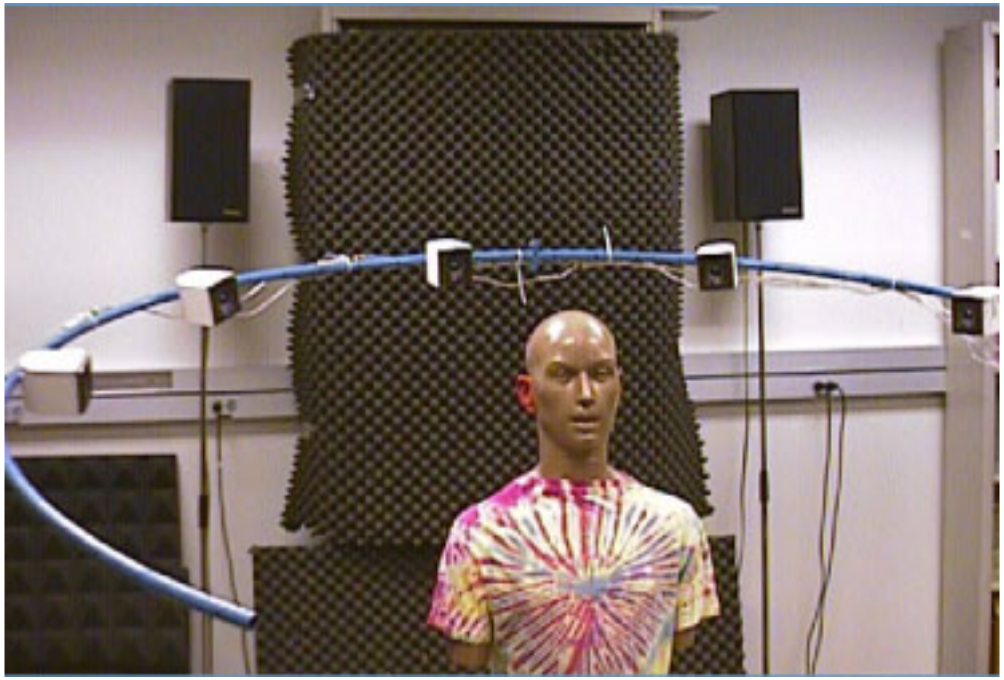
OSSIC 3D Audio Headphones

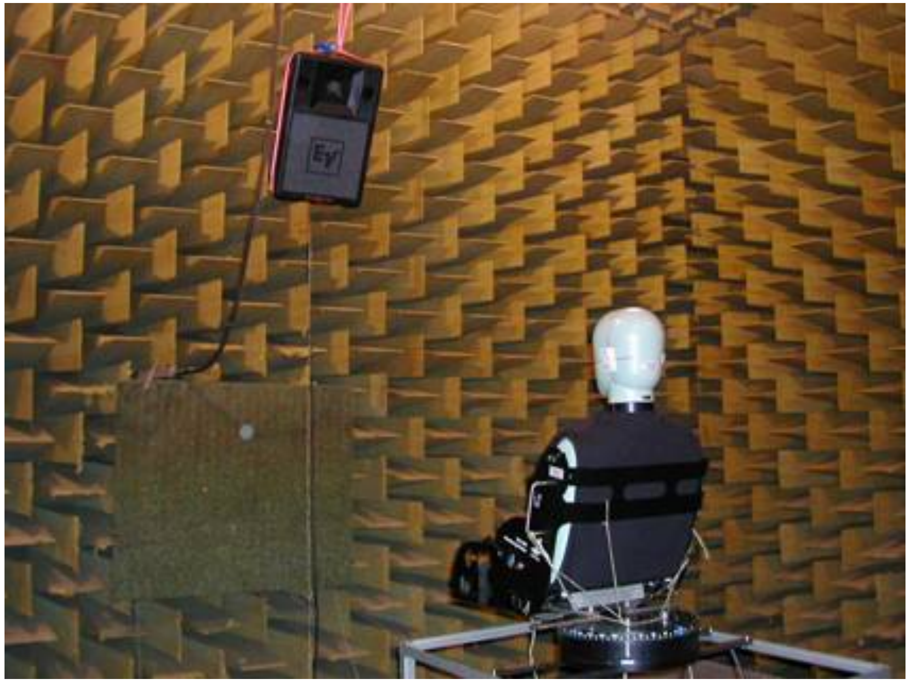
- https://www.ossic.com/3d-audio/

OSSIC Demo

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

Measuring HRTFs





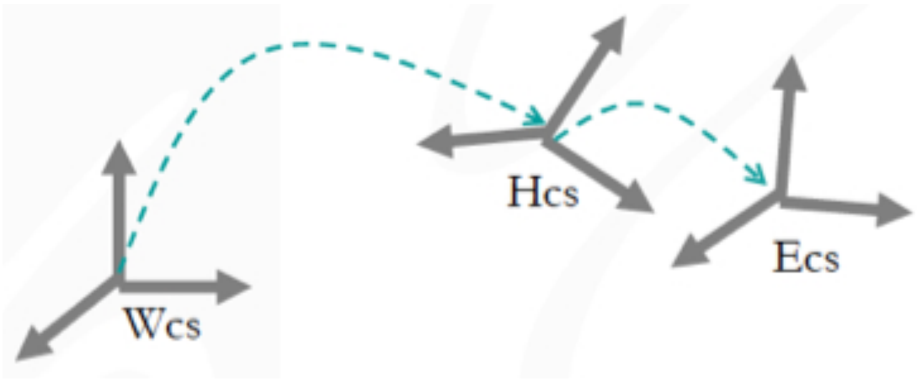
- Putting microphones in Manikin or human ears
- Playing sound from fixed positions
- Record response

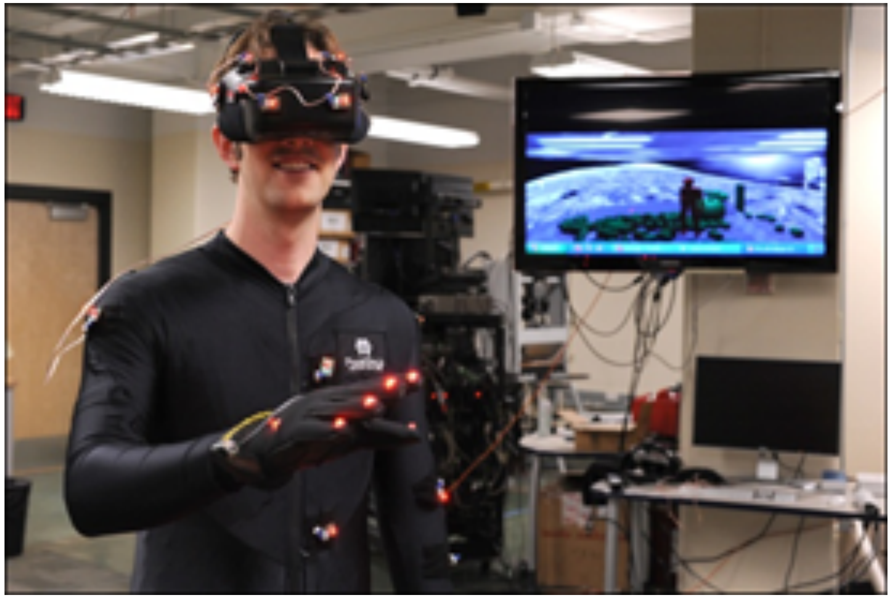
More About HRTFs

- Functions take into account, for example,
  - Individual ear shape
  - Slope of shoulders
  - Head shape
- So, each person has his/her own HRTF!
  - Need to have a parameterizable HRTFs
- Some sound cards/APIs allow you to specify an HRTF
- Check Wikipedia or Google for more info!

TRACKING

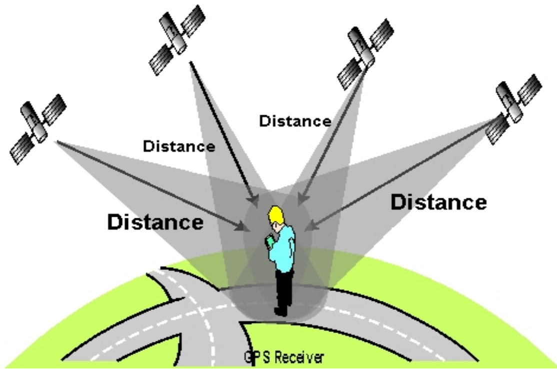
Tracking in Virtual Reality



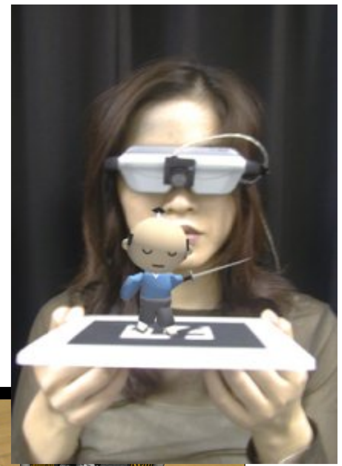


- Registration
  - Positioning virtual object wrt real/virtual objects
- Tracking
  - Continually locating the users viewpoint/input
    - Position (x,y,z), Orientation (r,p,y)

Tracking Technologies



- **Active**
  - Mechanical, Magnetic, Ultrasonic
  - GPS, Wifi, cell location
- **Passive**
  - Inertial sensors (compass, accelerometer, gyro)
  - Computer Vision
    - Marker based, Natural feature tracking
- **Hybrid Tracking**
  - Combined sensors (eg Vision + Inertial)



Mechanical Tracker

- Idea: mechanical arms with joint sensors

Microscribe

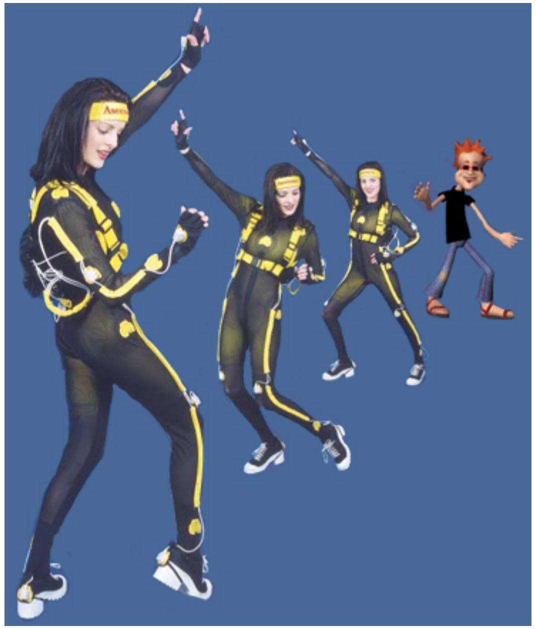
Sutherland

- ++: 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

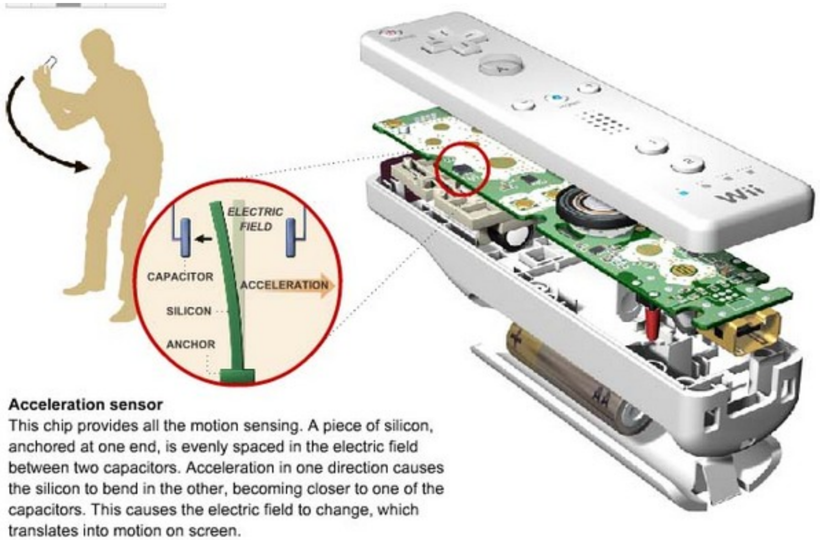
Razor Hydra Demo

- https://www.youtube.com/watch?v=jnqFdSa5p7w

Inertial Tracker

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

IS300 (Intersense)



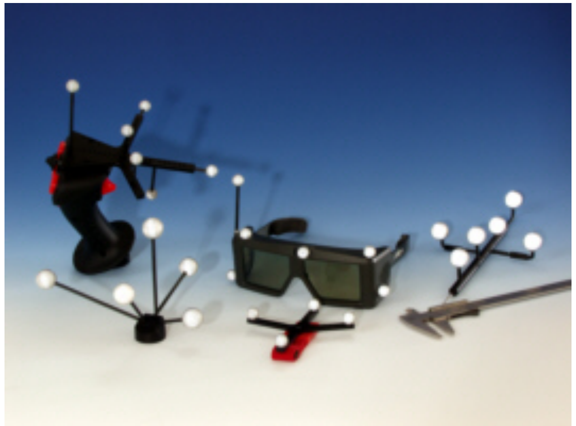
Wii Remote

- ++: no transmitter, cheap, small, high frequency, wireless
- -- : drift, hysteris only 3DOF

Optical Tracker

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

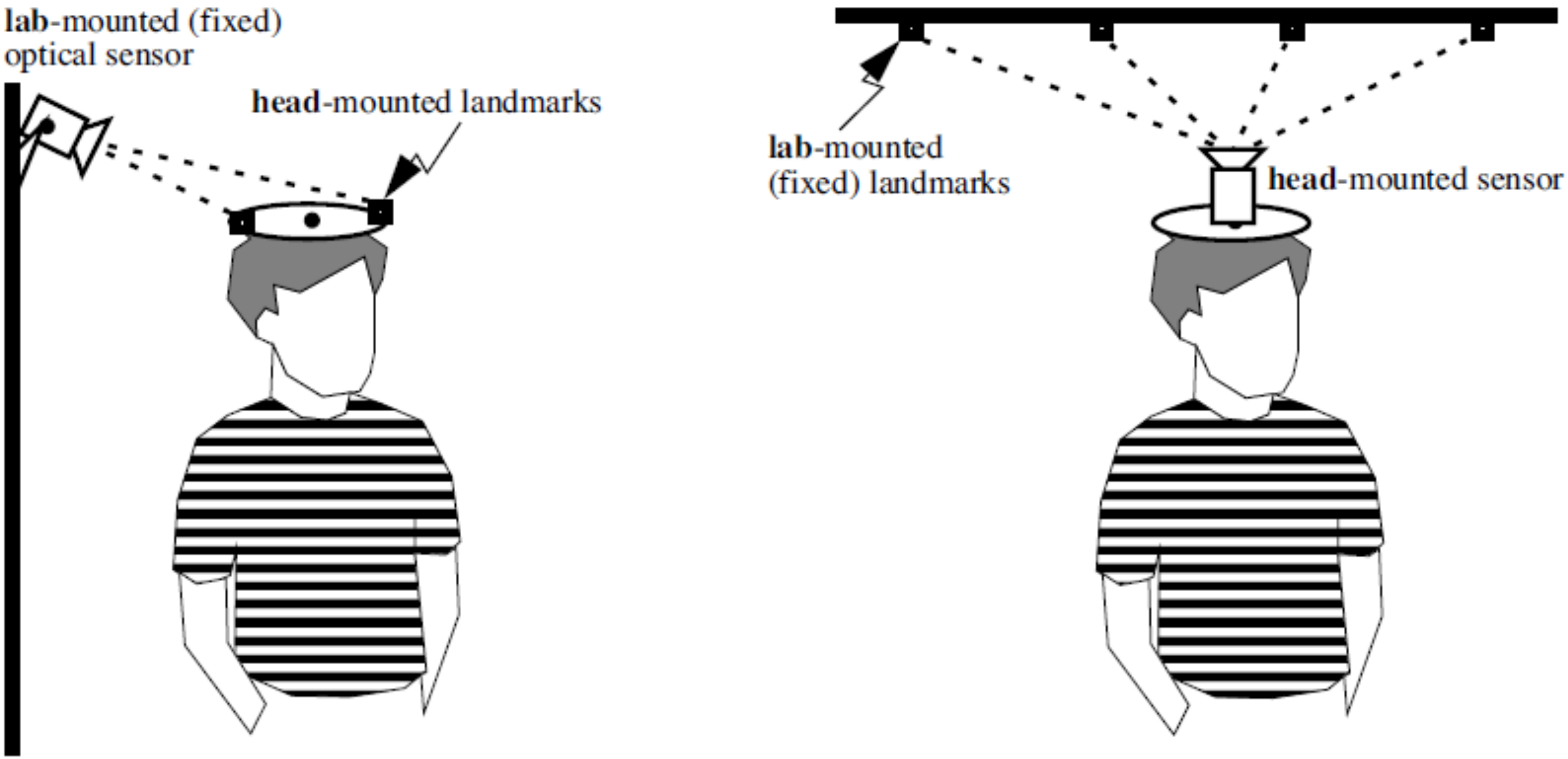
ART



Hi-Ball

- Monocular Based Vision Tracking

Outside-In vs. Inside-Out Tracking



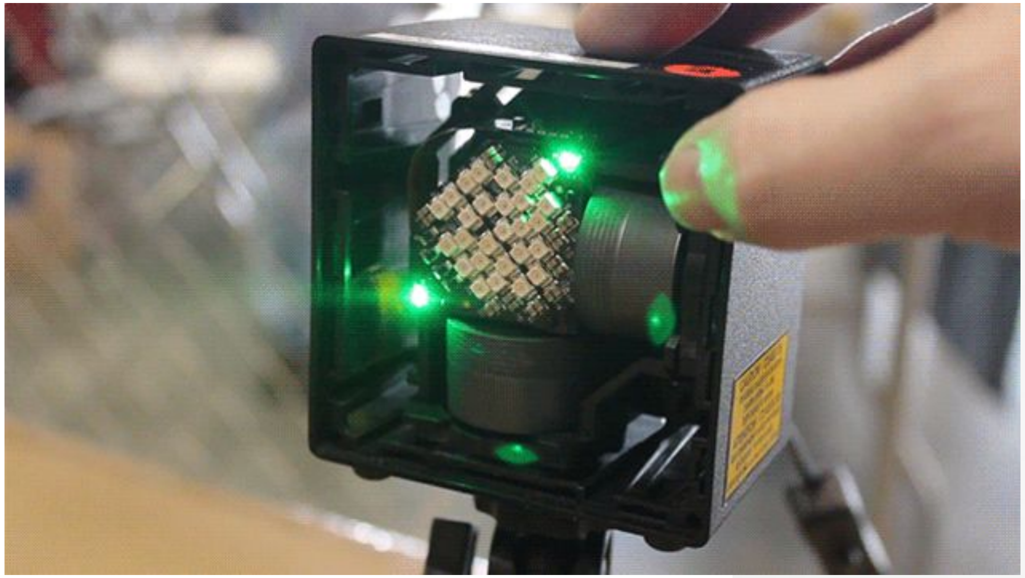
Outside-Looking-In

Inside-Looking-Out

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
  - 2mm RMS tracking accuracy
- See http://doc-ok.org/?p=1478

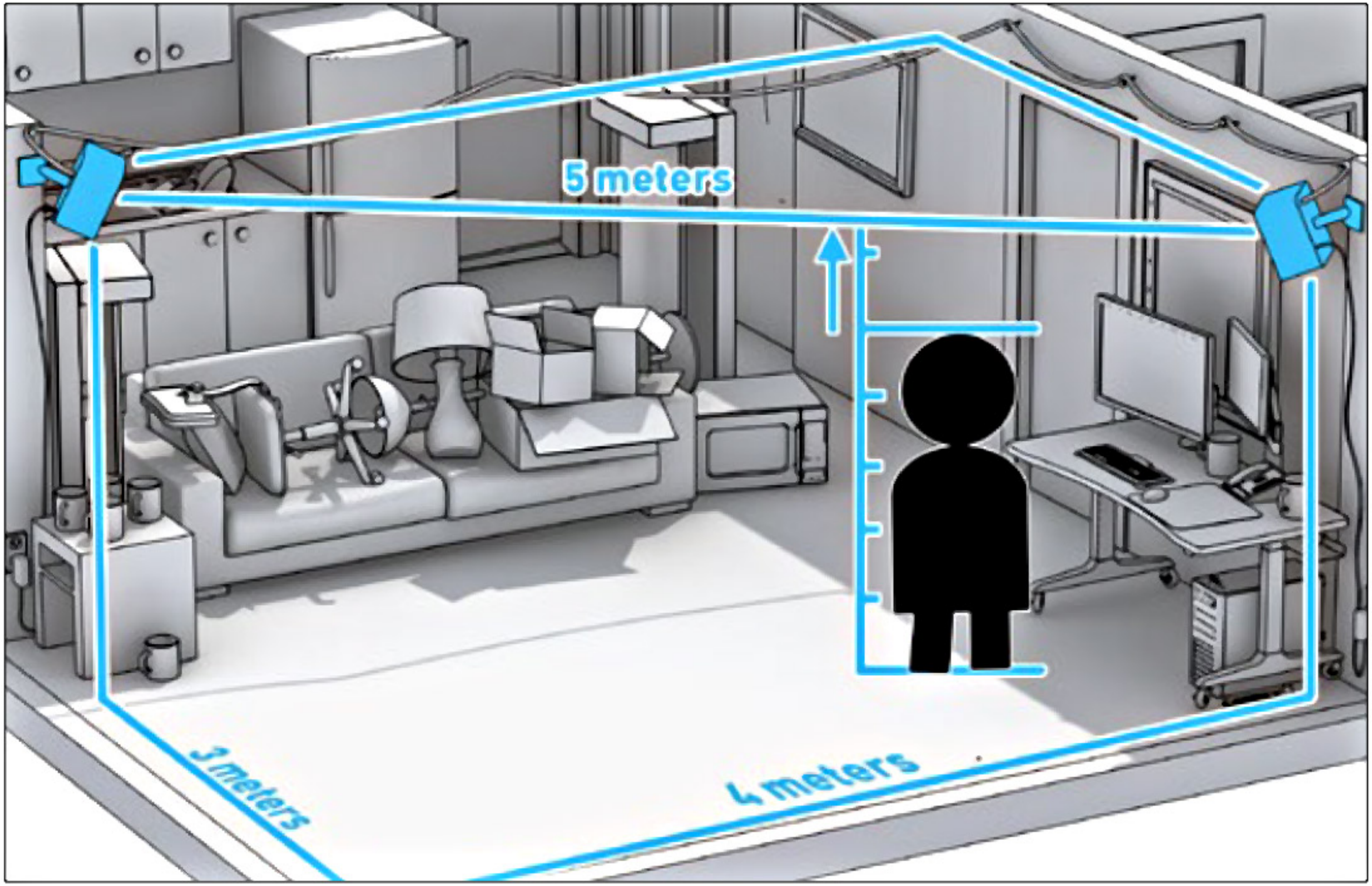
Lighthouse Components



Base station
  - IR LED array
  - 2 x scanned lasers

Head Mounted Display
  - 37 photo sensors
  - 9 axis IMU

Lighthouse Setup



How Lighthouse Tracking Works

- Position tracking using IMU
  - 500 Hz sampling
  - But drifts over time
- Drift correction using optical tracking
  - IR synchronization pulse (60 Hz)
  - Laser sweep between pulses
  - Photo-sensors recognize sync pulse, measure time to laser
  - Know *when* sensor hit and *which* sensor hit
  - Calculate position of sensor relative to base station
  - Use 2 base stations to calculate pose
- Use IMU sensor data between pulses (500Hz)
- See http://xinreality.com/wiki/Lighthouse

Lighthouse Tracking

Base station scanning

Room tracking

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

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