北京交通大學

Human-Computer Interaction (HCI) and Virtual Reality (VR)

3rd week 3rd week

4th week 3.25

2nd Semester, Spring 2022

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Overview

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

1. real / not real
2. real + not real

Presence

Personal Social Environmental

+NPC

+ NPC +

Environmental real _ not real

more details

Sensation

⇓

Perception

30% sight

hearing 3%

8% touch

Smell

taste

sight

100 M. ill.

Rods → night b&w

Cones → day color

FOV – Horizontal 210°

Vertical 115°

hearing

3 dimension (3)

Azimuth

distance

PRESENCE

Today

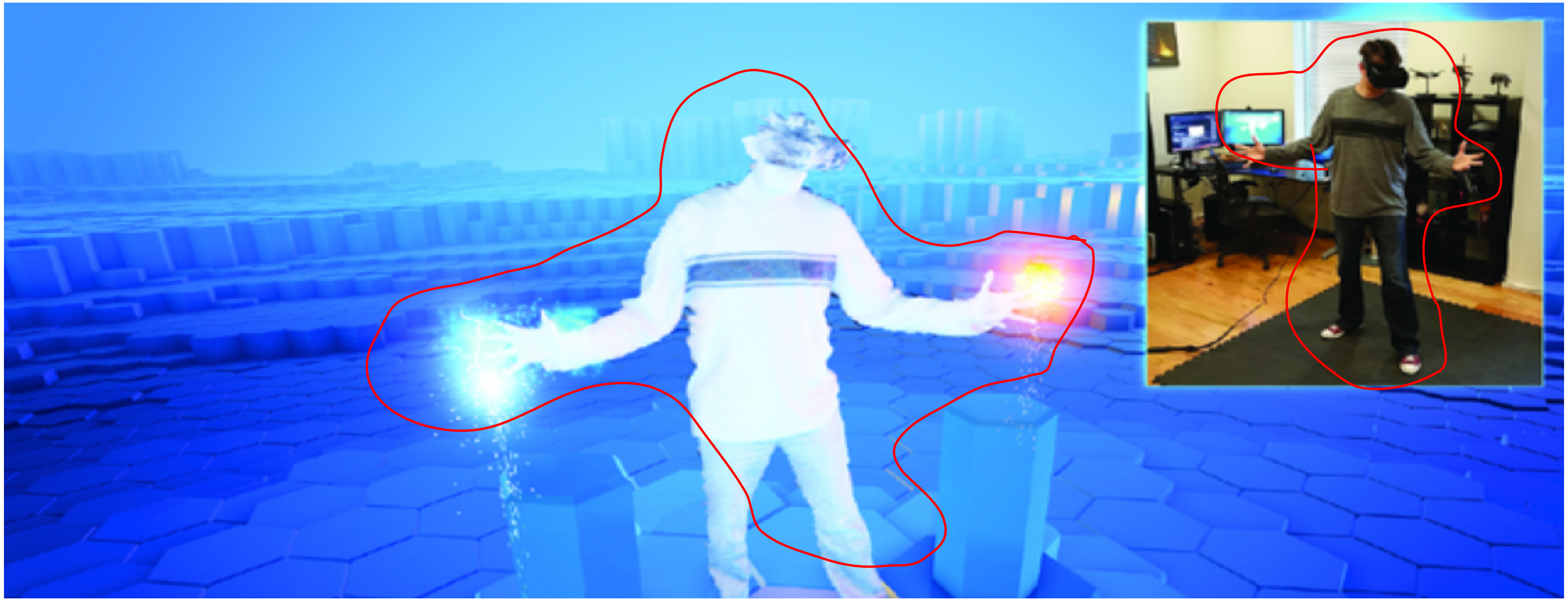
Tomorrow

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

-Roy Kalawsky (1993)

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.

Presence Definition

"Presence is a psychological state .. in which even though part or all of an individual's current experience is generated by .. technology, part or all of the individual's perception fails to .. acknowledge the role of the technology in the experience."

International Society for Presence Research, 2016
https://ispr.info/

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

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.

Three Types of Presence

- **Personal Presence,** the extent to which the person feels like he or she is part of the virtual environment;
- **Social Presence,** the extent to which other beings (living or synthetic) also exist in the VE;

NPC

- **Environmental Presence,** the extent to which the environment itself acknowledges and reacts to the person in the VE.

hit

throw

VE

Heeter, C. (1992). Being there: The subjective experience of presence. *Presence: Teleoperators & Virtual Environments*, *1*(2), 262-271.

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 Research
  - 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

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)

NPC / Players

Factors Contributing to Presence

Table I. *Factors Hypothesized to Contribute to a Sense of Presence*

Control Factors	Sensory Factors	Distraction Factors	Realism Factors
Degree of control	Sensory modality	Isolation	Scene realism
Immediacy of control	Environmental richness	Selective attention	Information consistent with objective world
Anticipation of events	Multimodal presentation	Interface awareness	Meaningfulness of experience
Mode of control	Consistency of multimodal information		Separation anxiety/ disorientation
Physical environment modifiability	Degree of movement perception		
	Active search		

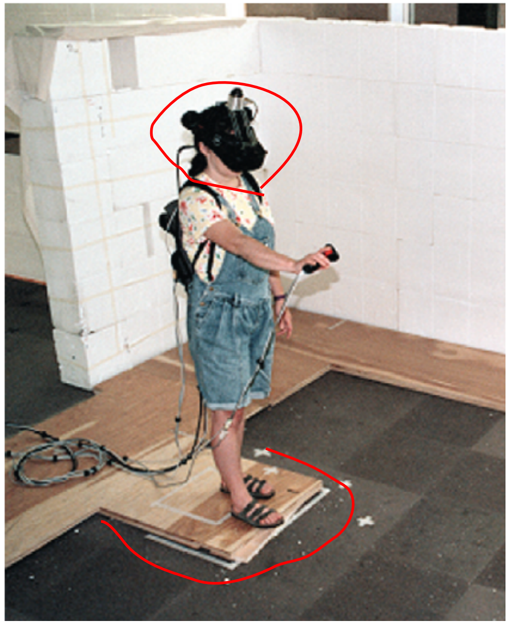
- From
  - Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence*, *7*(3), 225-240.

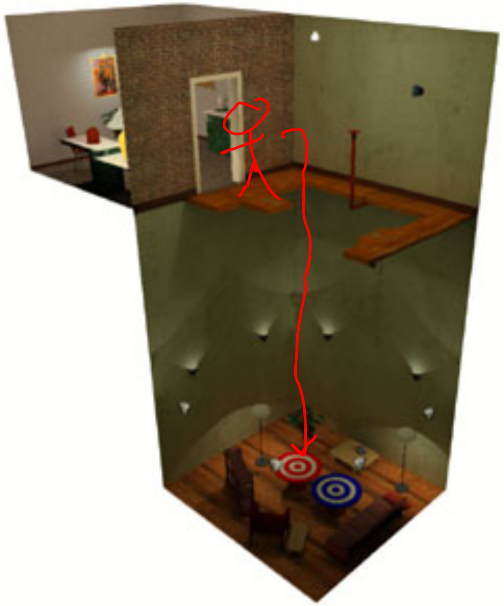
Presence Guidelines (Sadowski 2002)

Factors	Guideline
Ease of Interaction	Provide seamless interaction such that users can readily orient in, traverse in, and interact with the virtual environment.
User-initiated control	Provide immediacy of system response, correspondence of user-initiated actions, and a natural mode of control.
Pictorial Realism	Provide continuity, consistency, connectedness & meaningfulness in presented stimuli.
Length of Exposure	Provide sufficient exposure time to provide VE task proficiency, familiarity with the VE, and sensory adaptation.
Social Factors	Provide opportunities to interact with and communicate with others verbally or by gestures. Provide confirmation that others recognize one's existence in the VE.
Internal Factors	Identify the types of individuals who will use a VE system and their preferred representational system (i.e., visual, auditory, kinesthetic).
System Factors	Providing stereopsis, head-tracking, a large field of view, increasing update rates, multi-modal interaction, and ergonomically sound sensors/ effectors facilitate presence.

Example: UNC Pit Room (2002)

- 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

Richie's Plank

Video → real? [illegible]

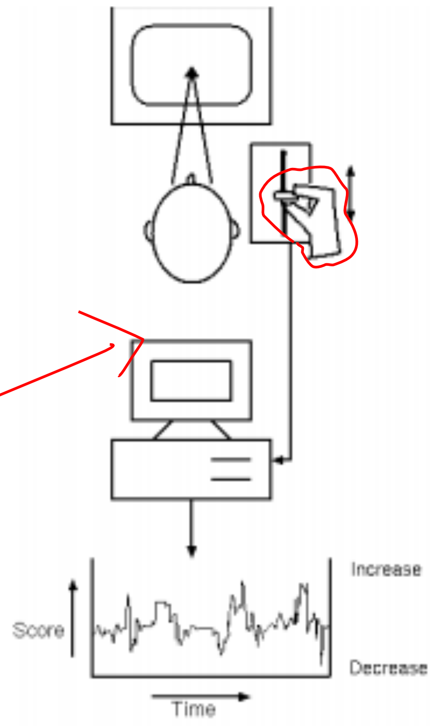
5min break
17:05

- https://www.youtube.com/watch?v=4M92kfnpg-k

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

ECG



Presence Slider

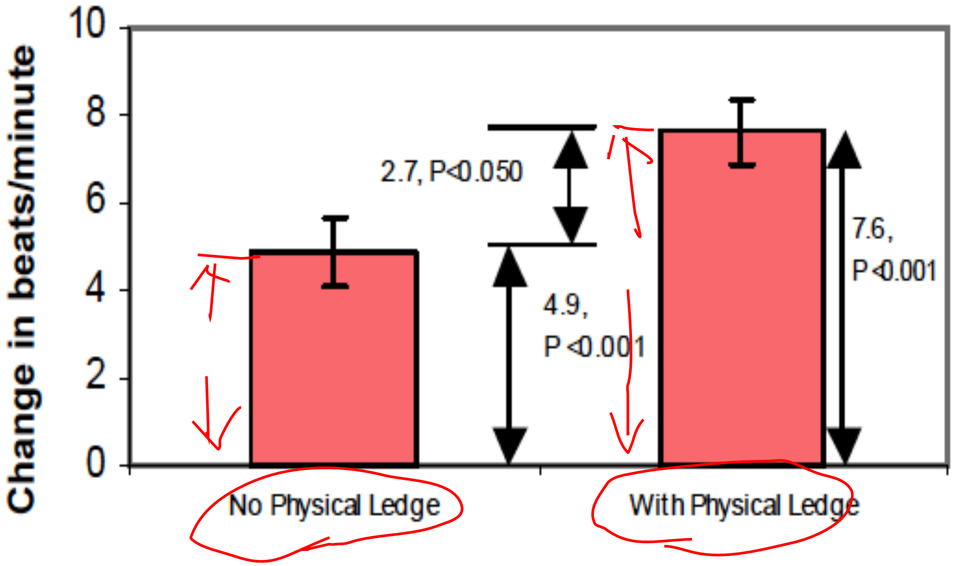
Example: Witmer and Singer (1998)

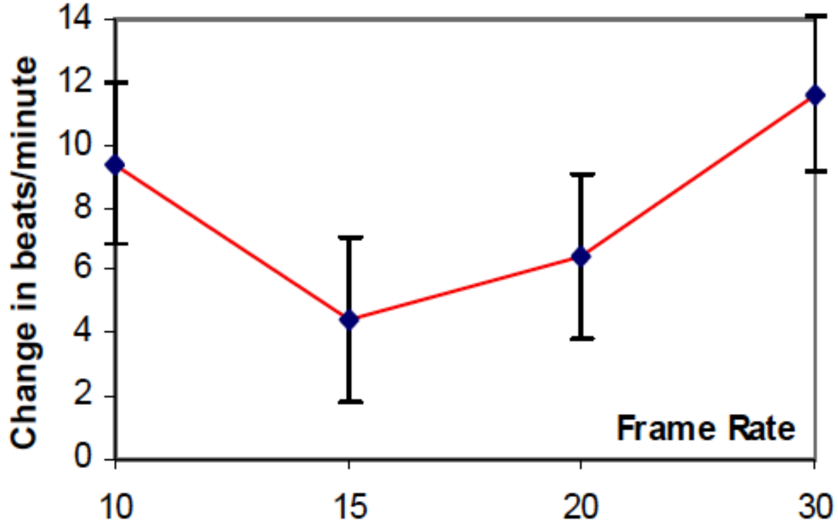
Table 2. Presence Questionnaire Item Stems (Version 2.0)

Item Stems	Factors	Subscale	*ITCorr*
1. How much were you able to control events?	CF	INV/C	0.43*
2. How responsive was the environment to actions that you initiated (or performed)?	CF	INV/C	0.56*
3. How natural did your interactions with the environment seem?	CF	NATRL	0.61*
4. How completely were *all* of your senses engaged?	SF		0.39*
5. How much did the visual aspects of the environment involve you?	SF	INV/C	0.48*
6. How much did the auditory aspects of the environment involve you?	SF	AUD[a]	0.32*
7. How natural was the mechanism which controlled movement through the environment?	CF	NATRL	0.62*
8. How aware were you of events occurring in the real world around you?	DF		0.03
9. How aware were you of your display and control devices?	DF		−0.14
10. How compelling was your sense of objects moving through space?	SF	INV/C	0.51*

- 32 questions in 4 categories/factors
  - Control (CF), Sensory (SF), Realism (RF), Distraction factors (DF)
- Answered on Likert scale from 1 to 7 (1 = low, 7 = high)

Example: Heartrate in Pit Experiment





- Physiological measures can be used as a reliable measure of Presence - especially change in heart rate (HR)
- Change in HR agreed with UCL subjective questionnaire
- HR increased with passive haptics, and increase in fps

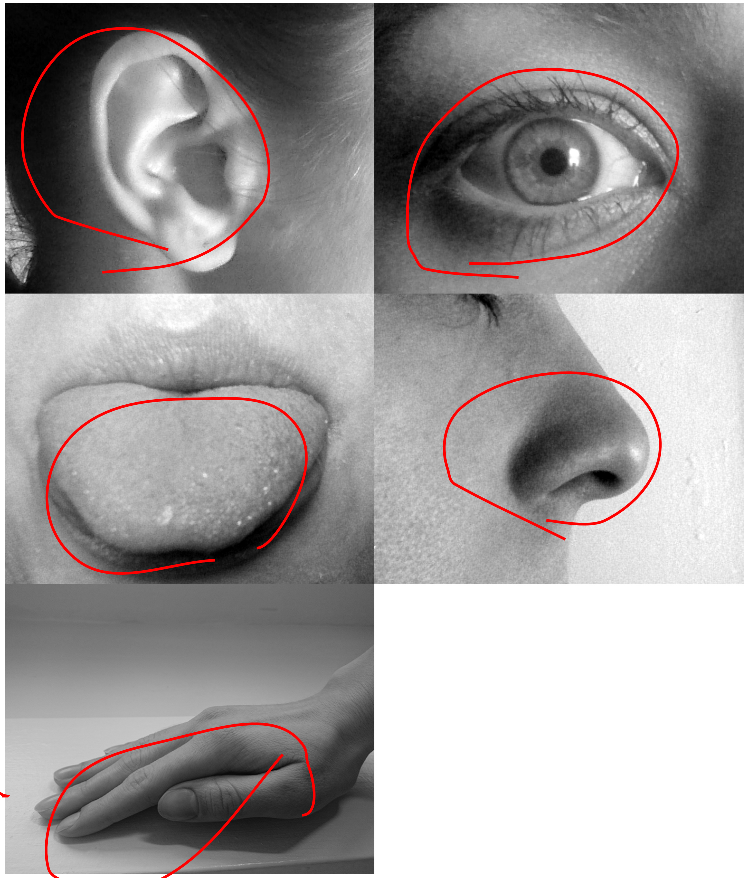
Meehan, M., Insko, B., Whitton, M., & Brooks, F. P. (2001). Physiological measures of presence in virtual environments. In *Proceedings of 4th International Workshop on Presence* (pp. 21-23).

Presence

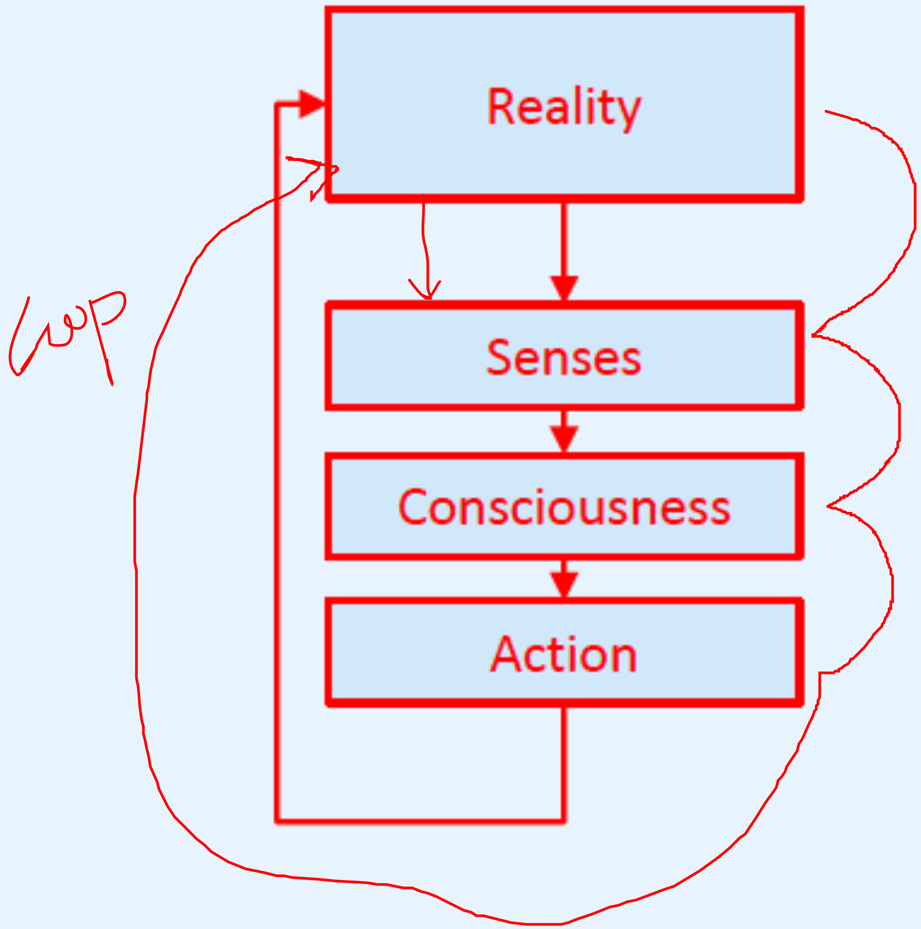
PERCEPTION AND VR

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

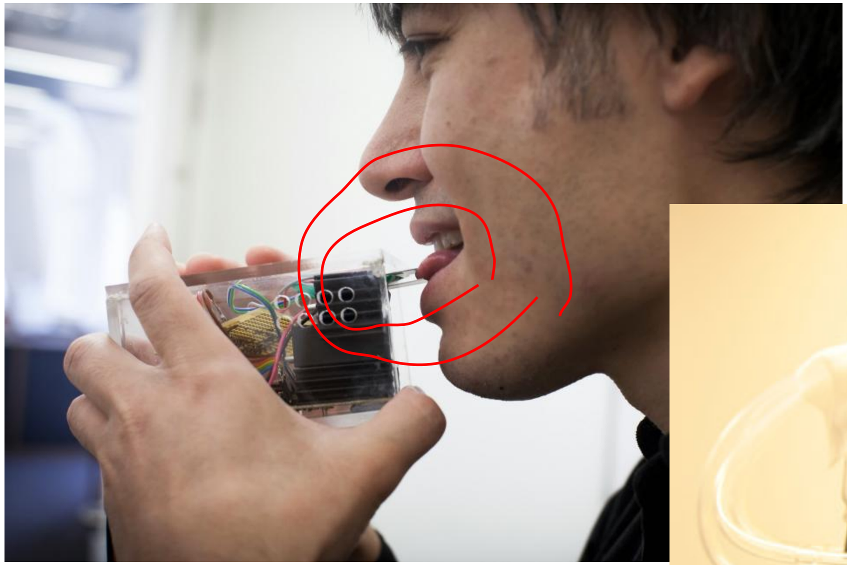
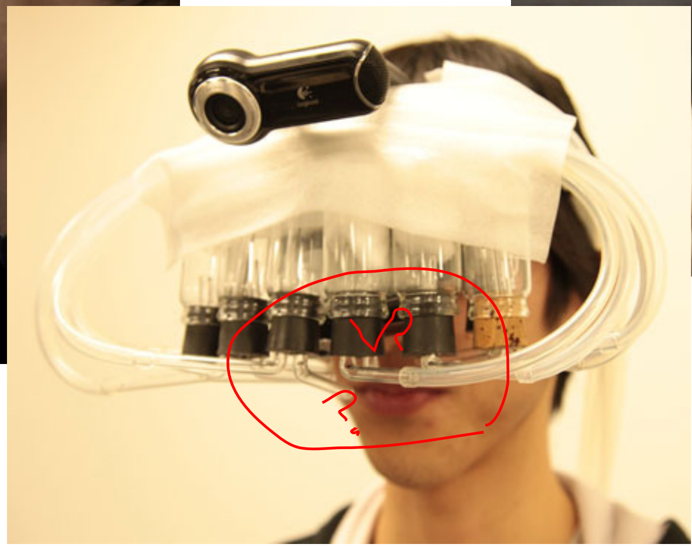
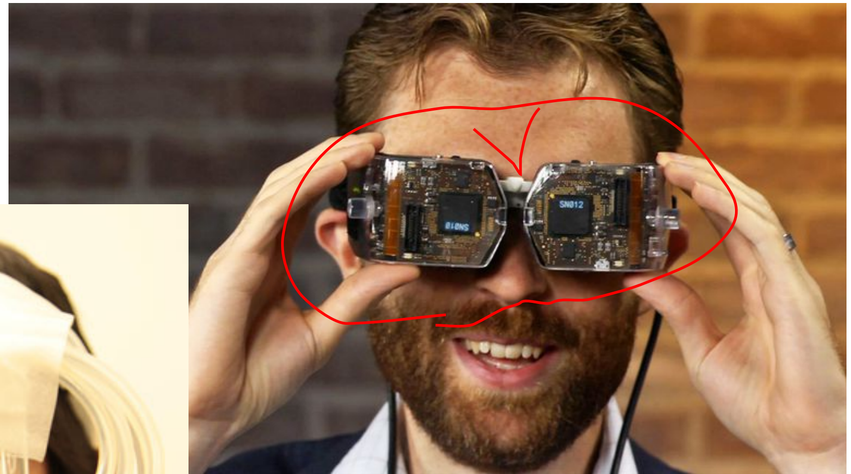
Co-founder, Oculus

VR

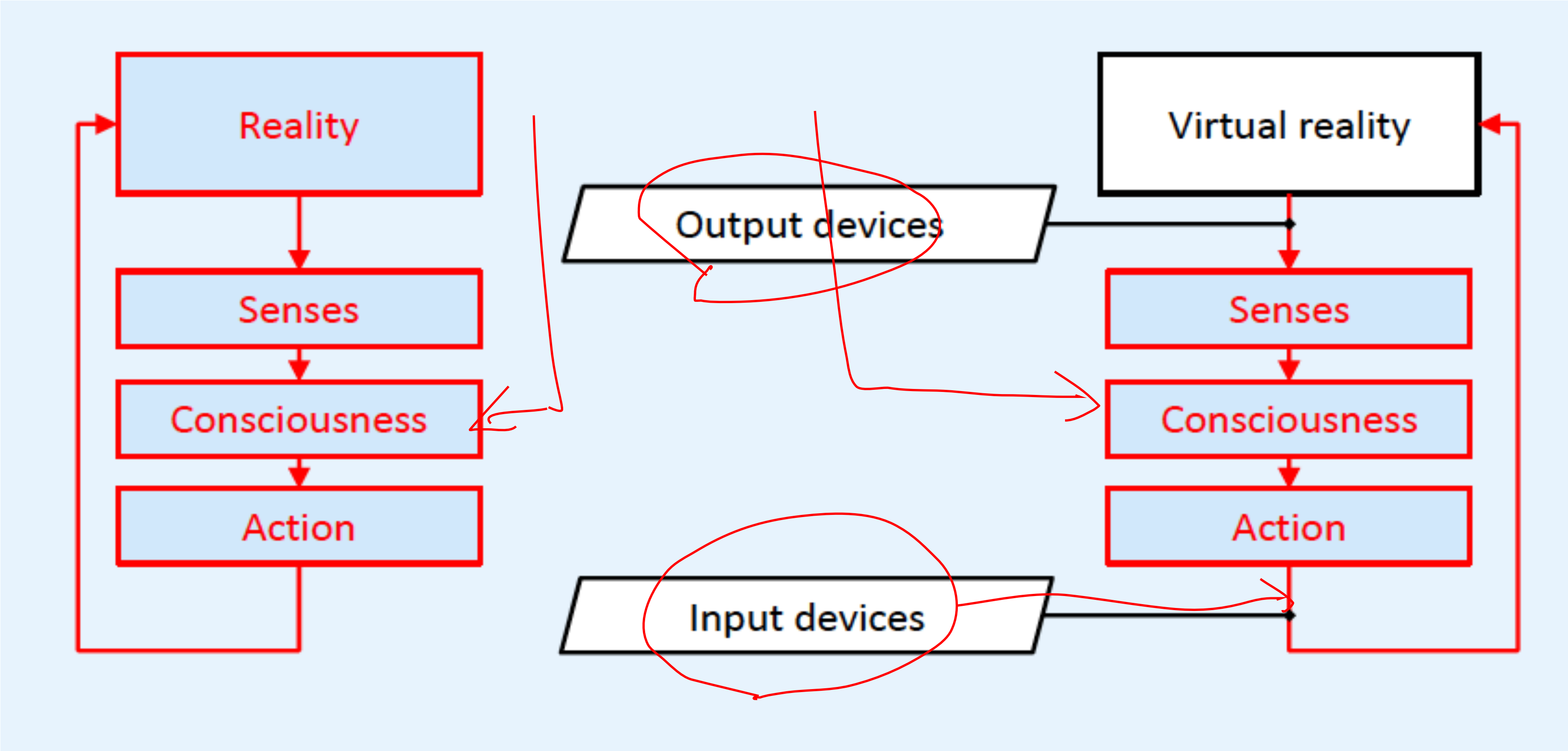
AR

Creating the Illusion of Reality

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

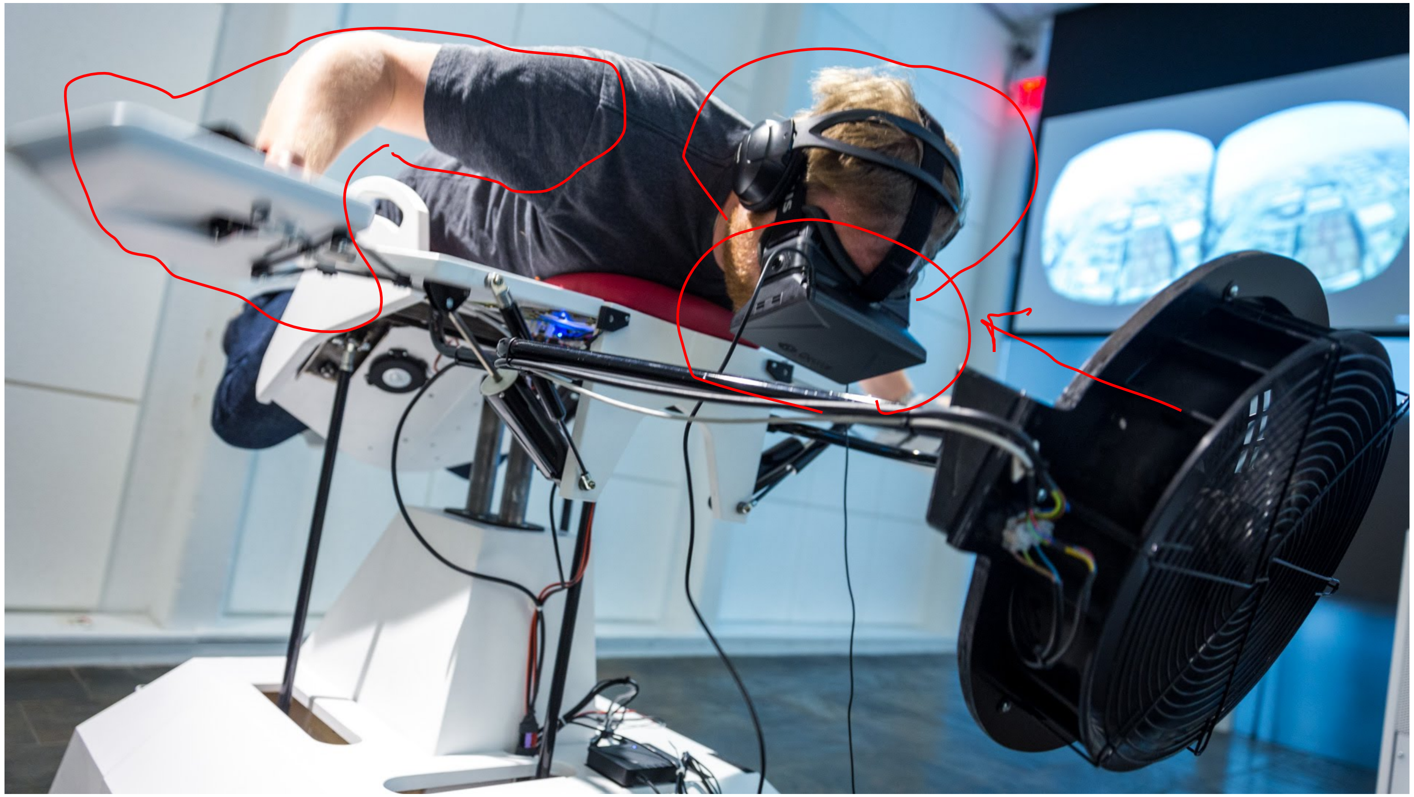




Reality vs. Virtual Reality



- In a VR system there are input and output devices between human perception and action
- Goal is to create illusion of reality – high Presence

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



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

Birdly Demo

1 funny → try
2 stupid → not try
3 don't know

4D
cinema
5D

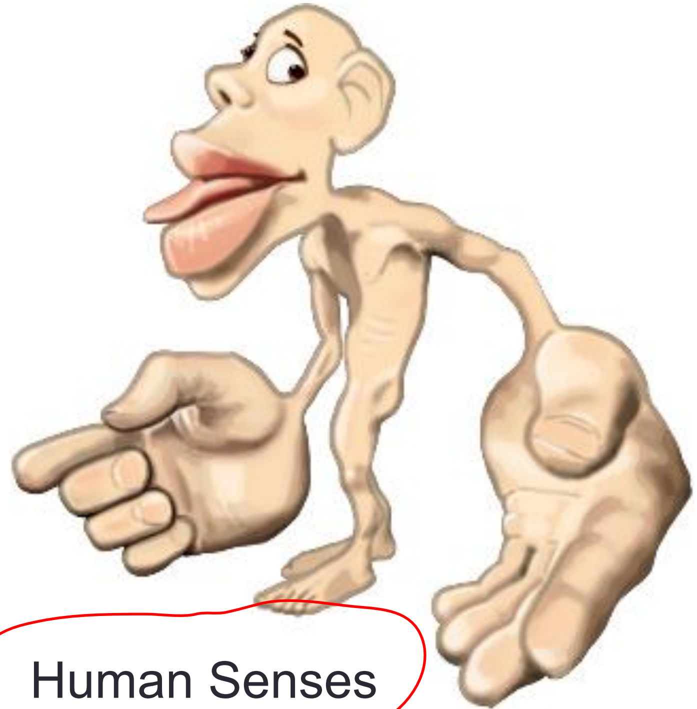
- https://www.youtube.com/watch?v=JApQBIsCK6c

Presence → Sensation → Perception

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 (but there are more..):
  1. Sight (Opthalamoception)
  2. Hearing (Audioception) Vote
  3. Taste (Gustaoception)
  4. Smell (Olfacaoception)
  5. Touch (Tactioception)

Relative Importance of Each Sense

ICCV
CVPR

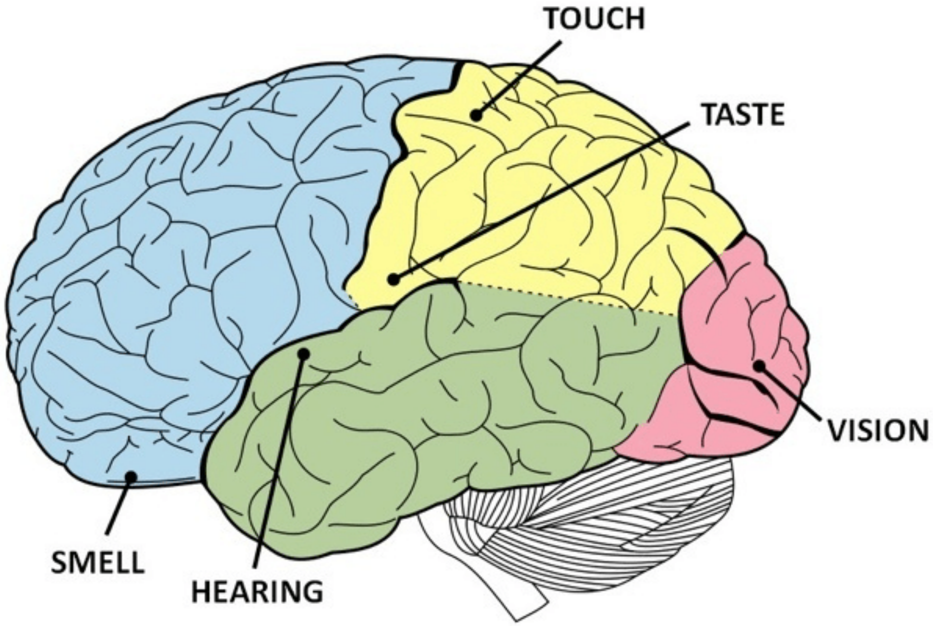
- Percentage of neurons in brain devoted to each sense
    - Sight – 30%
    - Touch – 8%
    - Hearing – 2%
    - Smell - < 1%

40%

CV

ICASSP

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



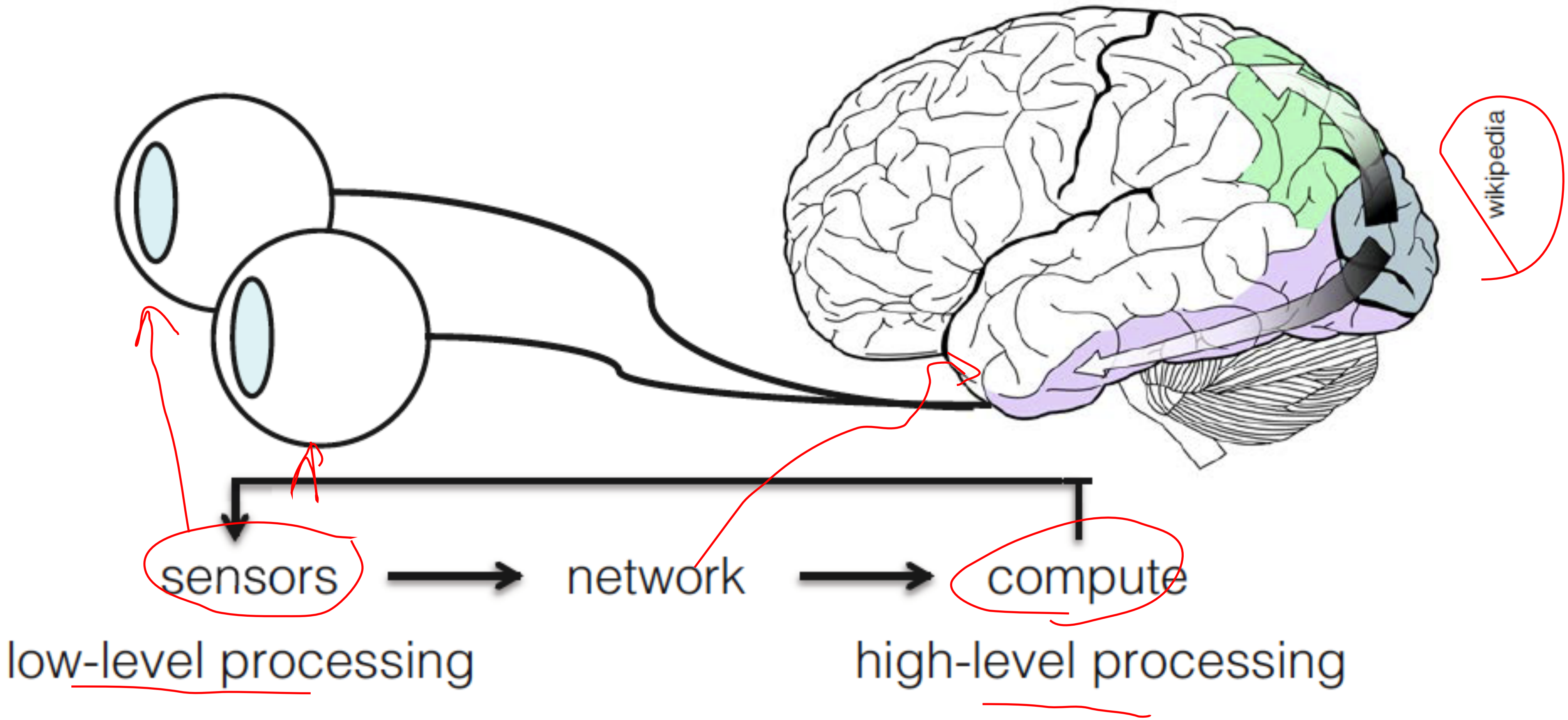
Other Lessor Known Senses..

perception

- 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

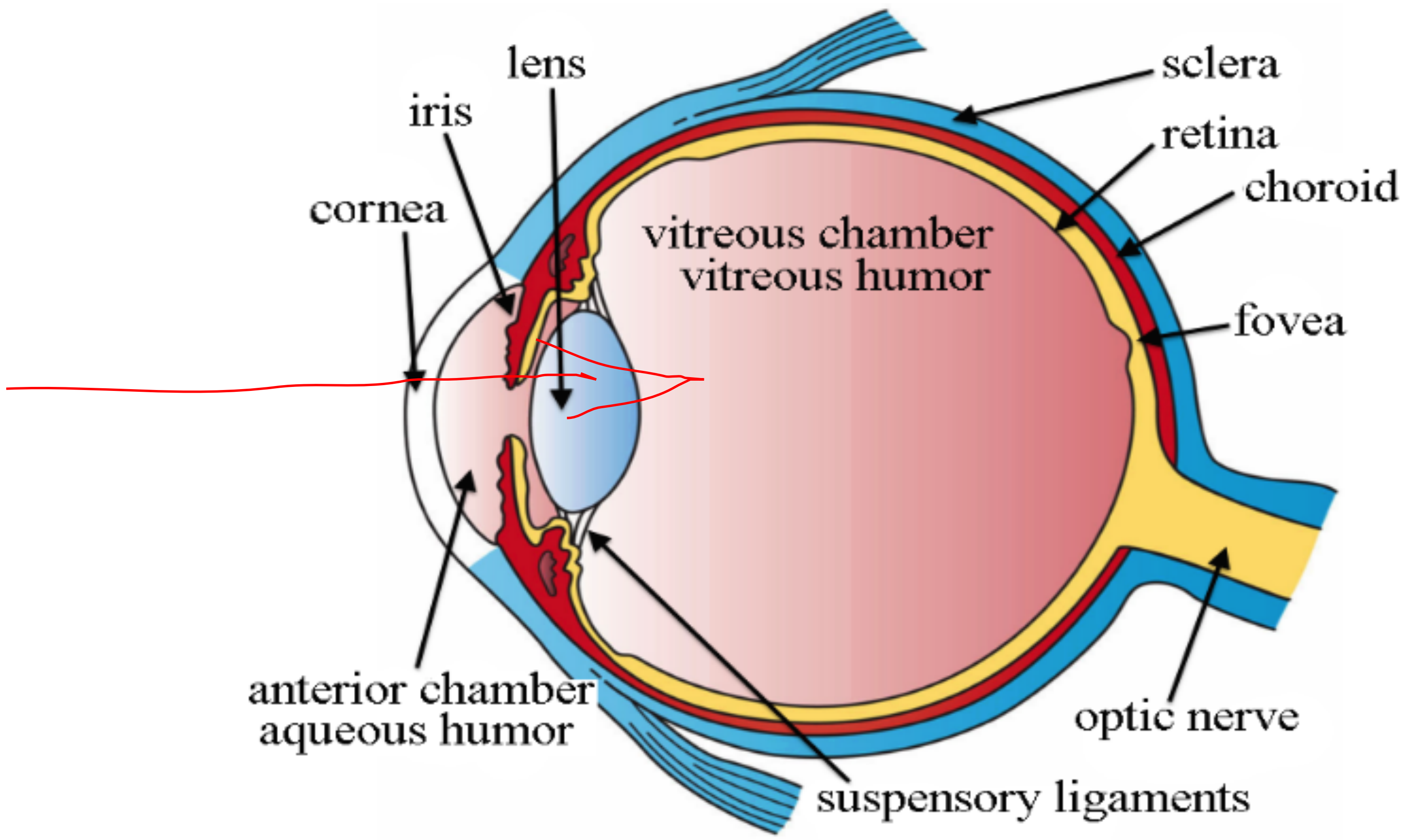

Sight

The Human Visual System



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

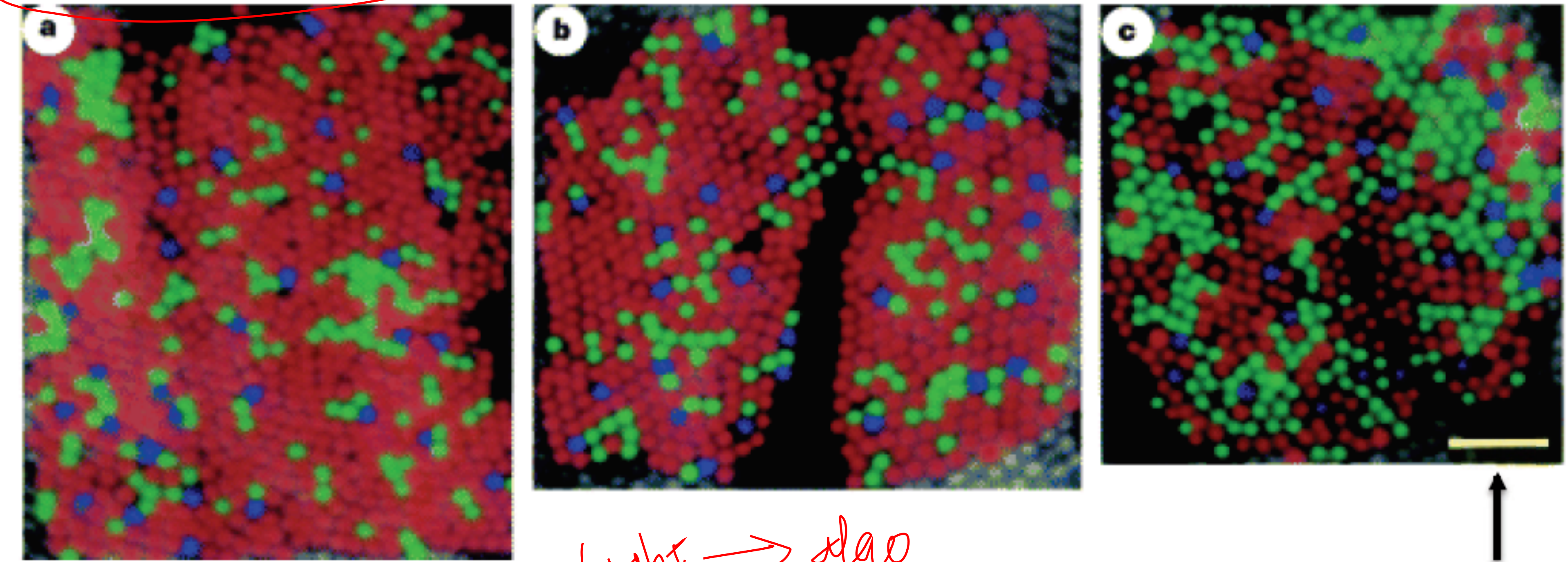
The Human Eye



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

Photoreceptors – Rods and Cones

Roorda & Williams, 1999, Nature

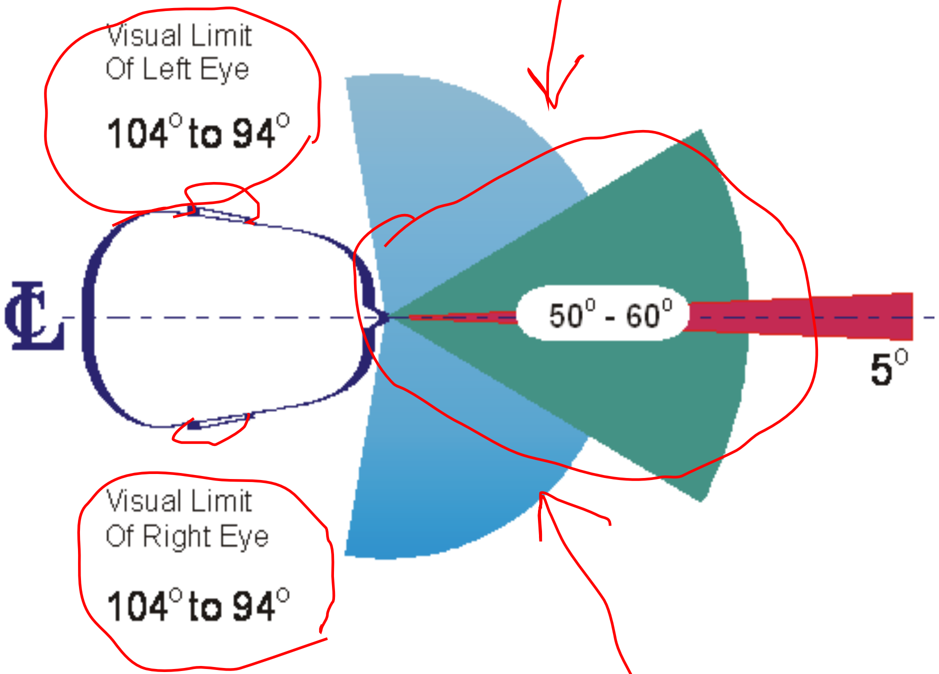


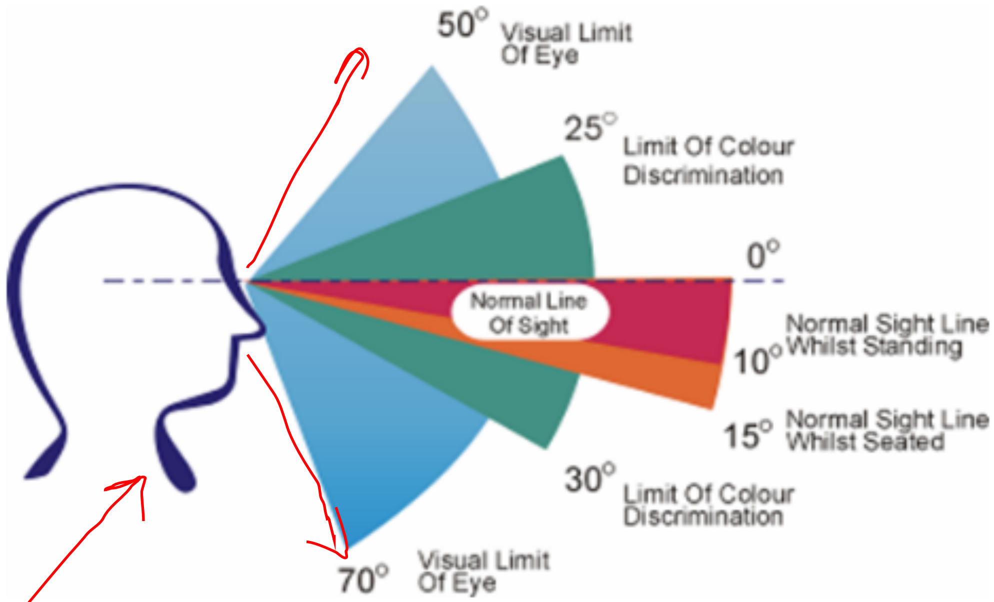
5 arcmin visual angle

CV → Light → algo

- Retina photoreceptors come in two types, Rods and Cones
  - Rods – 125 million, periphery of retina, no colour detection, night vision
  - Cones – 4-6 million, center of retina, colour vision, day vision

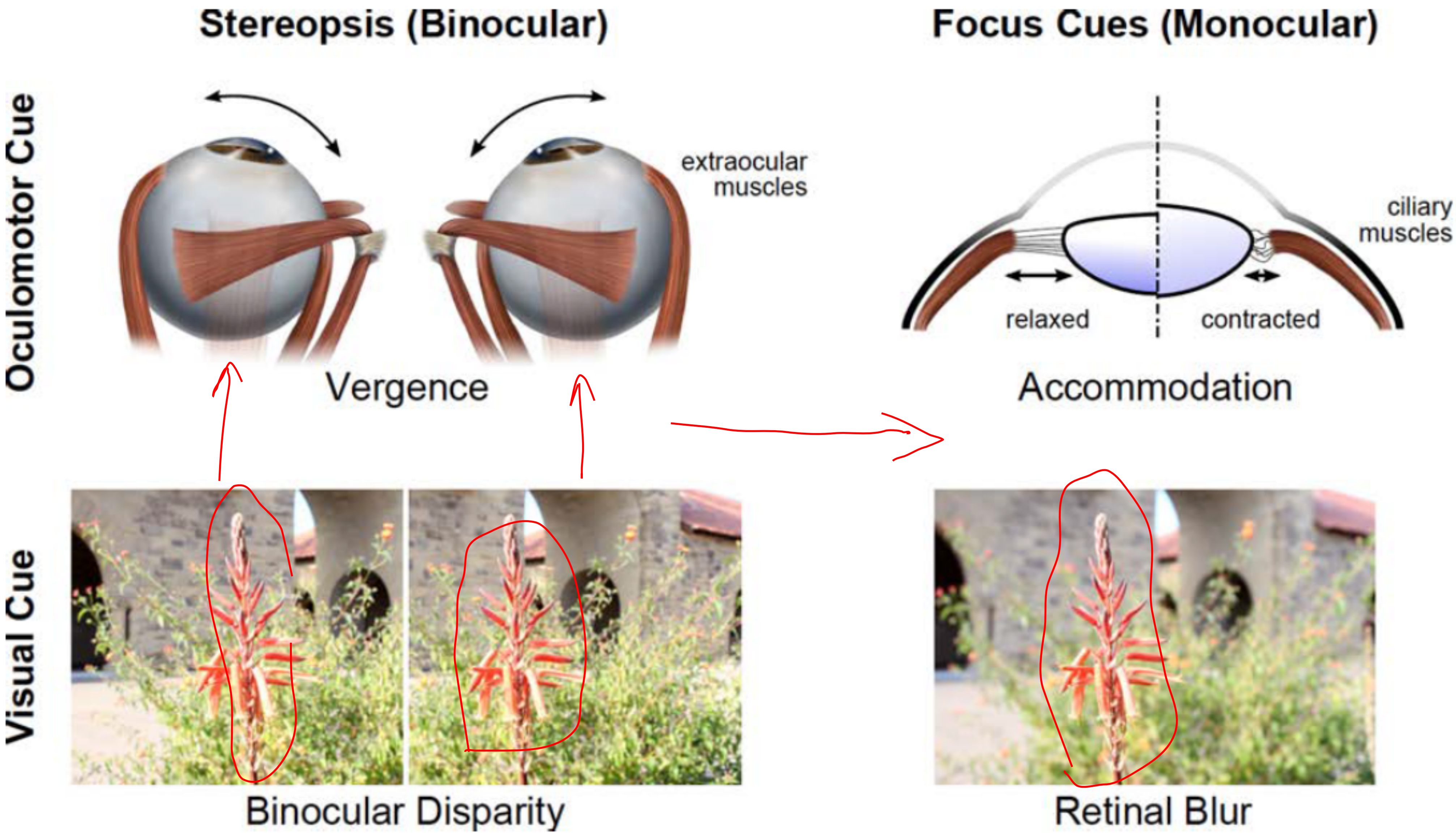
Human Horizontal and Vertical FOV



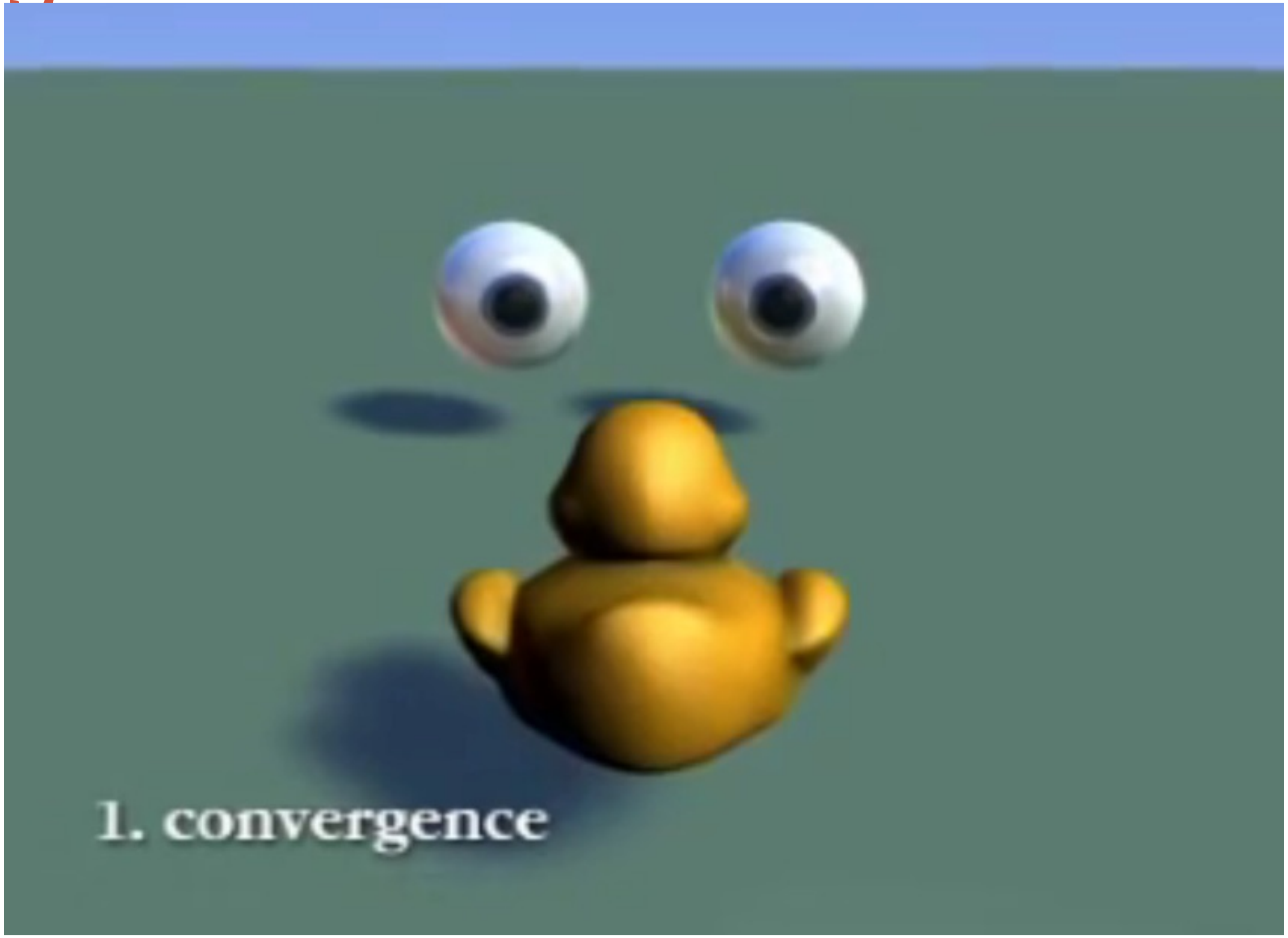


- Humans can see ~135° vertical (60° above, 75° below)
- See up to ~ 210° horizontal FOV, ~ 115° stereo overlap
- Colour/stereo in centre, Black & White/mono in periphery

Vergence + Accommodation



Vergence/Accommodation Demo



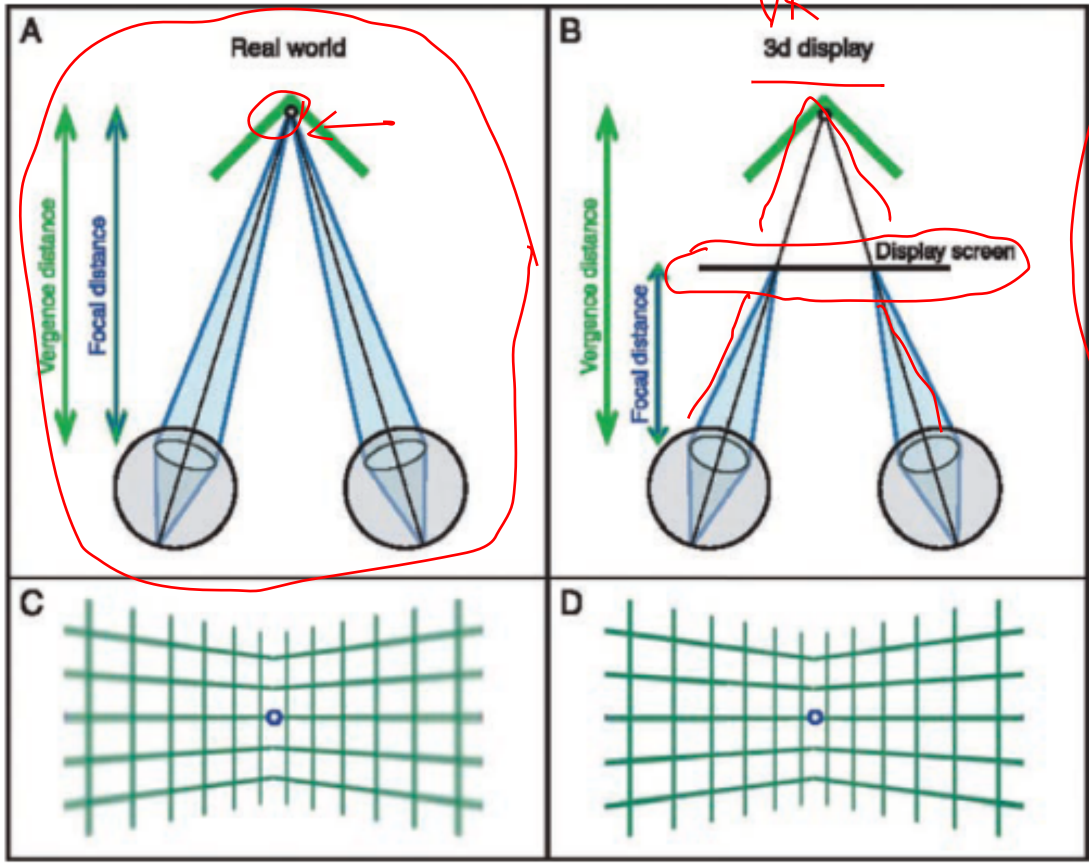
- https://www.youtube.com/watch?v=p_xLO7yxgOk

Vergence-Accommodation Conflict

5 mins
17:50

Marty Banks, UC Berkeley

VR



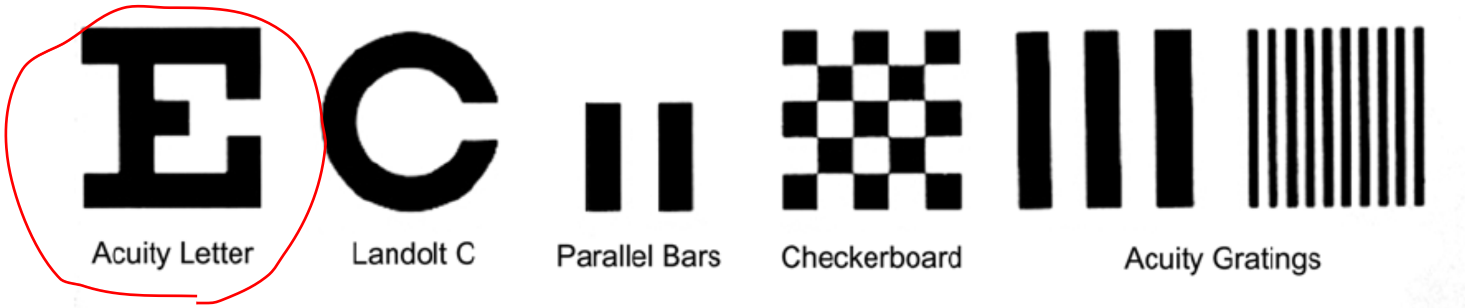
effects

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

cyber sickness

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

Visual Acuity

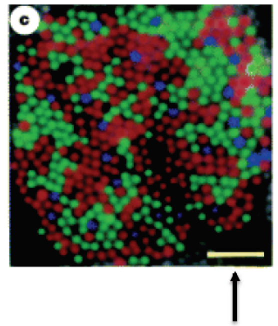


Visual Acuity Test Targets

- 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

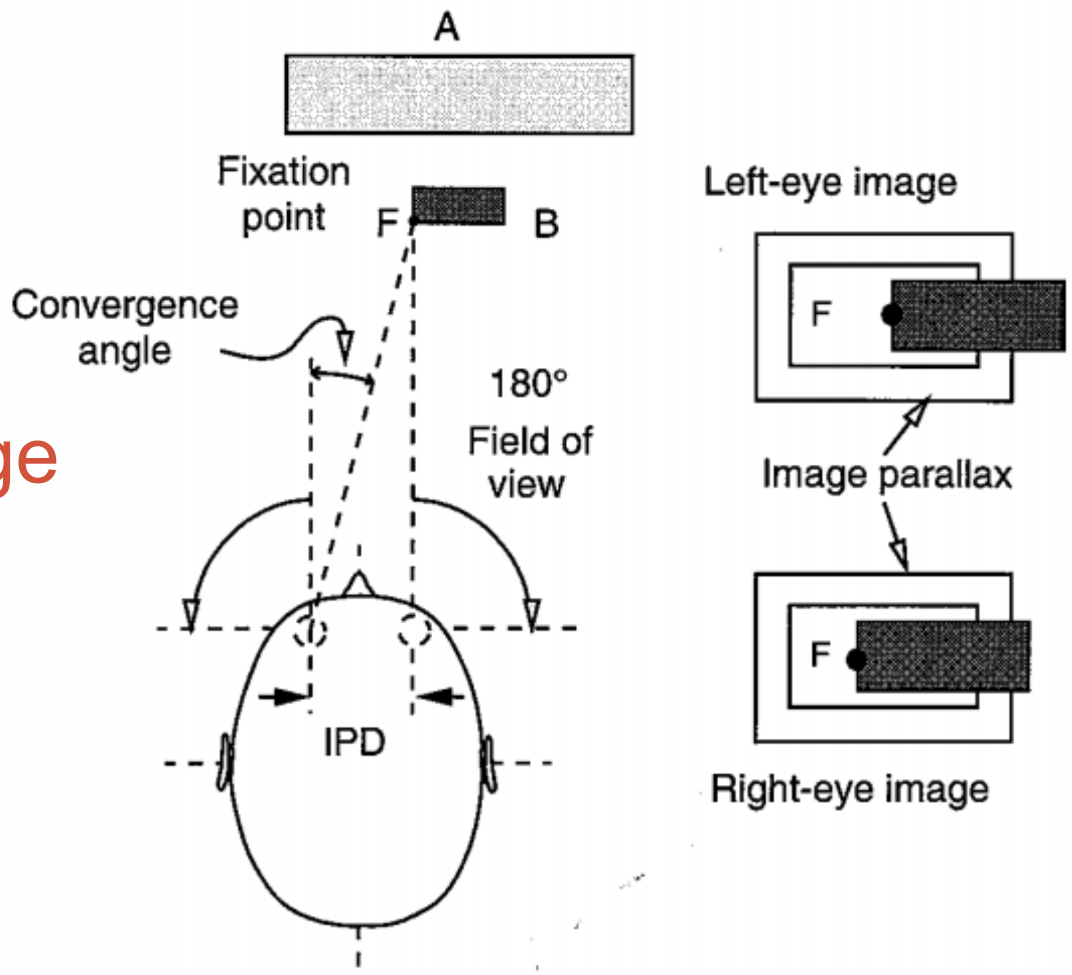
each photorecepter
~ 1 arc min (1/60 of a degree)

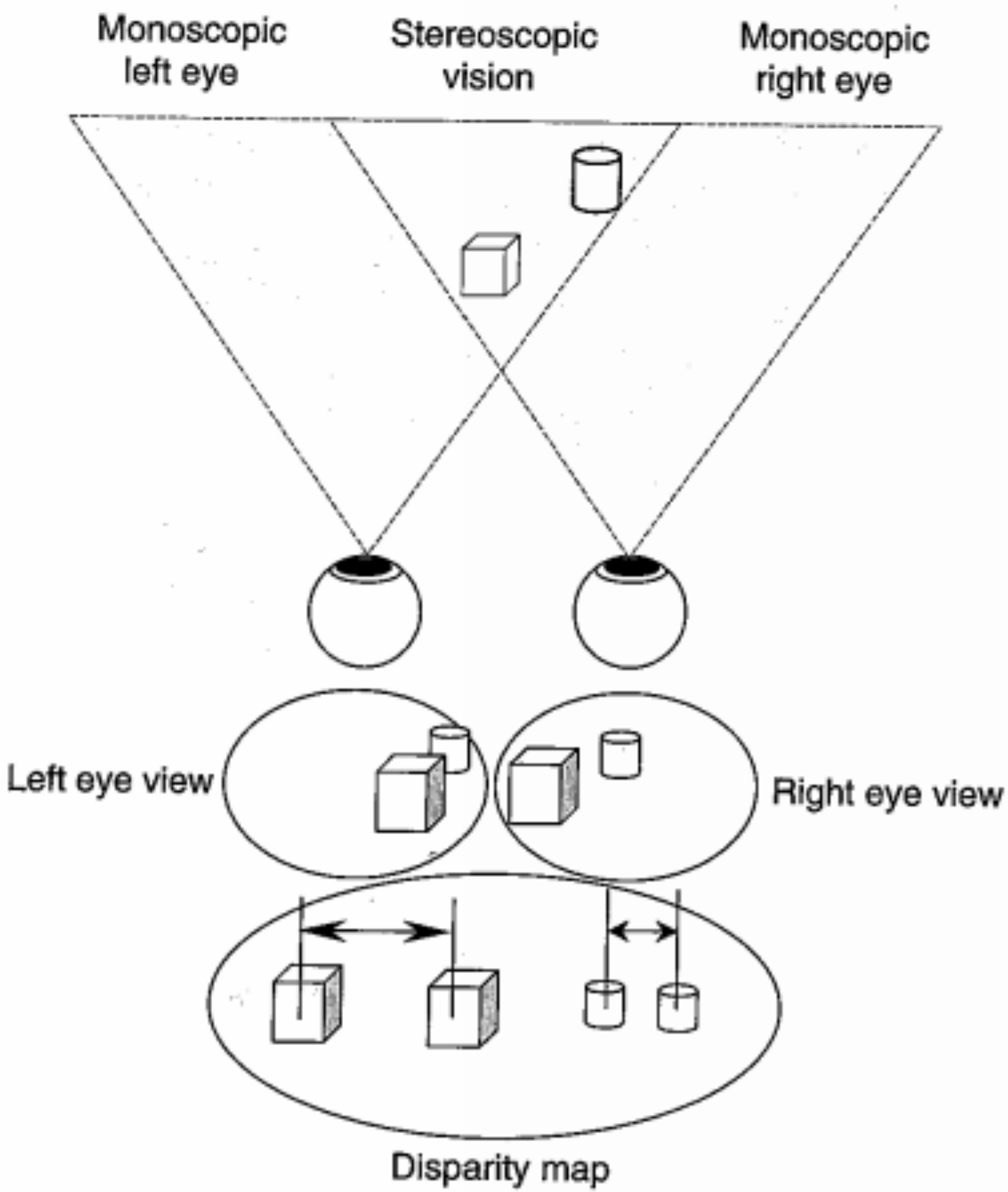


5 arcmin visual angle

Stereo Perception/Stereopsis

- Eyes separated by IPD
  - Inter pupillary distance
  - 5 – 7.5cm (avge. 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

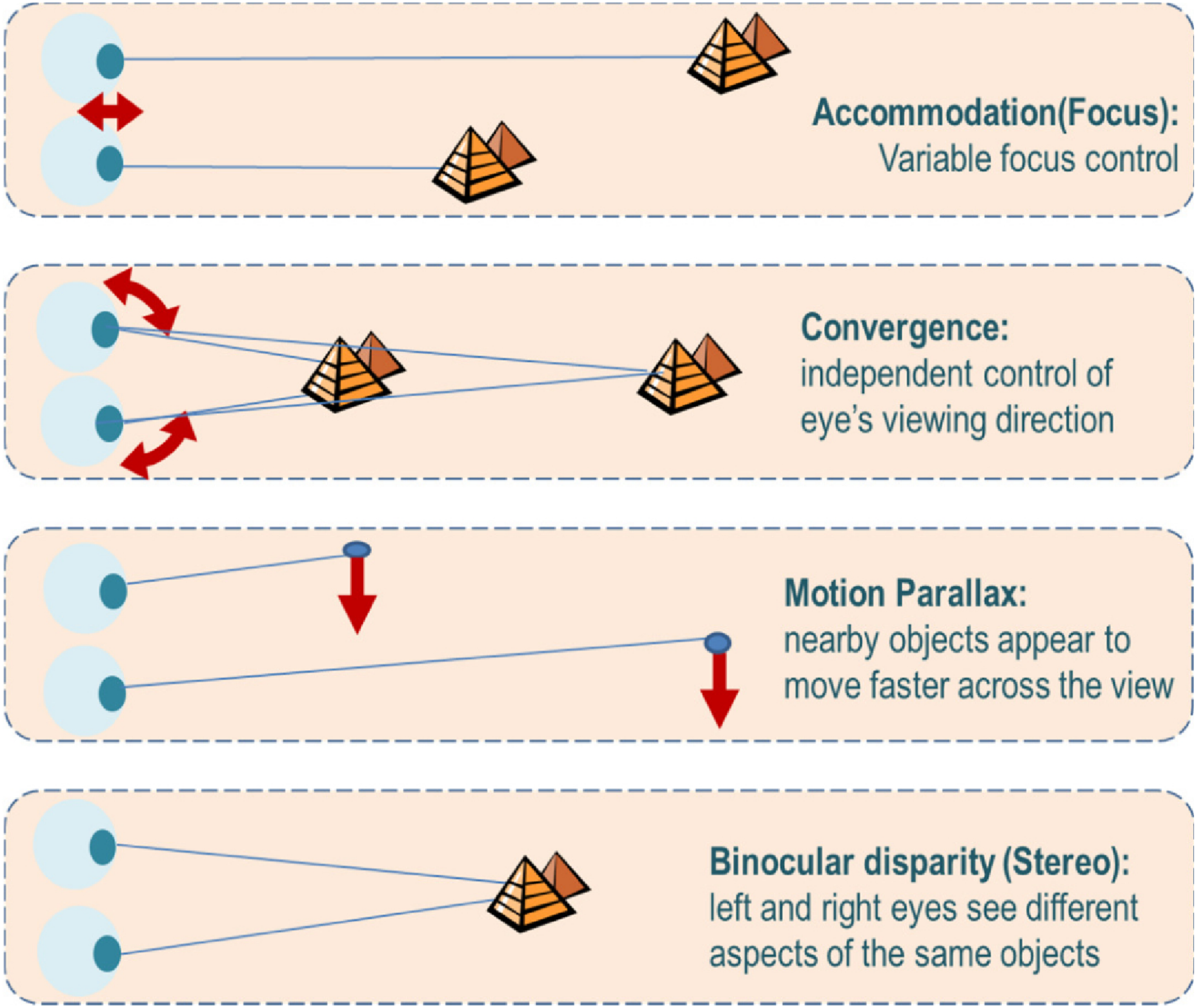
- The visual system uses a range of different Stereoscopic and Monocular cues for depth perception

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!

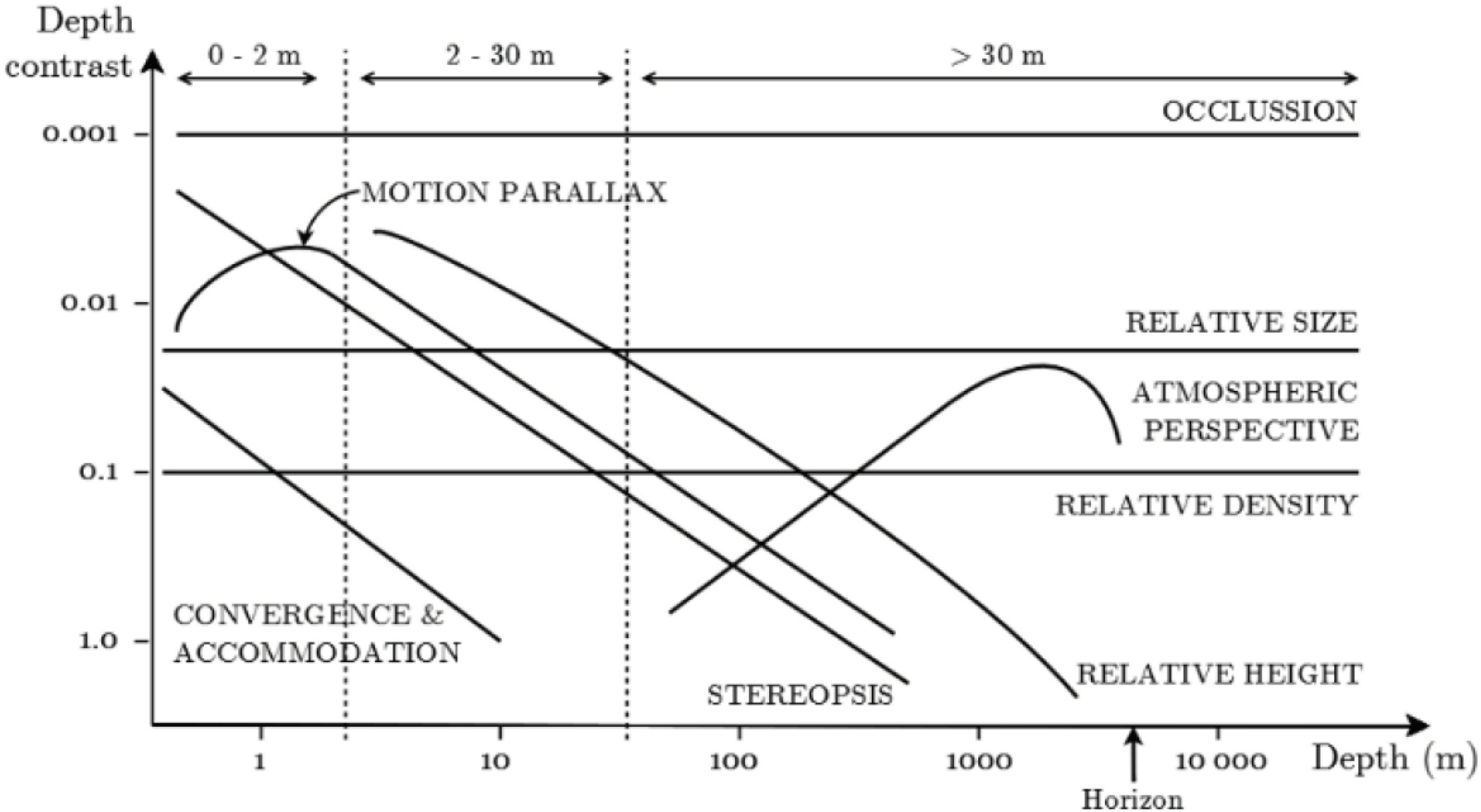
Stereoscopy is important for size and distance evaluation

Common Depth Cues



Depth Perception Distances

Cutting & Vishton, 1995

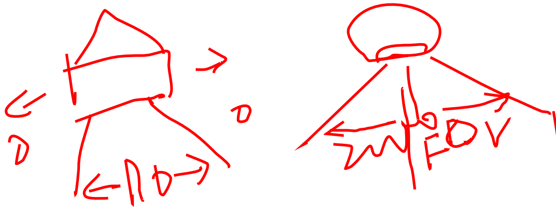


- i.e. convergence/accommodation used for depth perception < 10m

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 HMD



horizontal

vertical

60 up
75 below

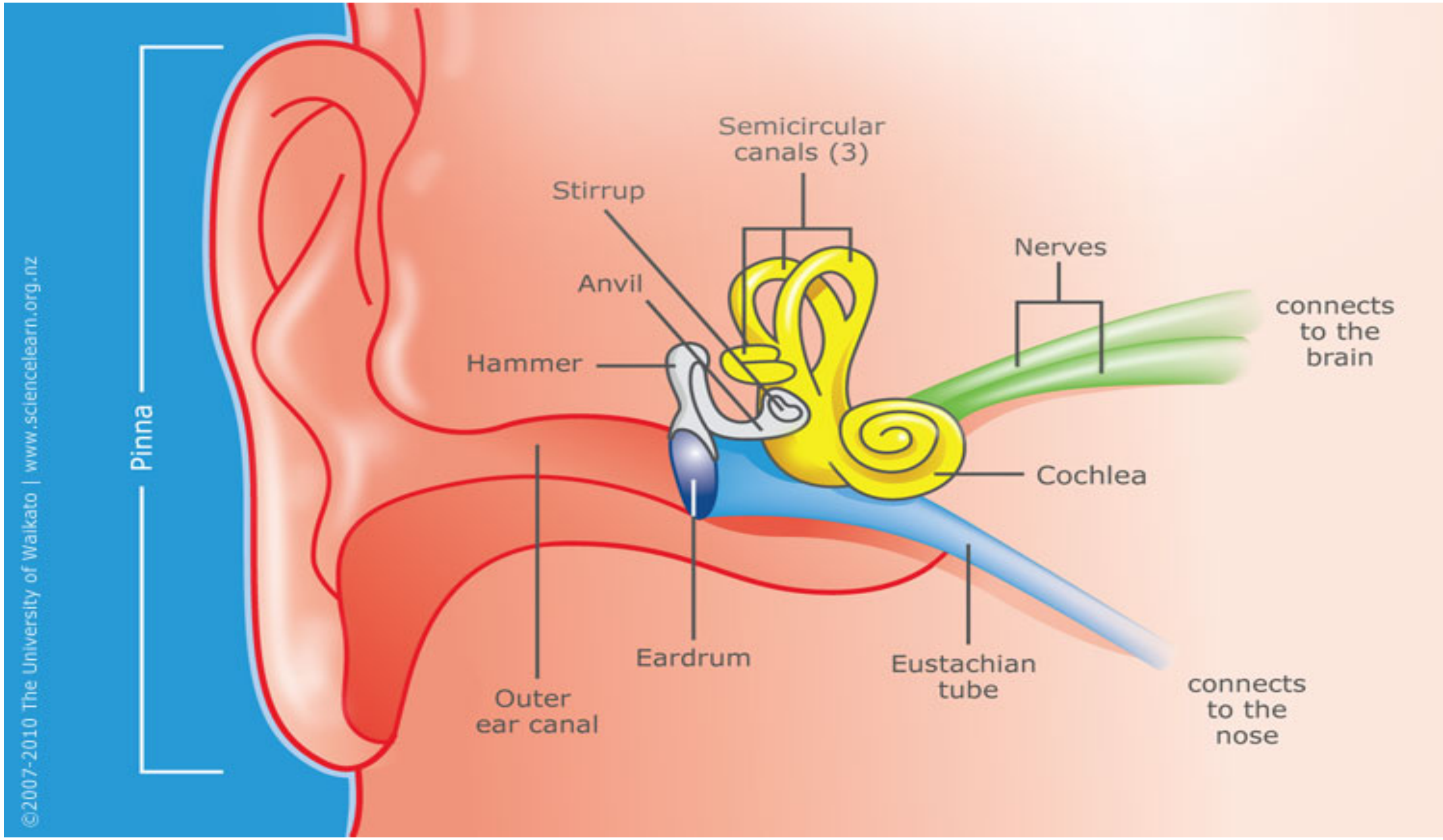
	Human Eyes	HTC Vive
FOV	200° x 135°	110° x 110°
Stereo Overlap	120°	110°
Resolution	30,000 x 20,000	2,160 x 1,200
Pixels/inch	>2190 (100mm to screen)	456
Update	60 Hz	90 Hz

<<

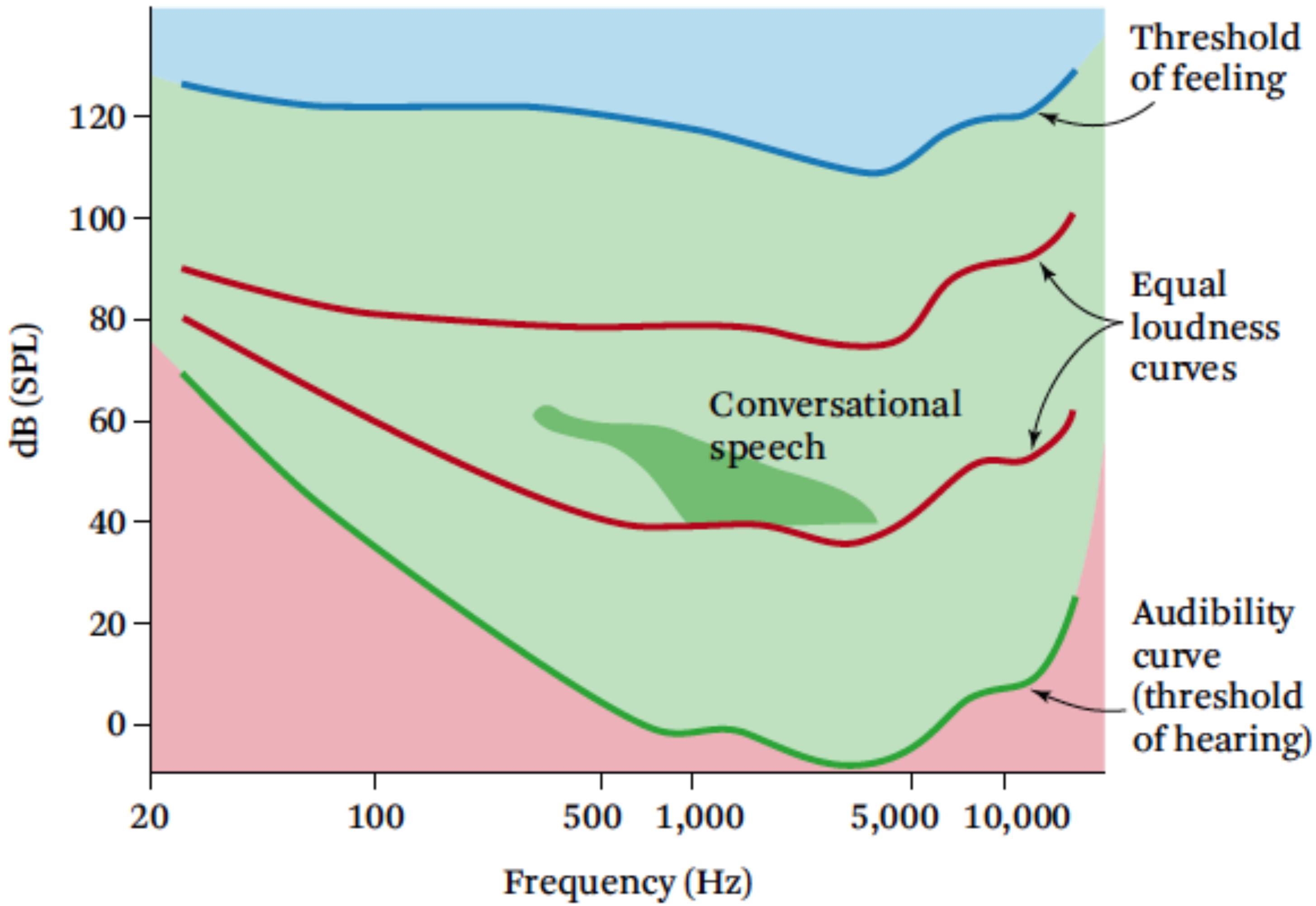
See http://doc-ok.org/?p=1414
http://www.clarkvision.com/articles/eye-resolution.html
http://wolfcrow.com/blog/notes-by-dr-optoglass-the-resolution-of-the-human-eye/


Hearing

Anatomy of the Ear



Auditory Thresholds



- Humans hear frequencies from 20 – 22,000 Hz
- Most everyday sounds from 80 – 90 dB

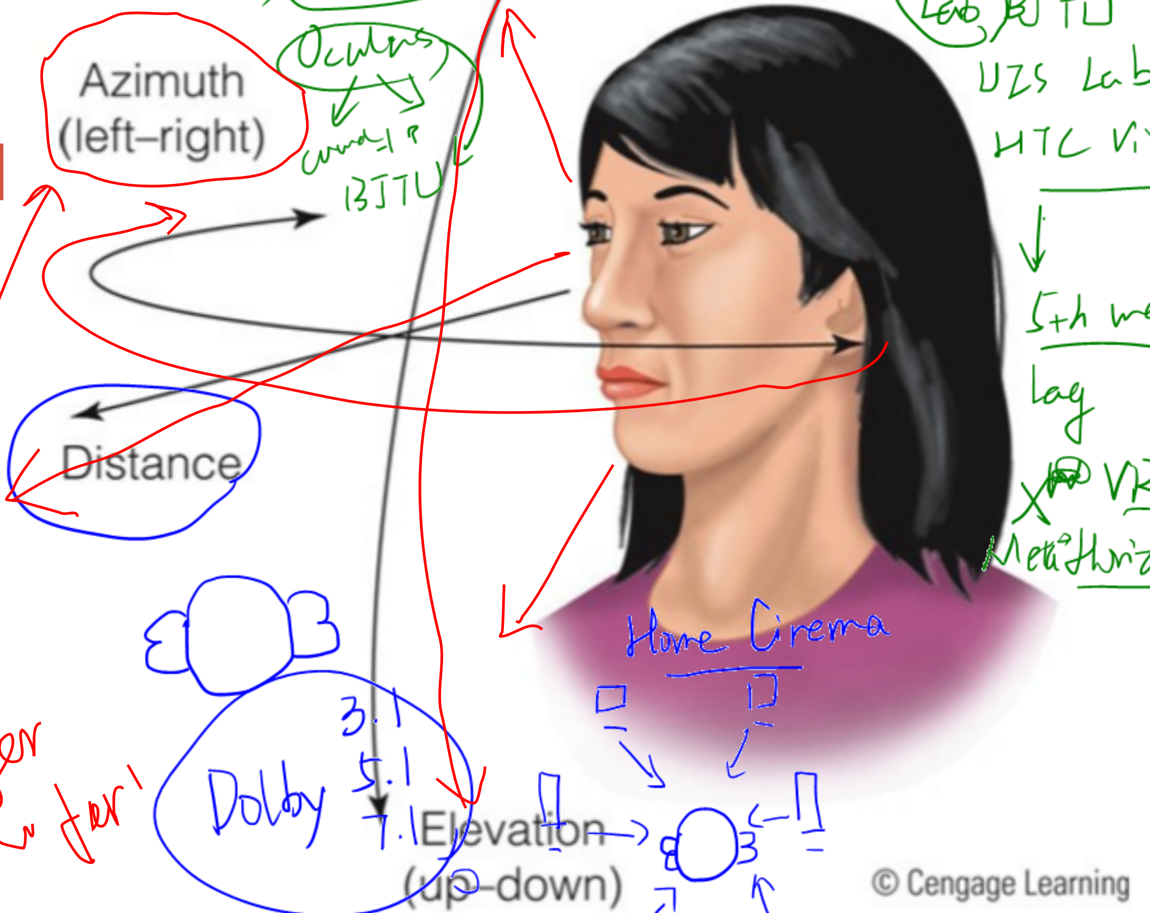
1 → world → show? → ① VR ②

Sound Localization

sight → Unreal 5
audio → HRTF
17:00
17 10
back

front

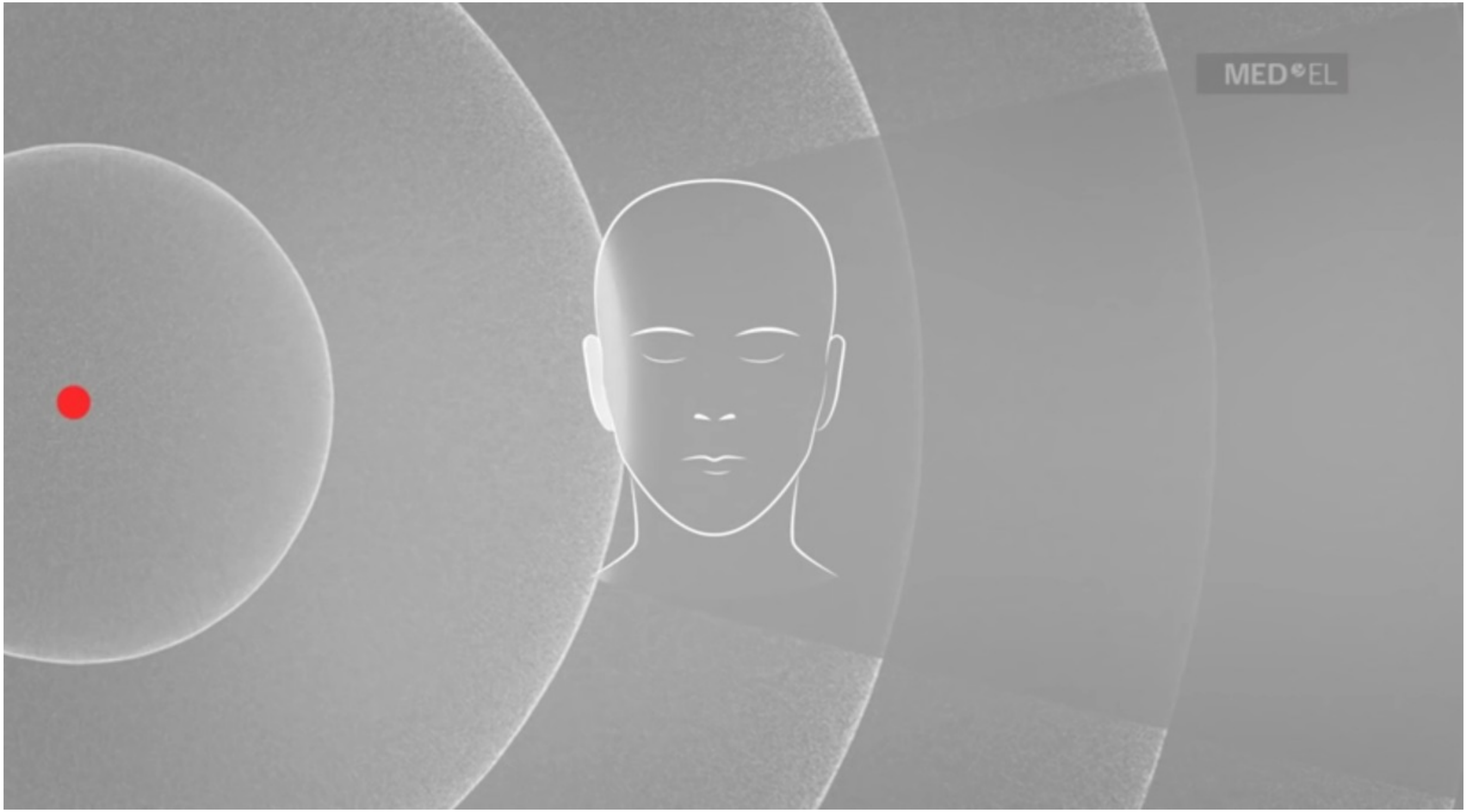
- Humans have two ears
  - localize sound in space
- Sound can be localized using 3 coordinates
  - Azimuth, elevation, distance



HTC Vive
Oculus
BJTU
2 Persons ① ②
VR E
Lab BJTU
UZS Lab
HTC Vive
5th week
lag
VR chat
Metahorizon
Home Cinema

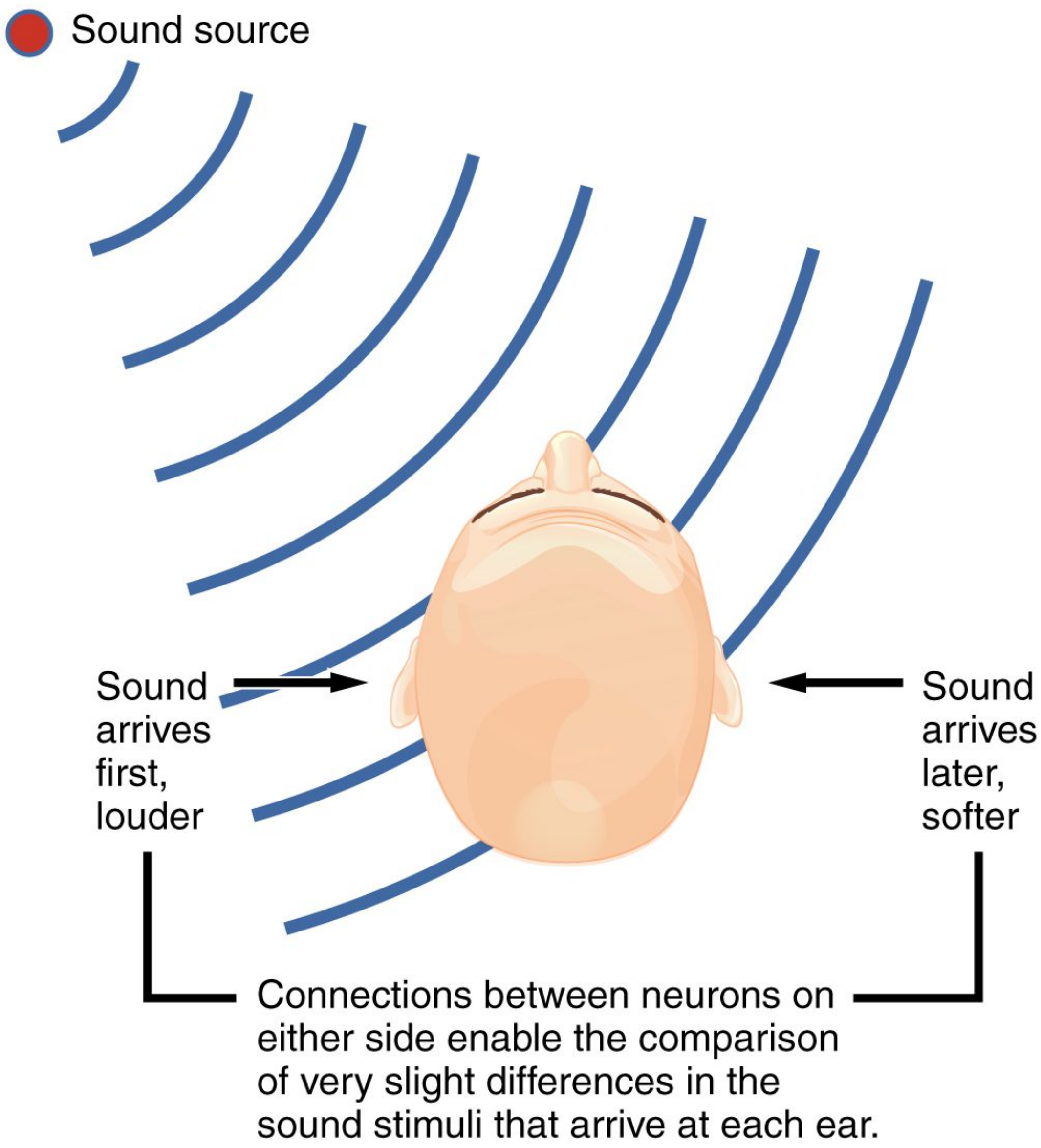
front
back
back
left
right
stronger
slower
Q: computer generate audio
Dolby 3.1 5.1 7.1
HRTF
Head-Related Transfer Function

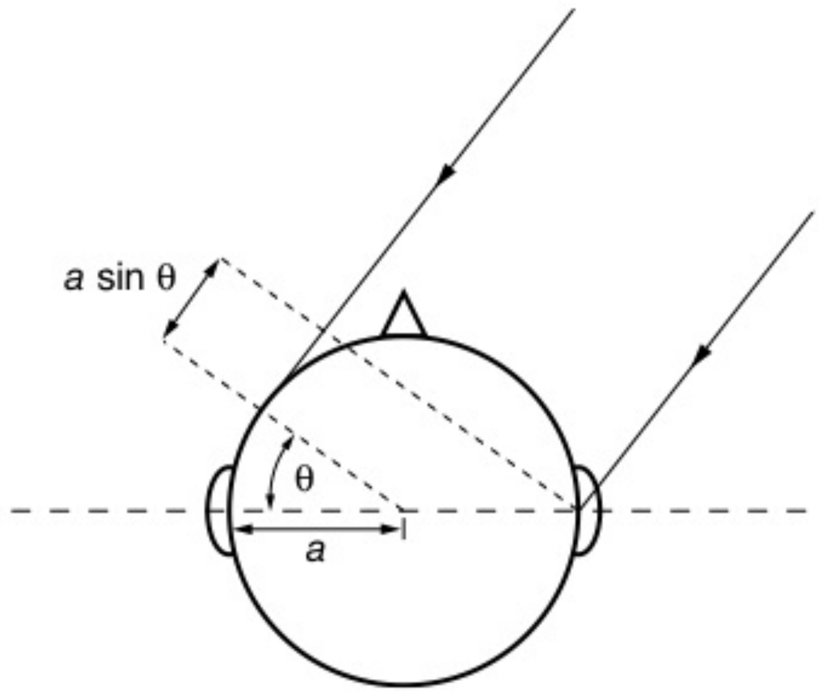
Sound Localization



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

Sound Localization (Azimuth Cues)



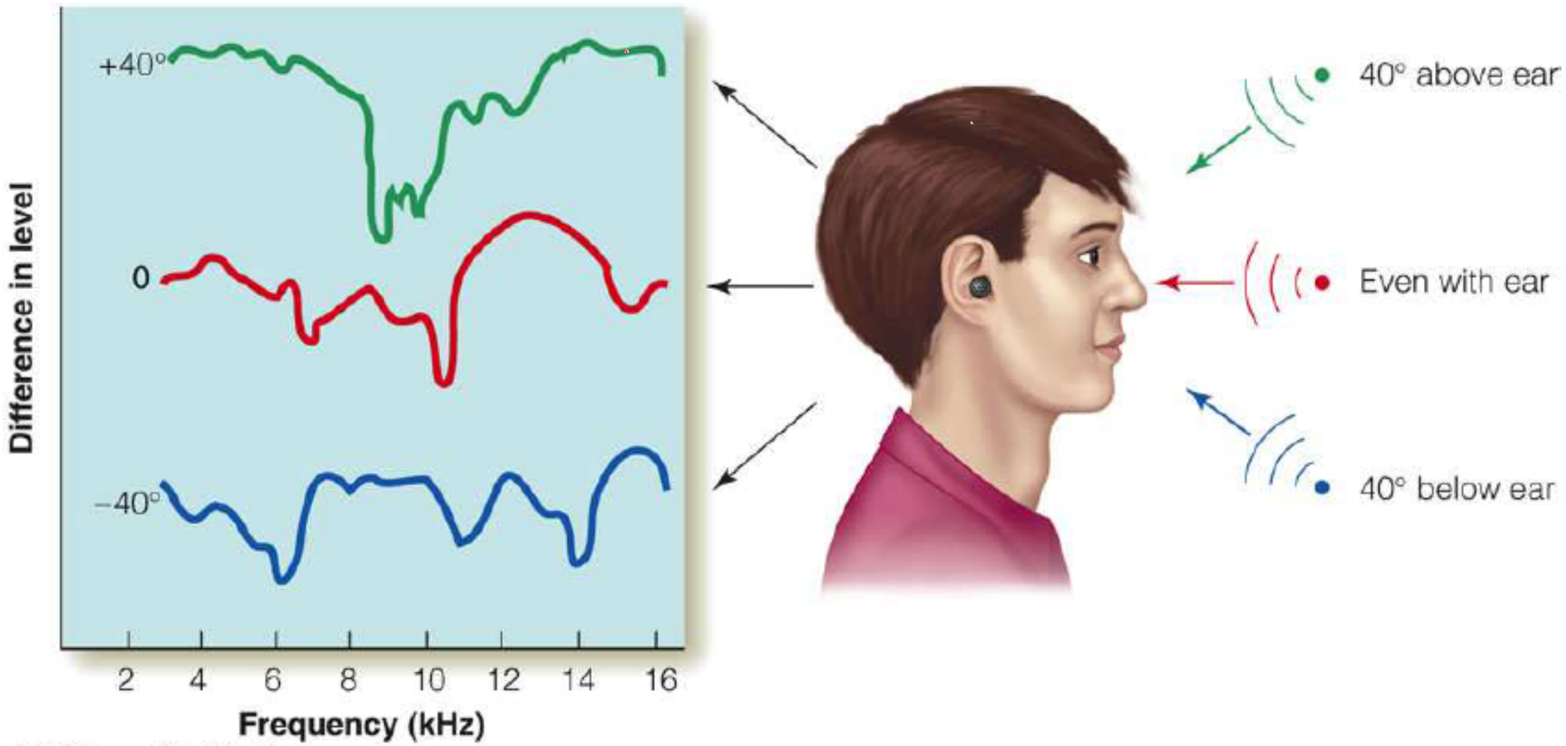


Interaural Time Difference

HRTF (Elevation Cue)

omnitone / gugle

- 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

more
back → front

- 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)

brain → mind → visual → front
back

① open eyes

homework → video → HRTF

② close eyes

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

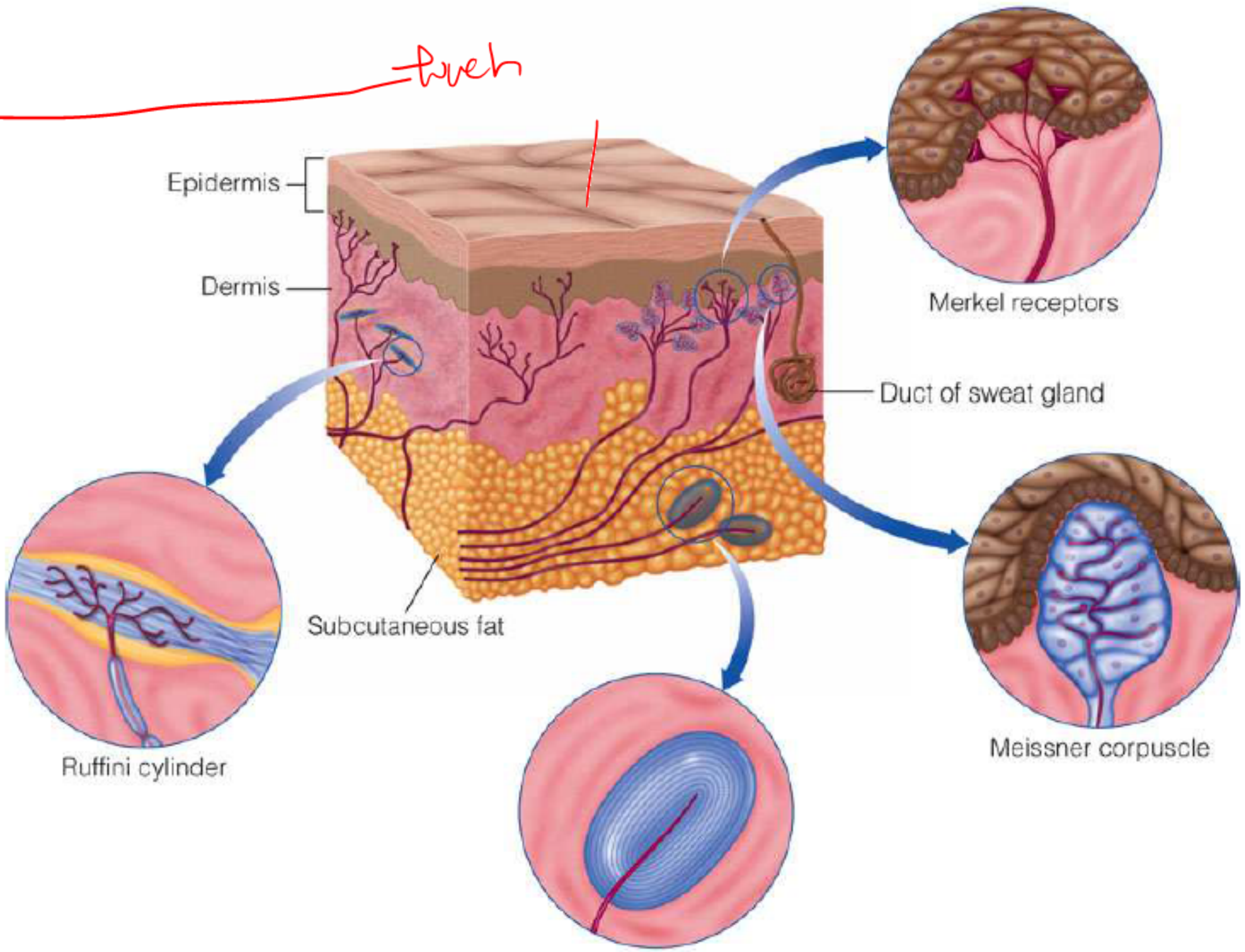
online

- 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

tuch



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

VR Glove

Design Interaction Devices

push harder

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

10 times

20 time

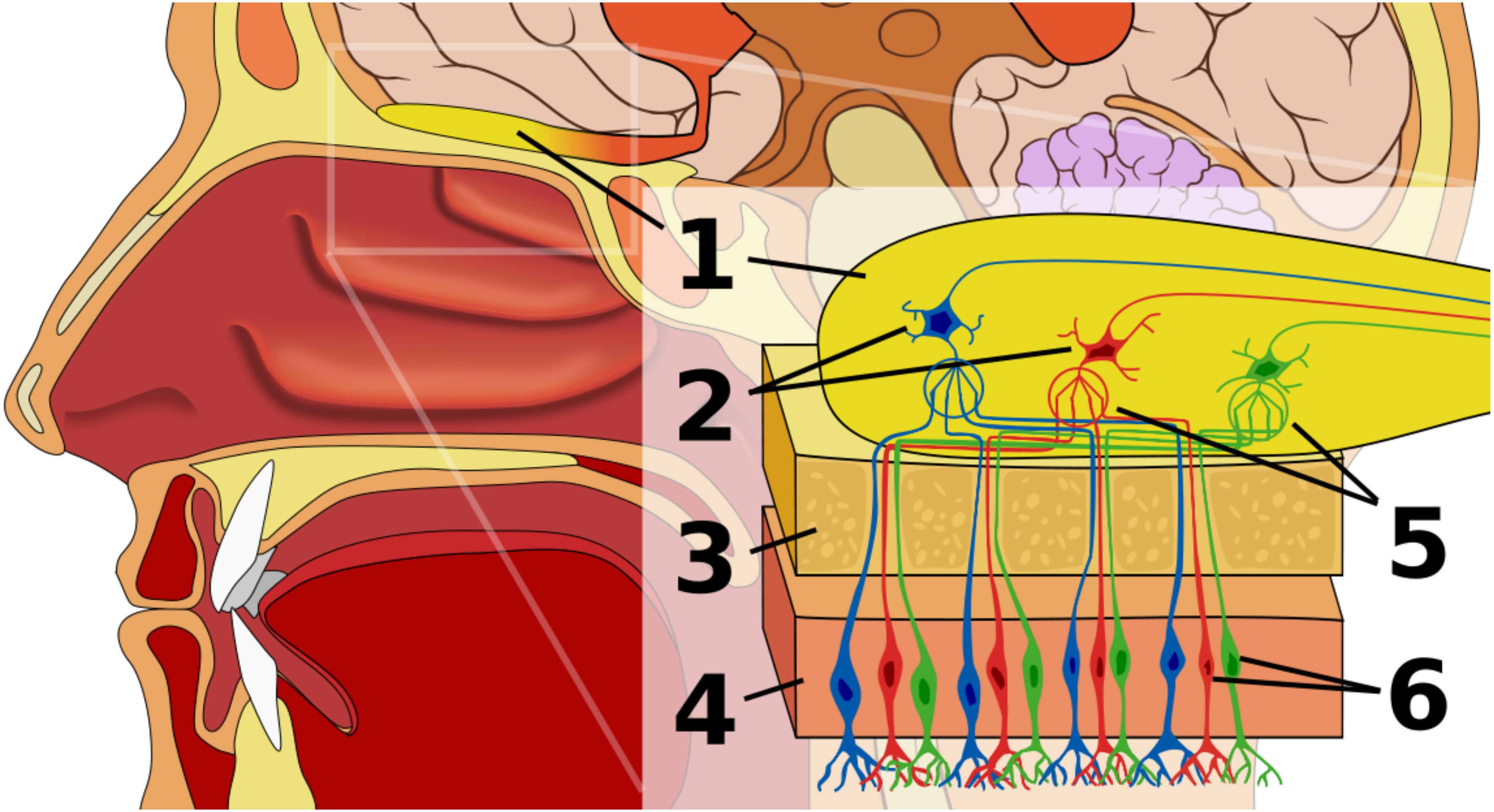
http://faculty.washington.edu/chudler/chsense.html

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

17:45 ✓

25

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

Sweet Sour Salty Bitter Umami

- 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.

Glove → Haptic → Sensation → wear Glove with you
⇓
not real

Unreal E → Visual

HRTF → Audio

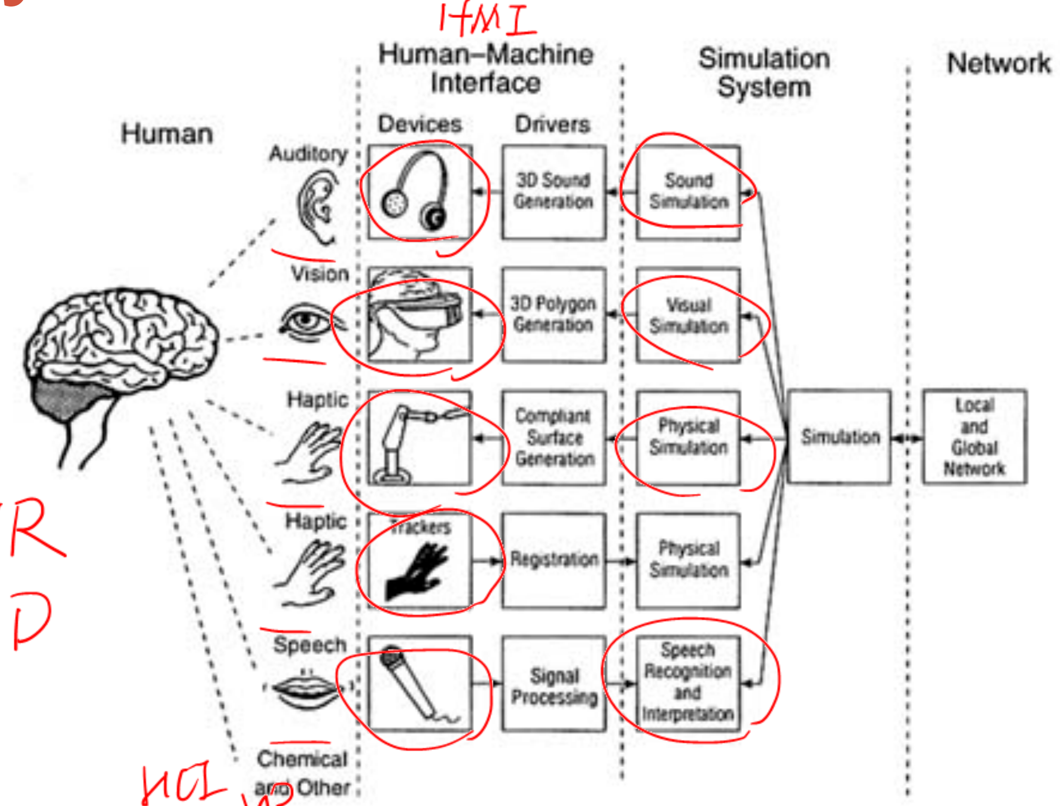
↓
Modern Solution

VR TECHNOLOGY

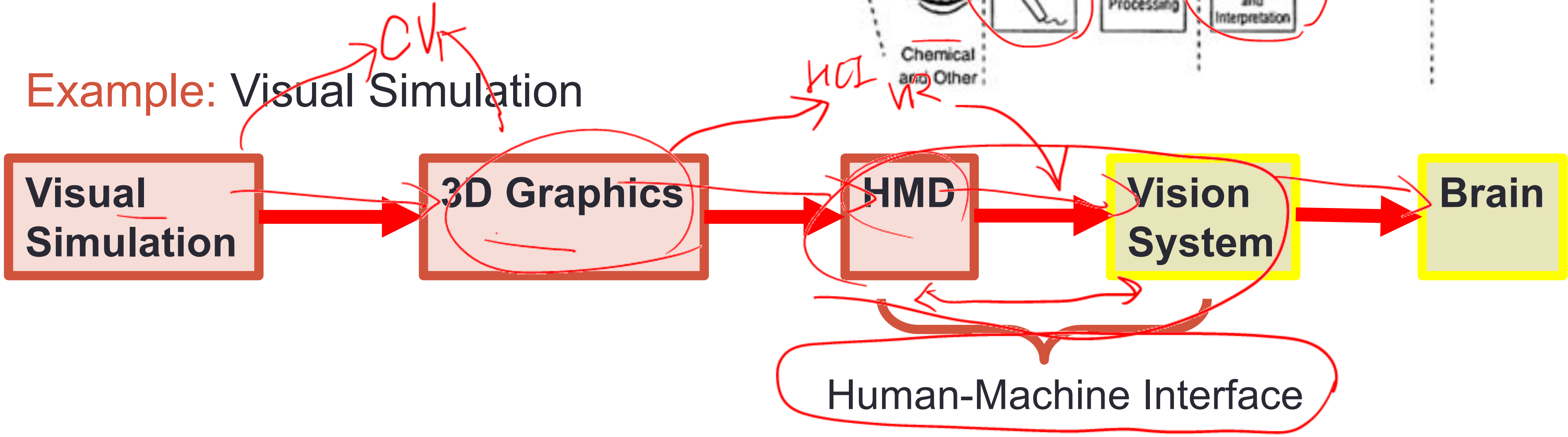
Using Technology to Stimulate Senses

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

VR
3D



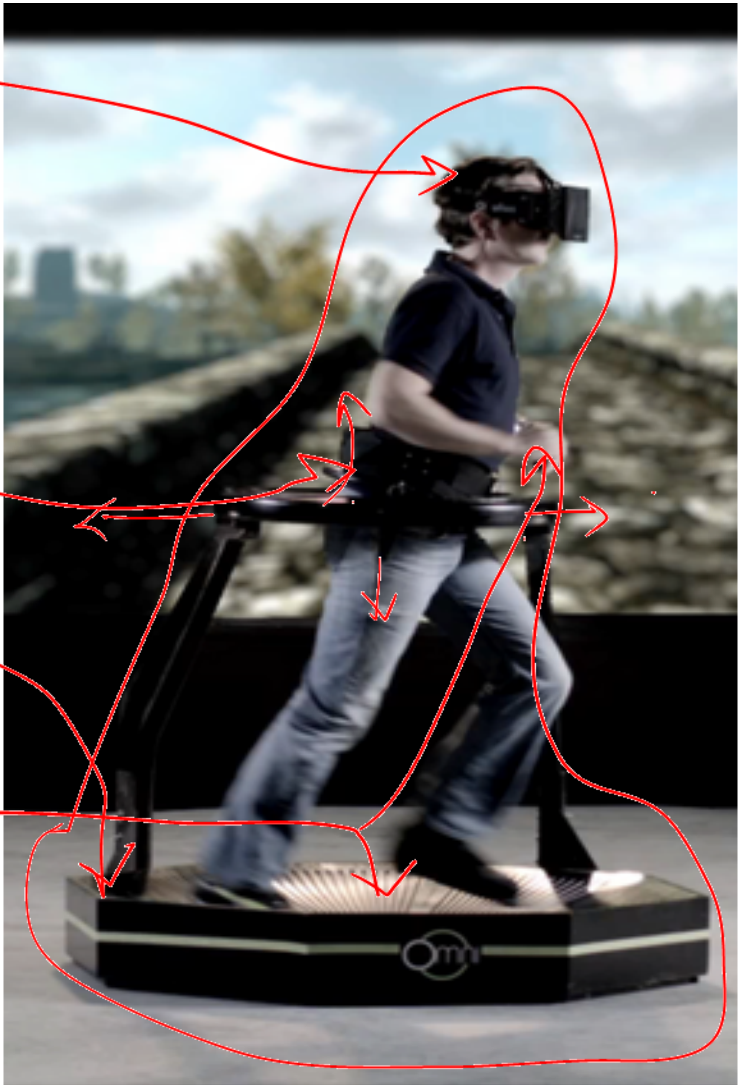
Example: Visual Simulation



Key Technologies for VR System

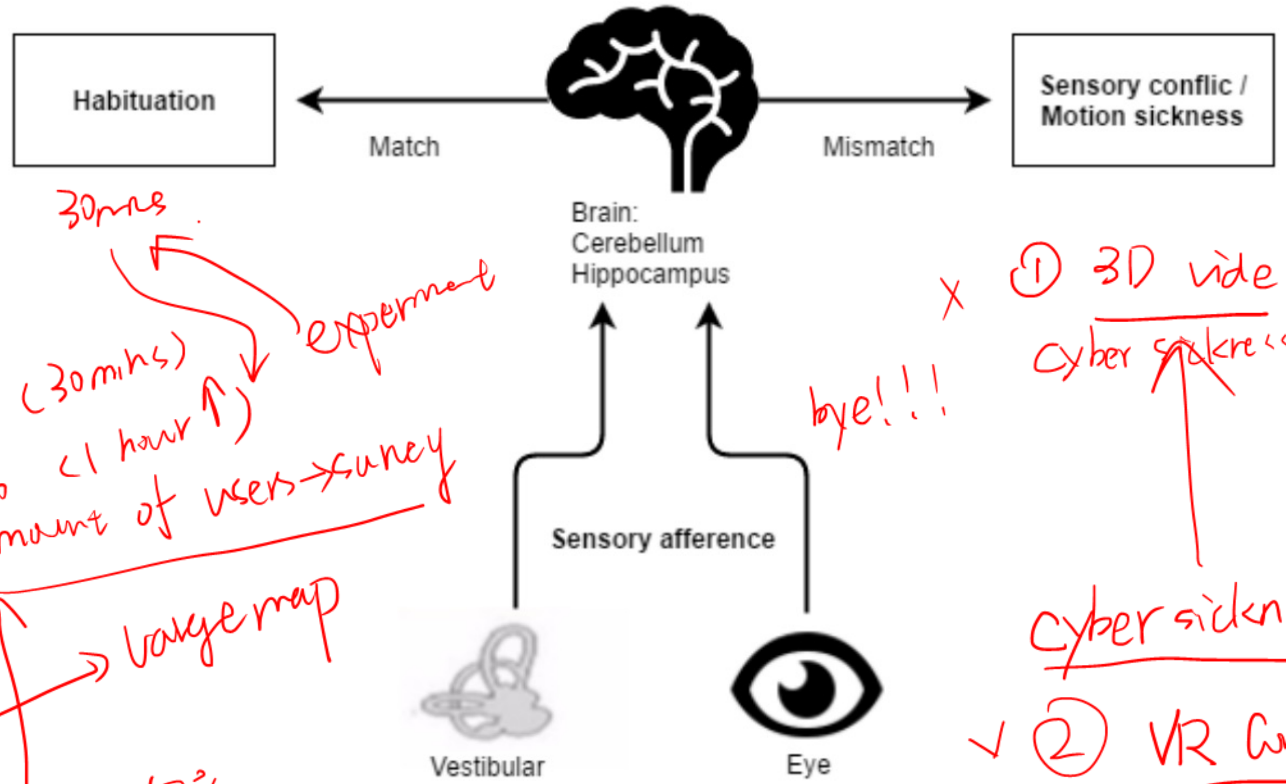
- Visual Display
  - Stimulate visual sense
- Audio/Tactile Display
  - Stimulate hearing/touch
- Tracking
  - Changing viewpoint
  - User input
- Input Devices
  - Supporting user interaction

Tell



What Happens When Senses Don't Match?

break
app → conti
rest
30mins rest
30mins
experiment

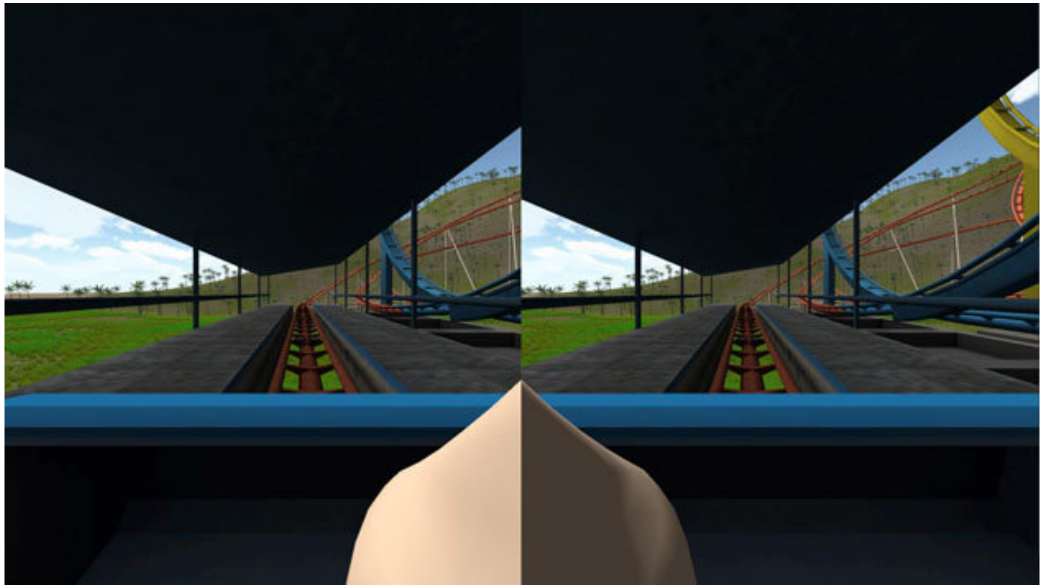


UCS-Lab
Cybersickness → 15% (30mins)
40% (<1 hour↑)
amount of users → survey
VR movement
content → large map
1. move
2.
3.
small map
58%
bye!!!
① 3D video → 1 → 2
cyber sickness
3D cinema movie (Transformer 3)
Close eyes 1 hour
cyber sickness
② VR Content → 1 → 2

- 20-30% VR users experience motion sickness
- Sensory Conflict Theory
  - Visual cues don't match vestibular cues
    - Eyes – "I'm moving!", Vestibular – "No, you're not!"

Avoiding Motion Sickness

- Better VR experience design
  - More natural movements
- Improved VR system performance
  - Less tracking latency, better graphics frame rate
- Provide a fixed frame of reference
  - Ground plane, vehicle window
- Add a virtual nose
  - Provide peripheral cue
- Eat ginger
  - Reduces upset stomach



5 Key Technical Requirements for Presence

- Persistence
  - > 90 Hz refresh, < 3 ms persistence, avoid retinal blur
- Optics
  - Wide FOV > 90 degrees, comfortable eyebox, good calibration
- Tracking
  - 6 DOF, 360 tracking, sub-mm accuracy, no jitter, good tracking volume
- Resolution
  - Correct stereo, > 1K x 1K resolution, no visible pixels
- Latency
  - < 20 ms latency, fuse optical tracking and IMU, minimize tracking loop

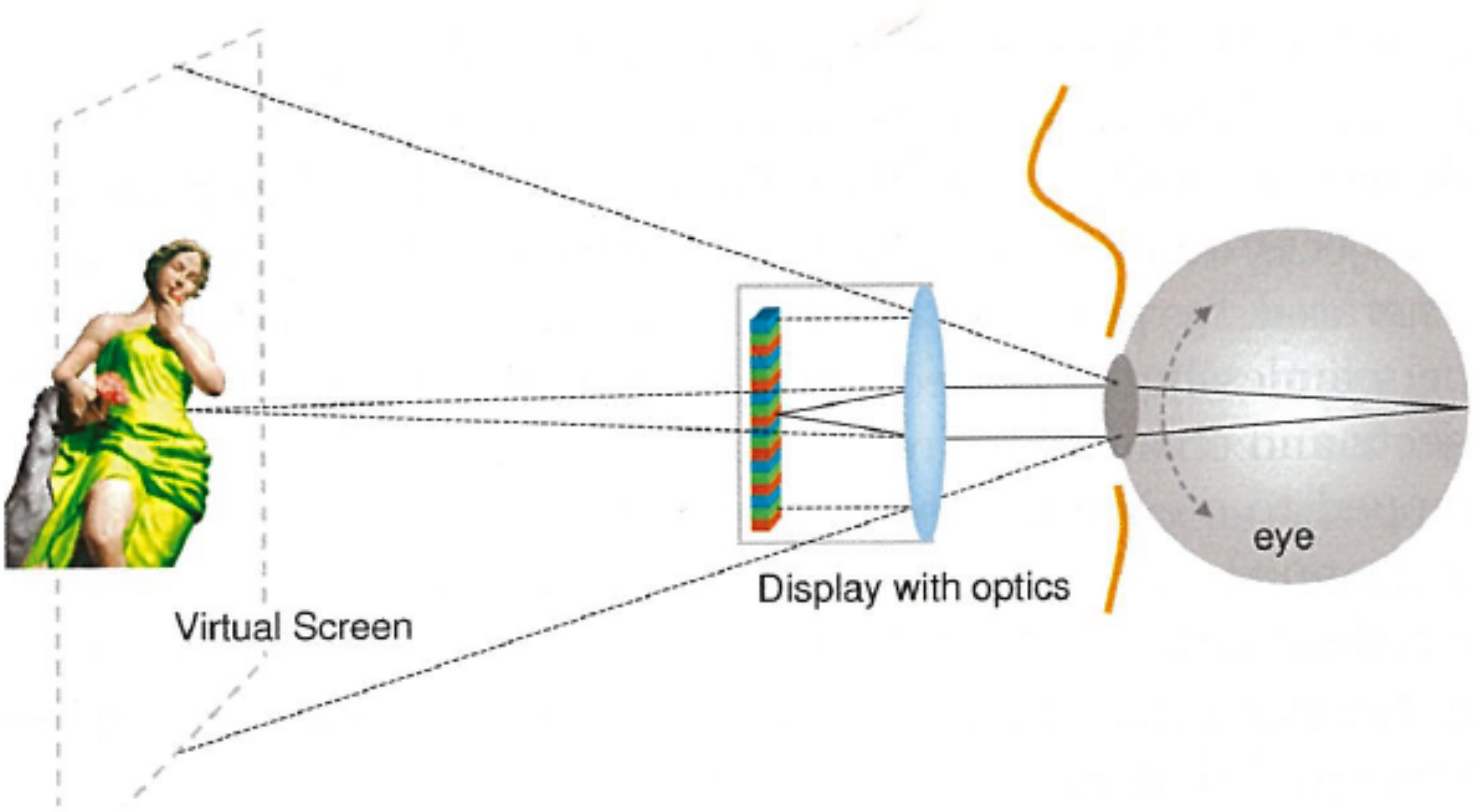
http://www.roadtovr.com/oculus-shares-5-key-ingredients-for-presence-in-virtual-reality/

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



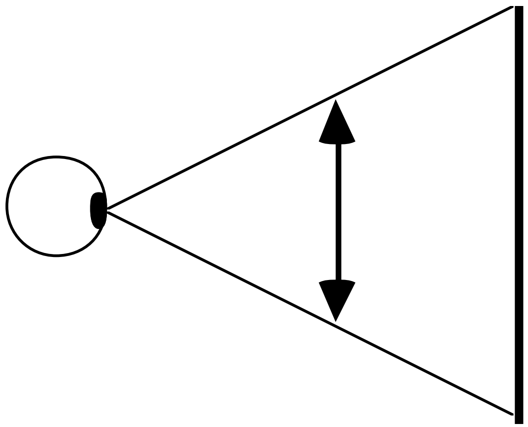
- Use display with optics to create illusion of virtual screen

Key Properties of HMDs

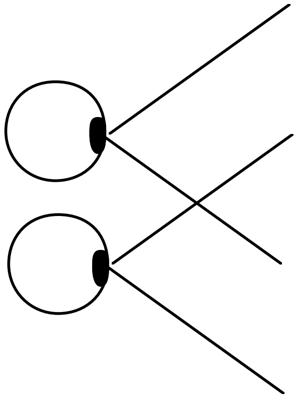
- Lens
  - Focal length, Field of View
  - Occularity, Interpupillary distance
  - Eye relief, Eye box
- Display
  - Resolution, contrast
  - Power, brightness
  - Refresh rate
- Ergonomics
  - Size, weight
  - Wearability

Field of View

Monocular FOV is the angular subtense of the displayed image as measured from the pupil of one eye.



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



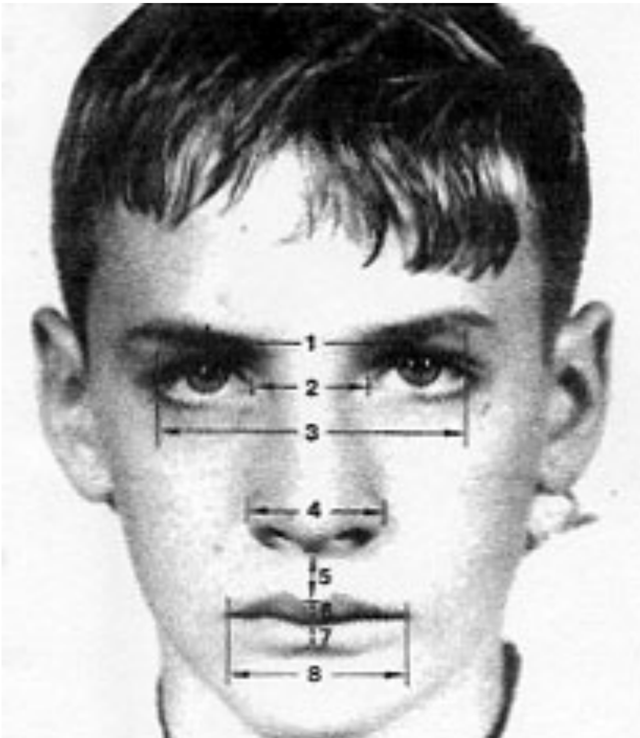
Binocular(or stereoscopic) FOV refers to the part of the displayed image visible to both eyes.

FOV may be measured horizontally, vertically or diagonally.

Ocularity

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

Interpupillary Distance (IPD)

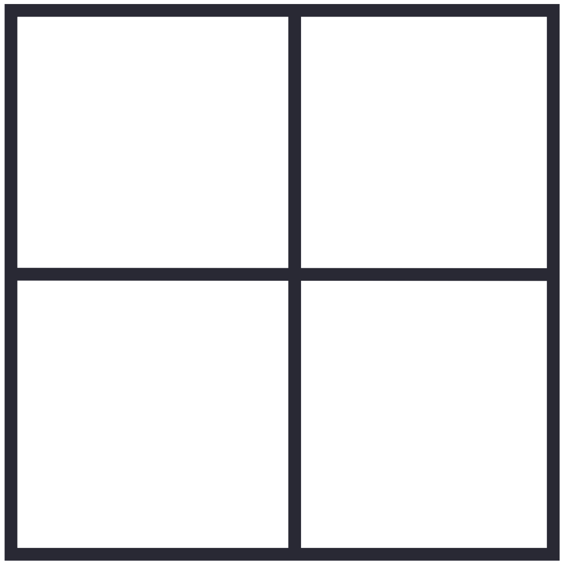


Interpupillary Distance Setting

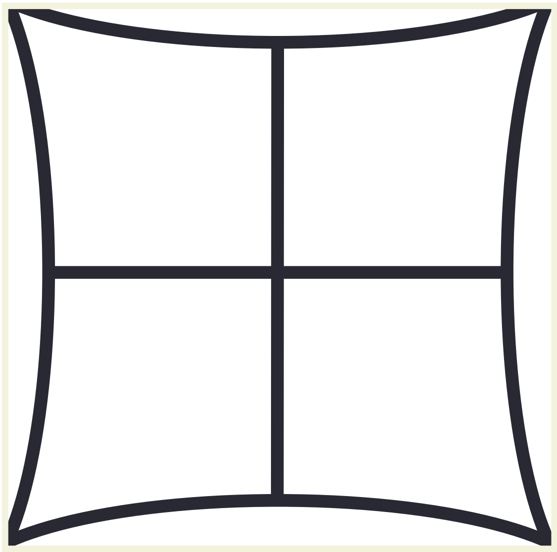
Figure 5

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

Distortion in Lens Optics



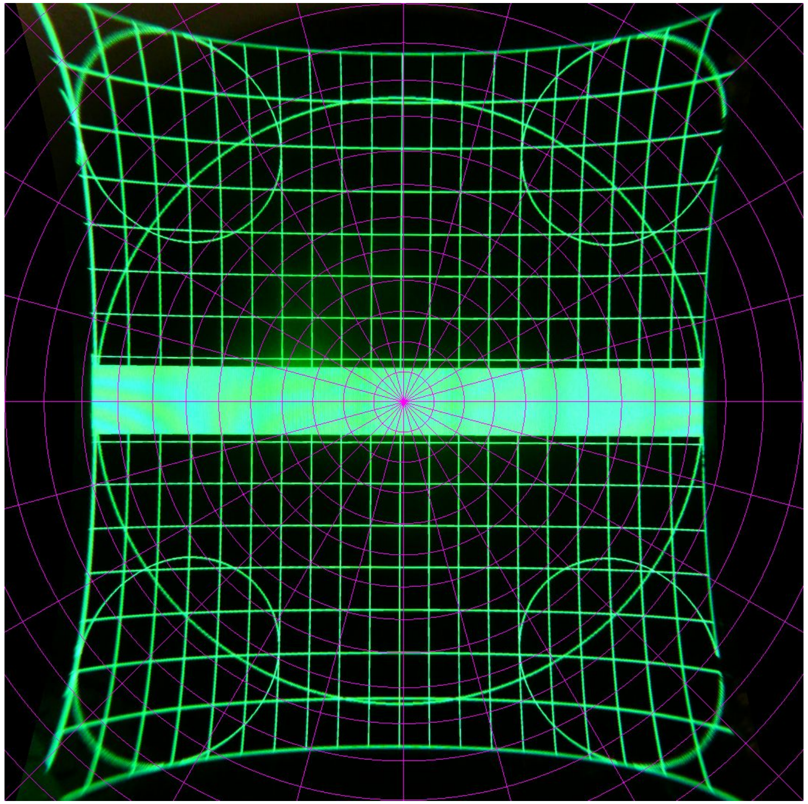
A rectangle



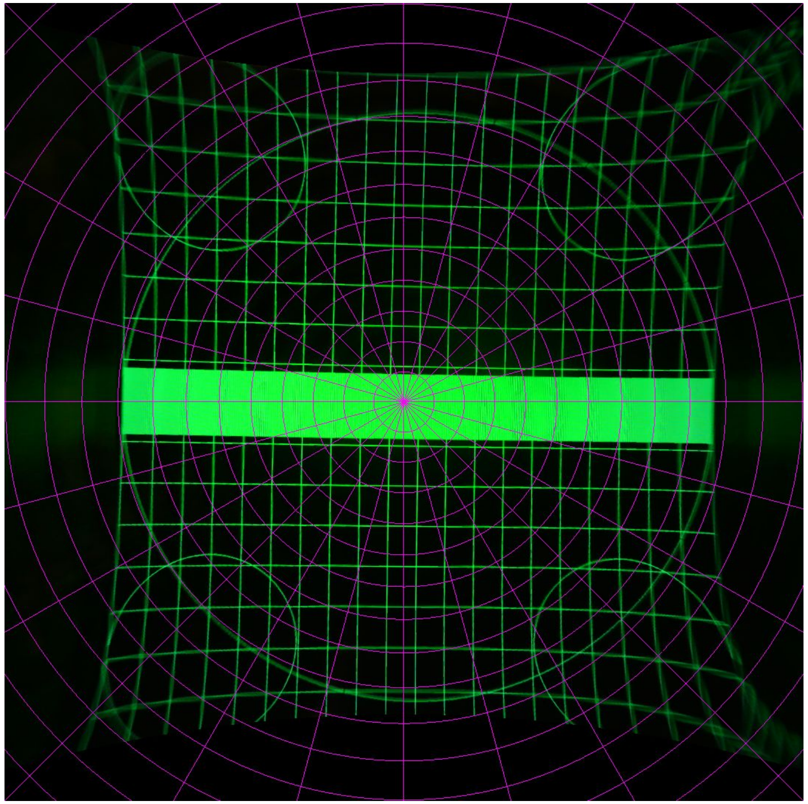
Maps to this

HMD optics distort images shown in them

Example Distortion

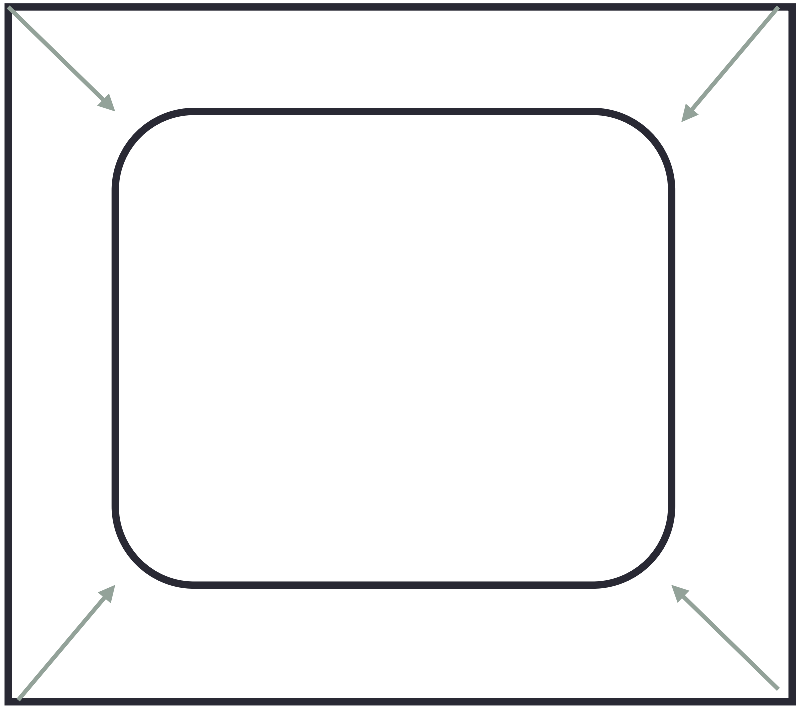


Oculus Rift DK2



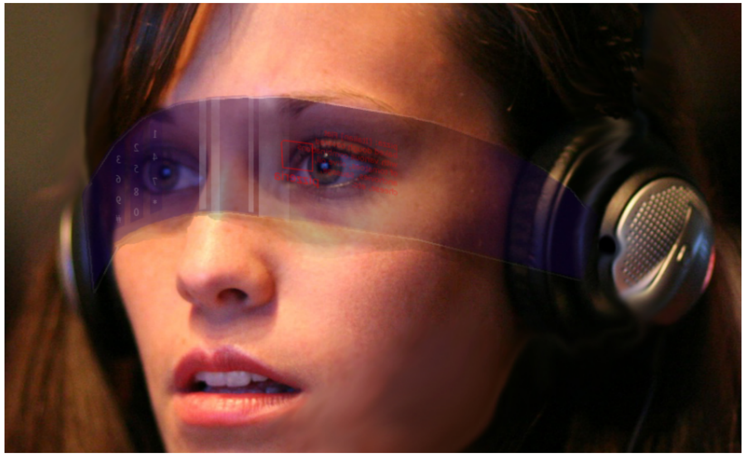
HTC Vive

To Correct for Distortion



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

HMD Design Trade-offs



vs.

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

Oculus Rift

- Cost: $399 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

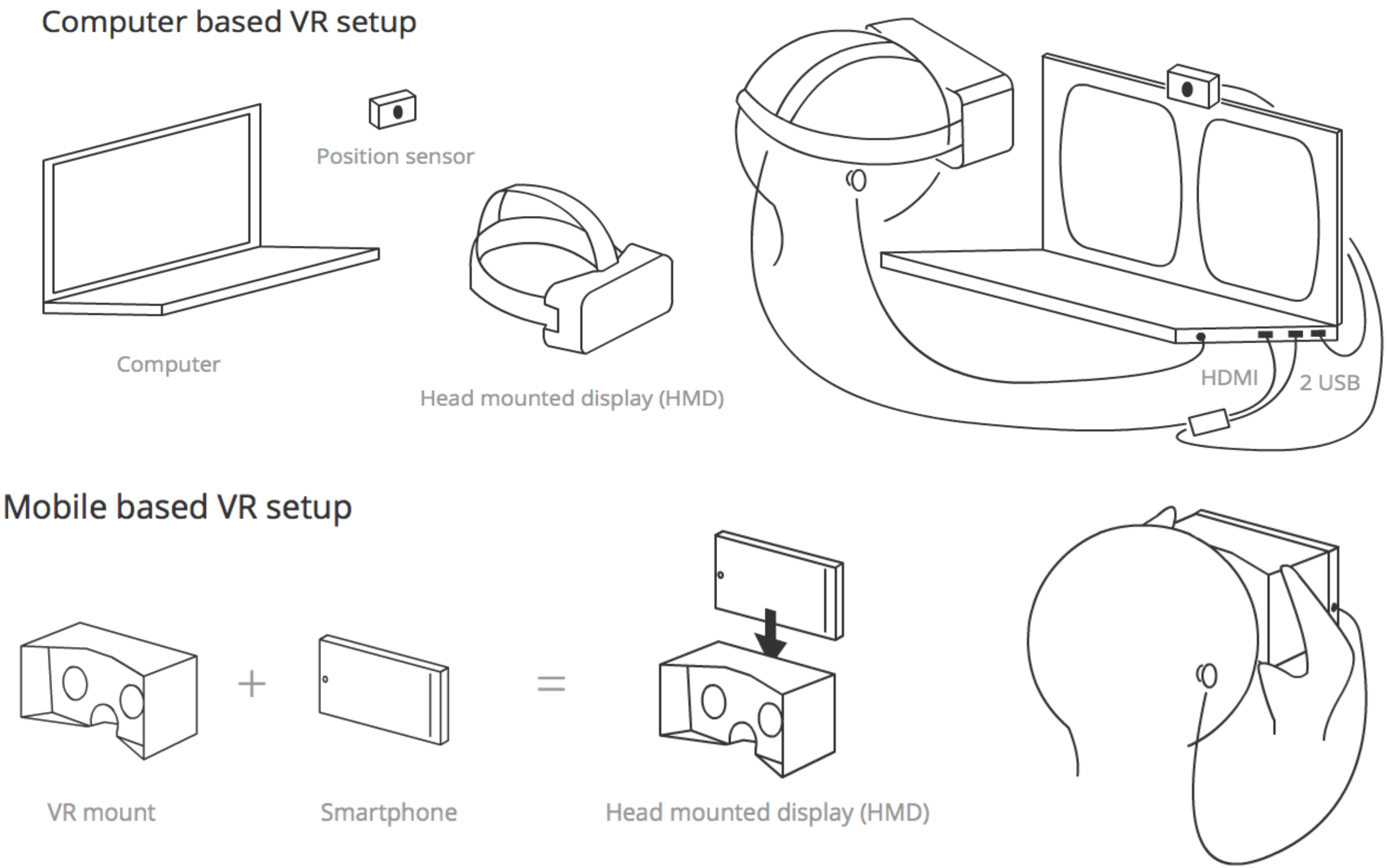
- Samsung 5.7" AMOLED: 1920x1080px, 75Hz
- 2 sets of lenses (for different prescriptions)
- InvenSense 6-axis IMU
- ARM Cortex-M3 MCU
- …

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

Comparison Between HMDs

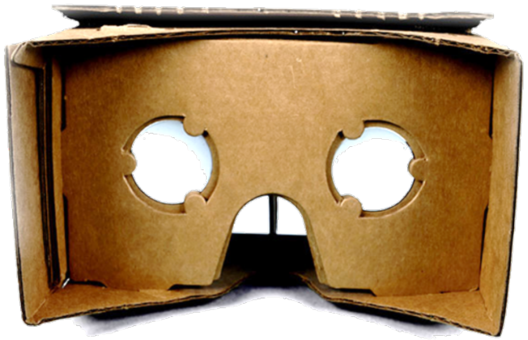
					
Name	**Oculus Rift**	**HTC Vive**	**PlayStation VR**	**StarVR**	**OSVR HDK**
Manufacturer	Oculus VR	HTC, Valve	Sony	Starbreeze	Razer, Sensics
Display	2x OLED	2x OLED	OLED	2x LCD	LCD
Resolution	2160x1200px	2160x1200px	1920x1080px	5120x1440px	1920x1080px
Framerate	90fps	90fps	120fps	60fps	60fps
Field of 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

+



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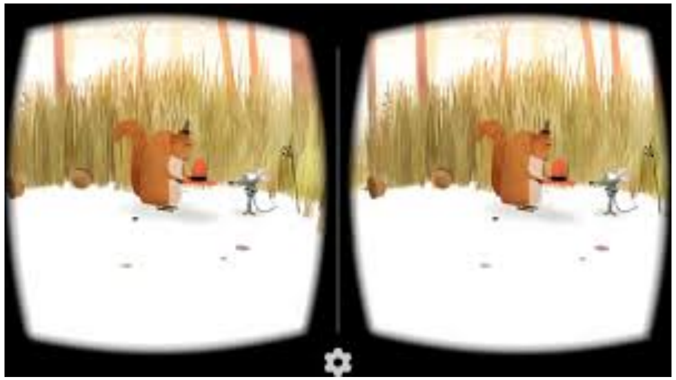


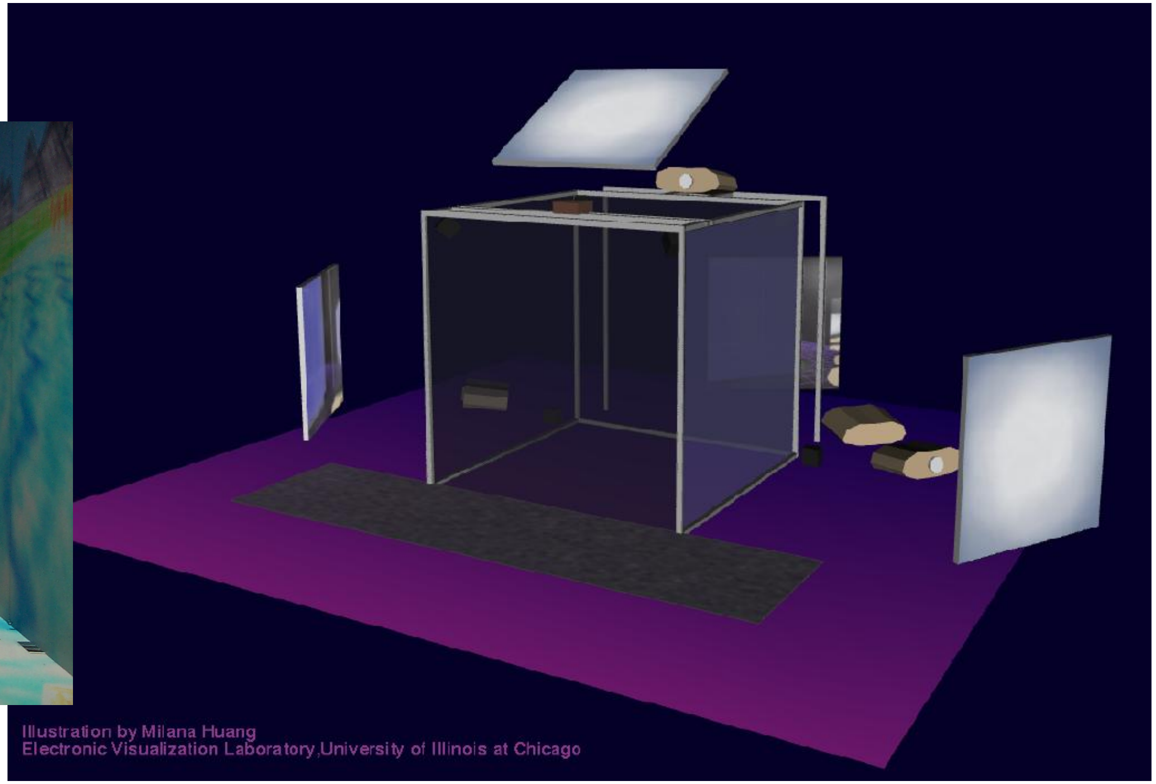
- Released 2014 (Google 20% project)
- >5 million shipped/given away
- Easy to use developer tools

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

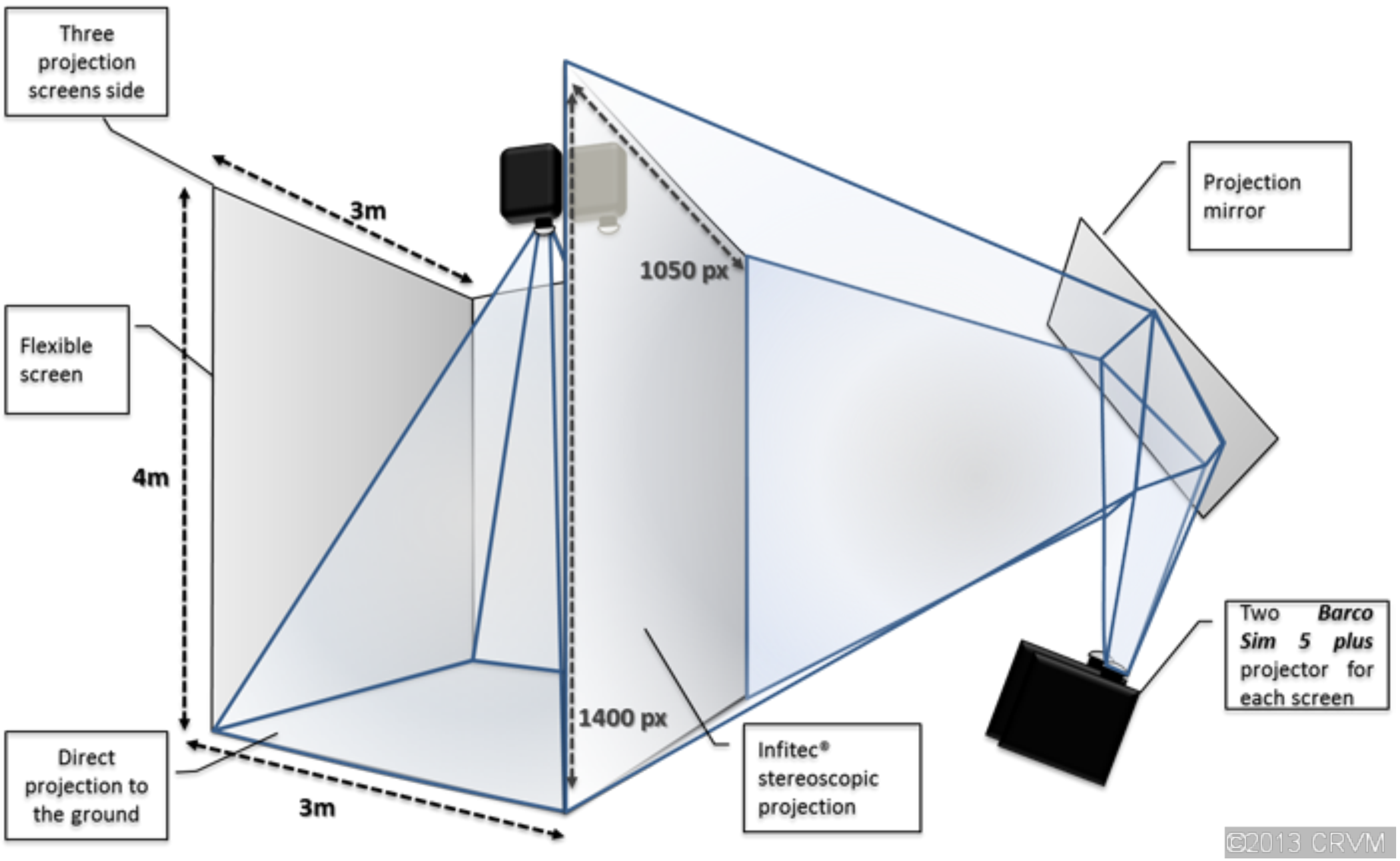
CAVE



- 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

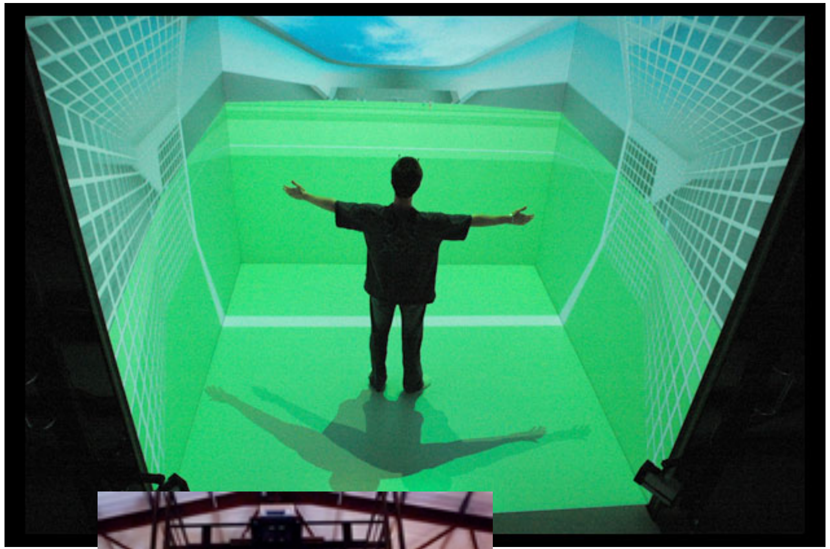


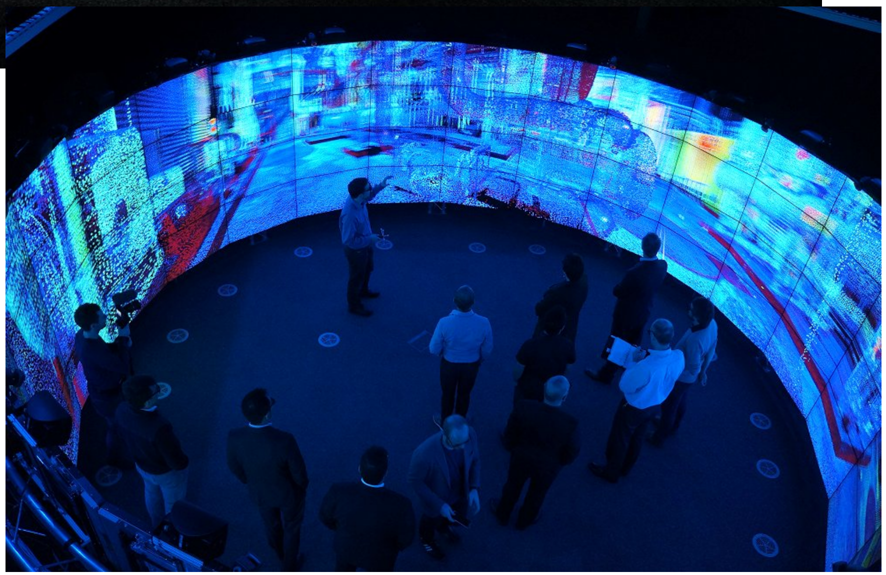
- 4 sides, rear projected stereo images

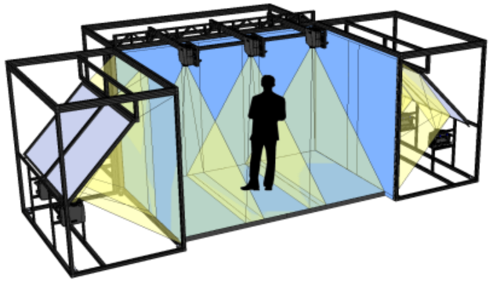
Demo Video – Wisconsin CAVE

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

CAVE Variations

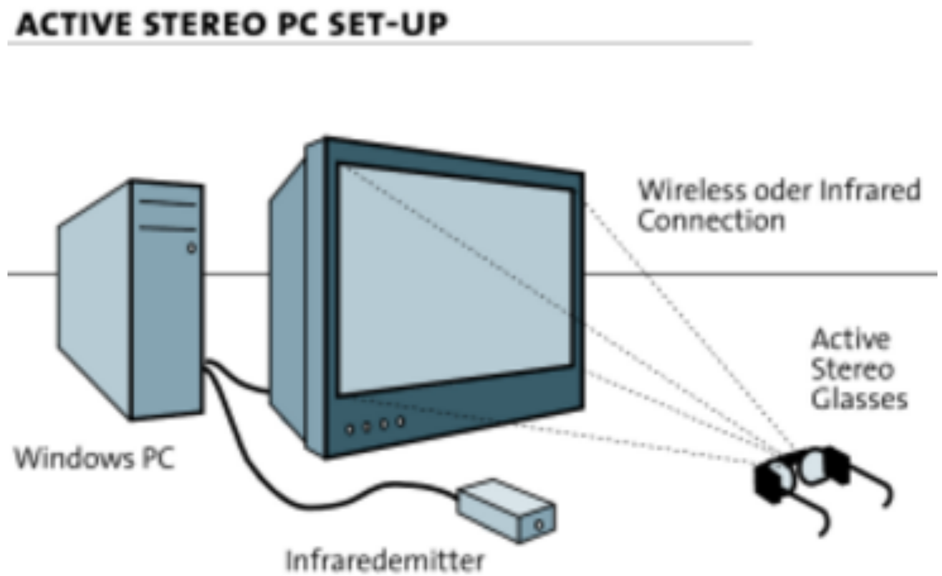


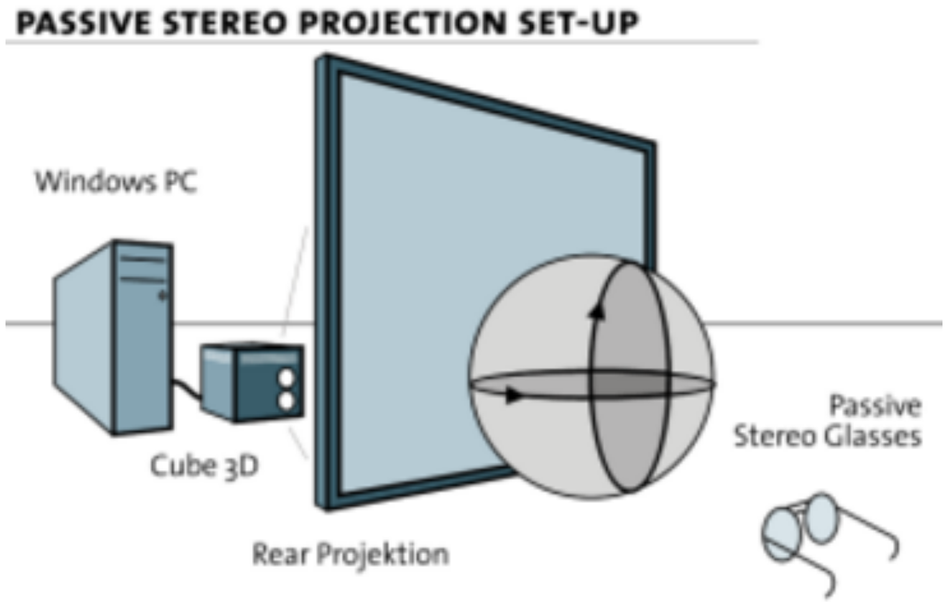




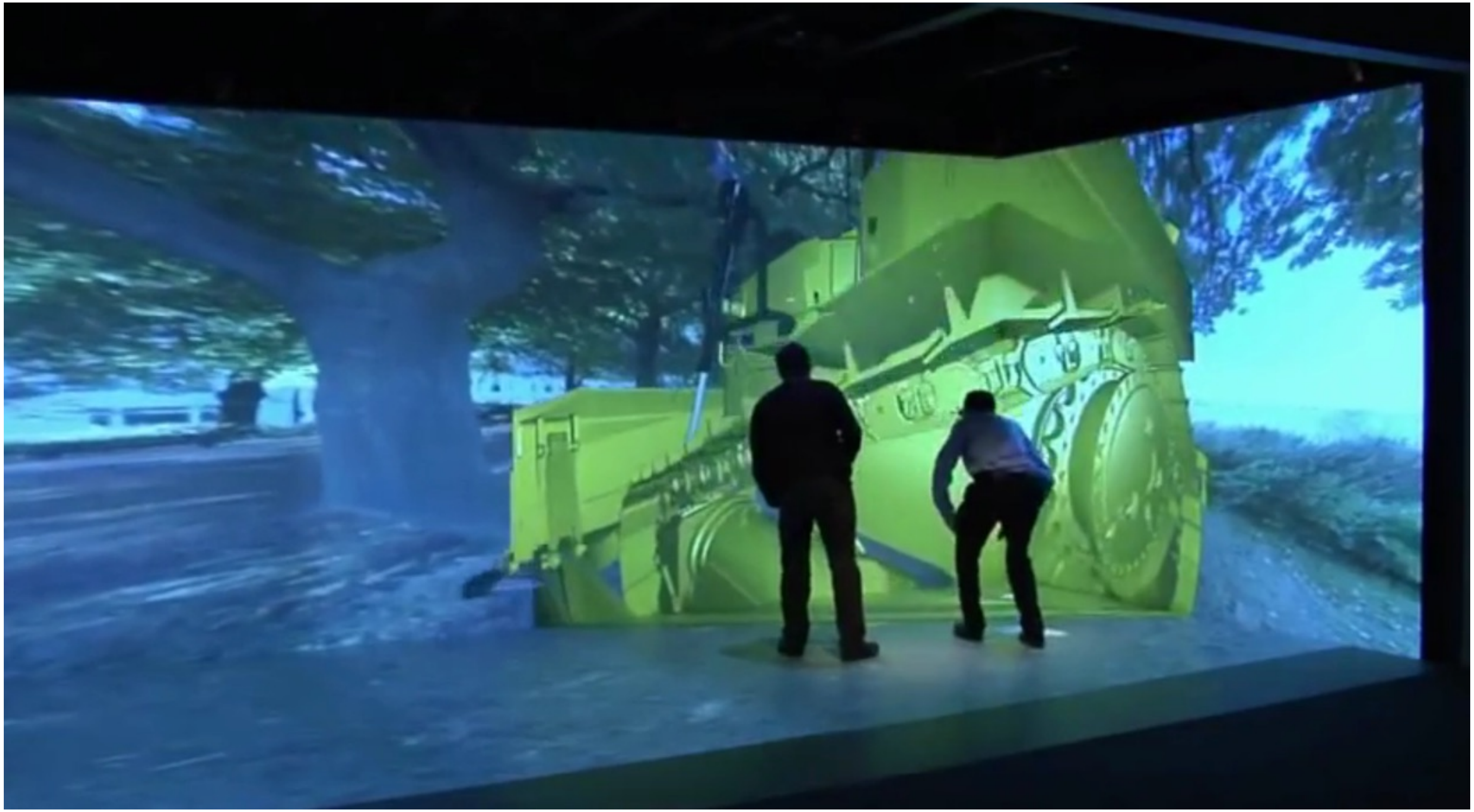
Stereo Projection

- 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

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