CIS 4930-001: Introduction to Augmented and Virtual Reality

Other Senses: Sound, Touch, Smell, and Taste

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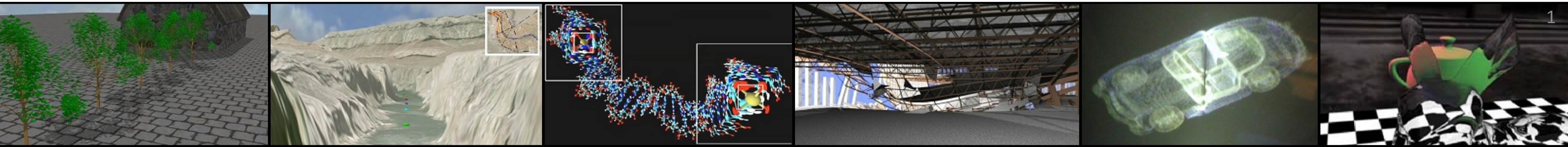


SENSES

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)

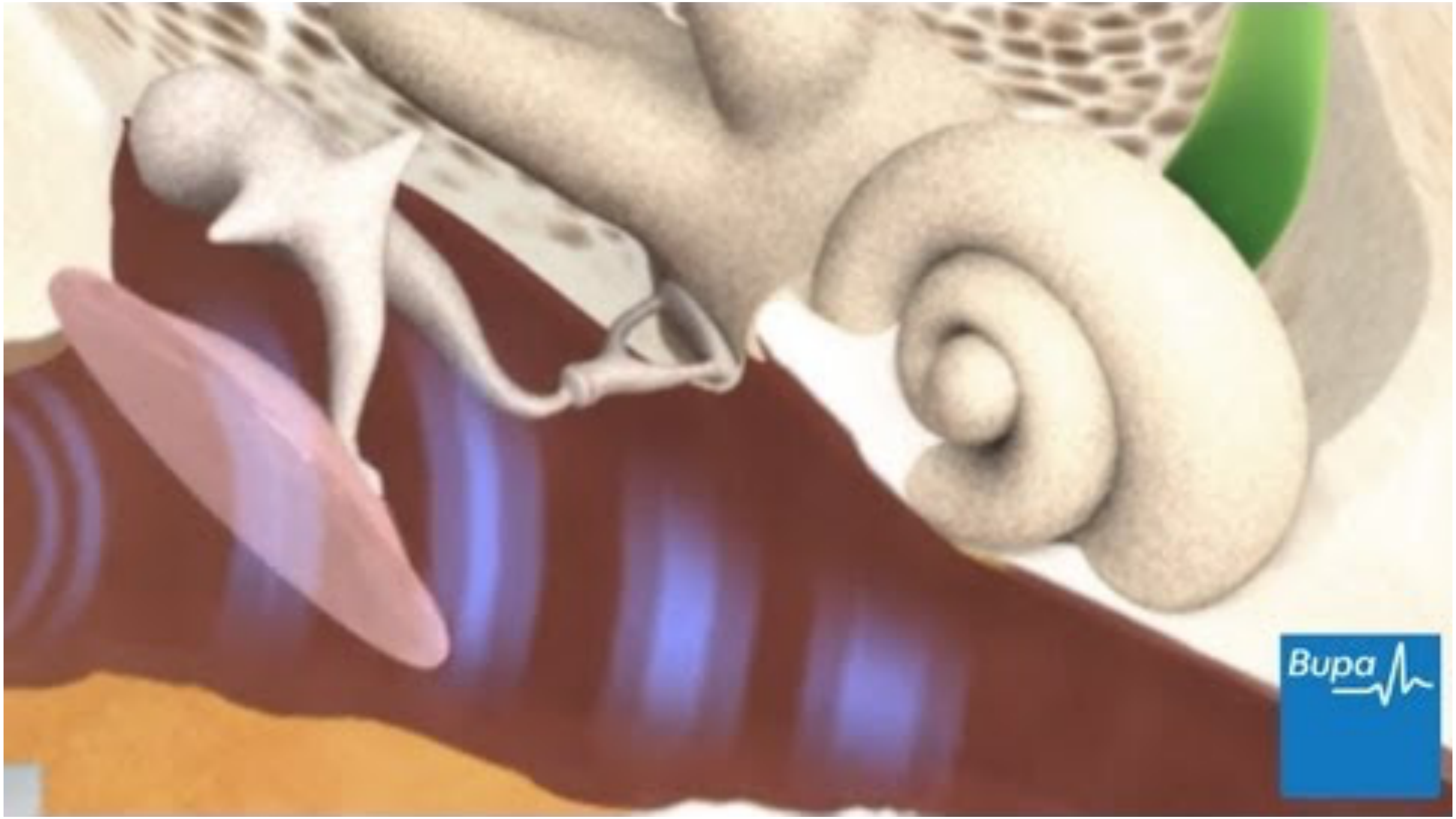
Senses

People have tried to address pretty much all the sensory modalities

- Are they solvable for the general case?
- Are they important?
- What is the future of VR?

Sound

How the ear works



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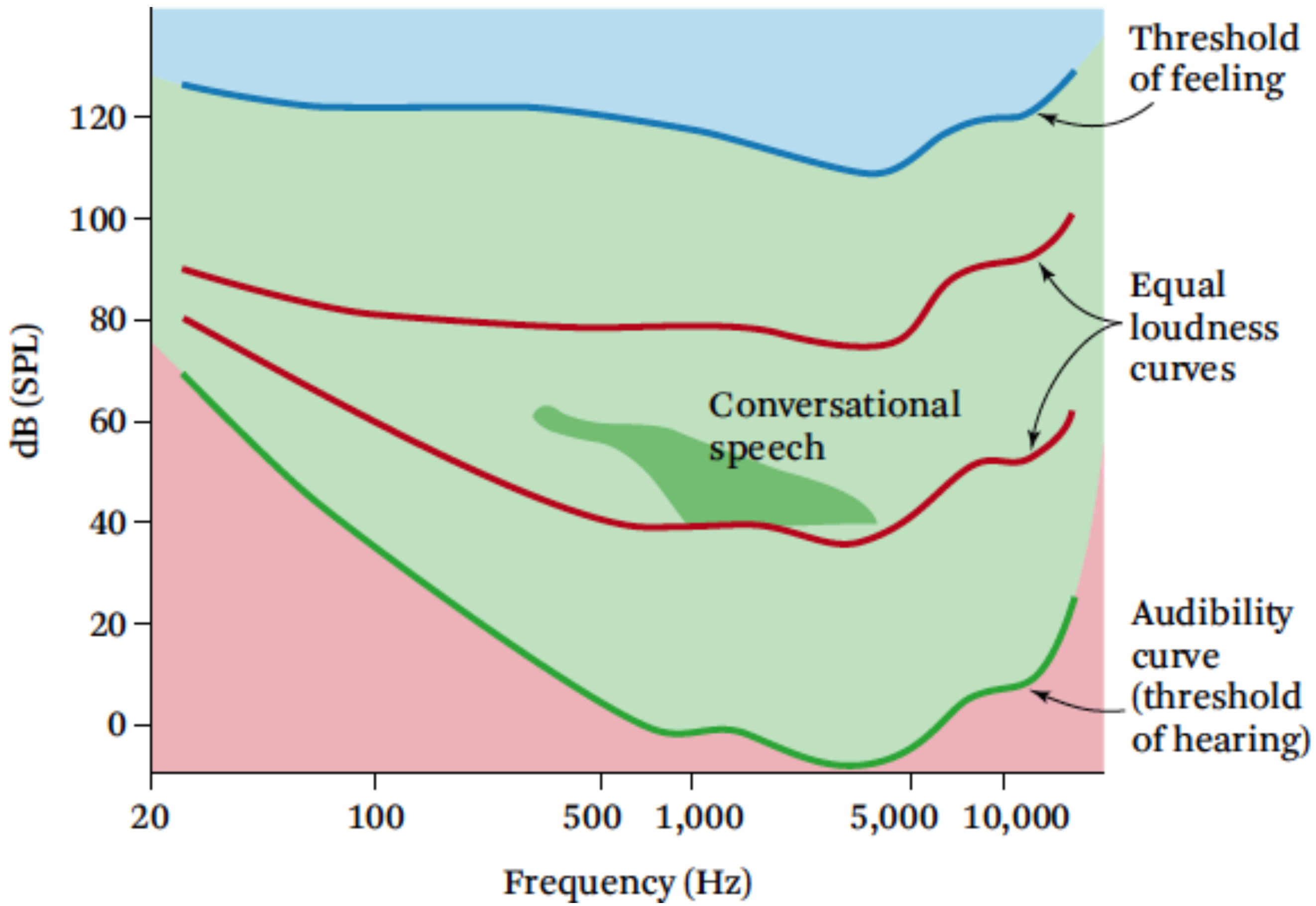
Auditory Thresholds

Humans hear frequencies from 20 – 22,000 Hz

Most everyday sounds from 80 – 90 dB

Lower frequencies more felt by the whole body than heard by the ears

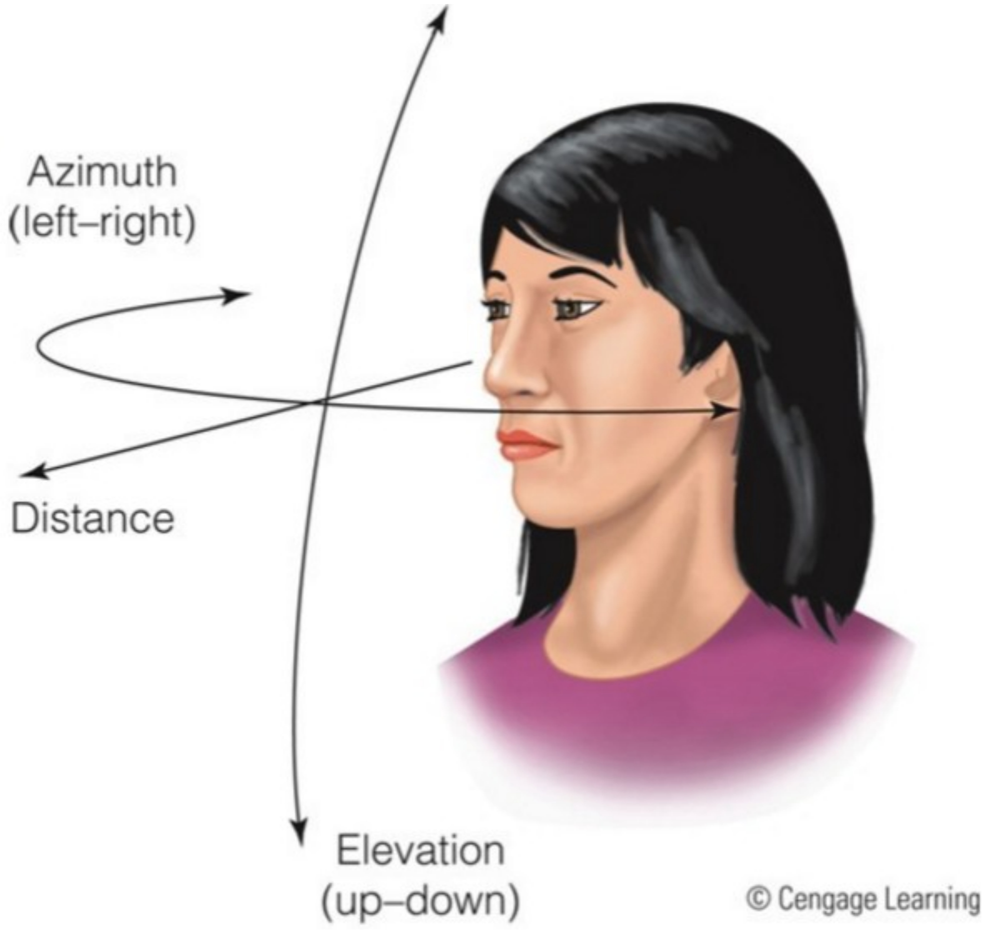


Sound Localization

Humans have two ears to help localize sound in space

Sound can be localized using 3 coordinates

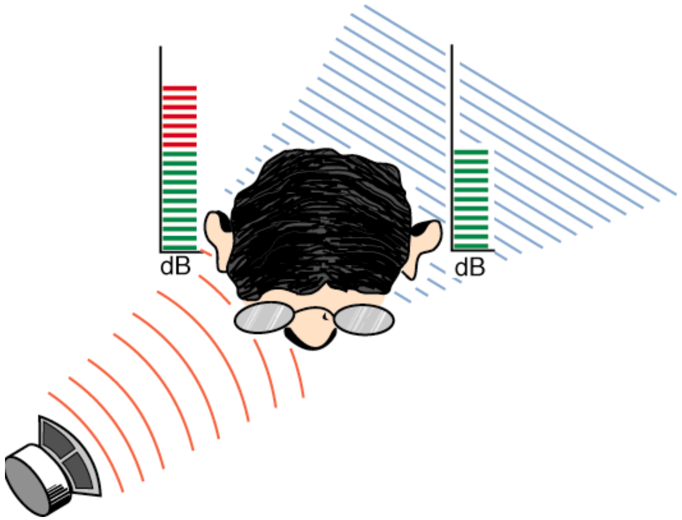
- Azimuth, elevation, distance



Sound localization

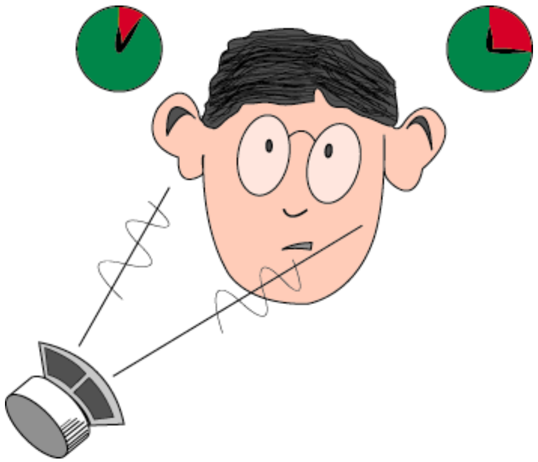
Primary Percepts

- **Interaural level differences (ILD)**: sound is louder at the ear that it is closer
- **Interaural time difference (ITD)**: the time delay between sounds arriving at the left and right ears

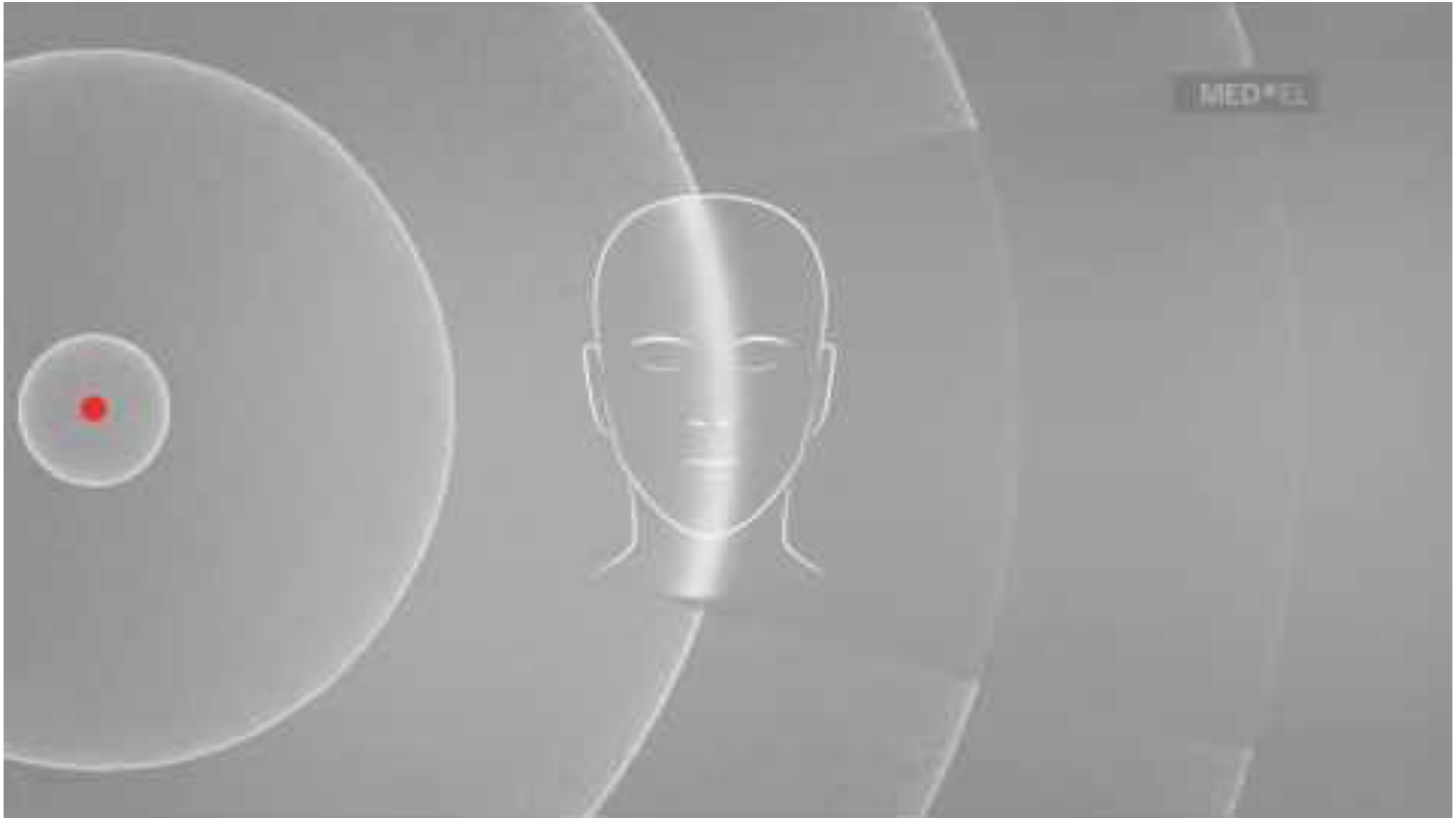


Secondary Percepts

- Head shadow: sound having to go through or around the head in order to reach an ear.
- Pinna response: the effect that the external ear, or pinna, has on sound.
- Shoulder echo: sound in the range of 1-3kHz are reflected from the upper torso of the human body.
- Head motion: movement of the head helps in determining a location of a sound source.
- Early echo response: occurs in the first 50-100ms of a sounds life.
- Reverberation: reflections from surfaces around.



Sound Localization



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ACCURACY OF SOUND LOCALIZATION

Sounds can be perceived to have an origin

- 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.

SOUND IN VR

Associate sounds with particular events

- Associate sounds with static objects
- Associate sound with the motion of an object
- Use localized sound to attract attention to an object
- Use ambient sounds to add to the feeling of immersion
- Use speech to communicate with devices or avatars
- Use sound as a warning or alarm signal

The need of audio in VR

In Virtual Reality the display has to produce the immersion in a 3D computer generated world. In addition to the visual and tactile displays, audio is needed. In VR:

- Sound enhances the presence of the simulation.
- It enhances the display of spatial information (particularly space beyond the field of view). This includes acoustical properties of the environment and the geometrical relationships of the source and listener
- Data-driven sound can convey simulated properties of the constituents of the environment. For instance mass, force of impact...
- Audio signals provide a higher degree of temporal resolution than visual display.
- Audio is also another channel of communication between the user and the environment.
- Useful in designing systems where a user monitor several communication channels at once ('cocktail-party effect')

Headphones vs. Speakers

Headphones:

- work well with head-coupled visual displays
- easier to implement spatialized 3D sound fields
- mask real-world noise
- greater portability
- Private

Speakers:

- work well with stationary visual displays
- greater user mobility
- little encumbrance
- multiuser access

AUDIO DISPLAYS: HEAD-WORN


Ear Buds


On Ear


Open Back


Closed


Bone Conduction

OSSIC Demo

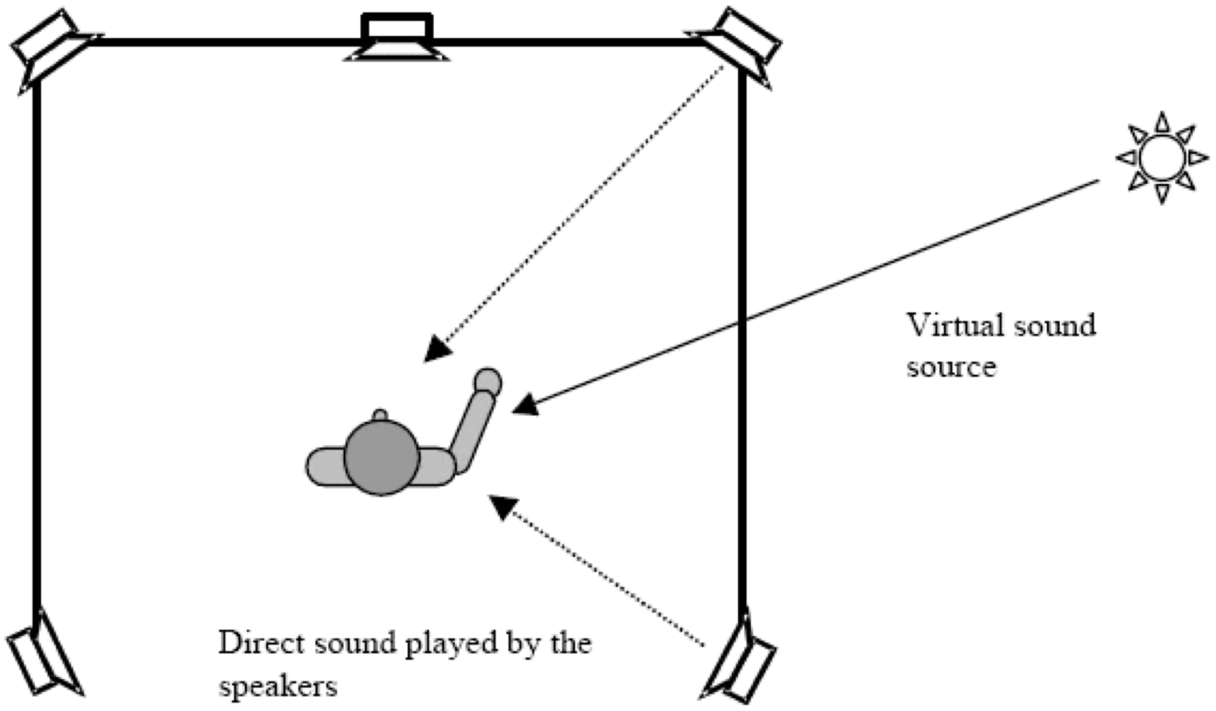
https://youtu.be/WjvofhhzTik

SPEAKER CONFIGURATION

Challenges

- Virtual sound sources move relative to speakers
- Listener moves relative to speakers
- All movements in 3D

Existing movie theater solutions designed for non-moving listener in 'sweet spot' or 'sweet area'; speakers in a plane: 2D sound



SOUND RENDERING

To generate correct echoes must model sound behavior in the space

- Rooms are complex
- Filled with different materials
- Reflective, Absorbent, Frequency filtering

AURALIZATION OR AUDIO IN 3D

3D audio is not:

- Extended Stereo, where an existing stereo (two channel) soundtrack add spaciousness and make it appear to originate from outside the left/right speaker locations.
- Surround sound, where another dimension front/back is added to the stereo.

3D interactive sound system

- Sounds are projected in all three dimensions (left/right, up/down, front/back) in real-time

Sound Waves

Generally sound waves propagate in all directions

Propagation affected by interference, reflection, diffraction, refraction -- much like light

Can interact with other media, e.g., can be transmitted from solids into fluids

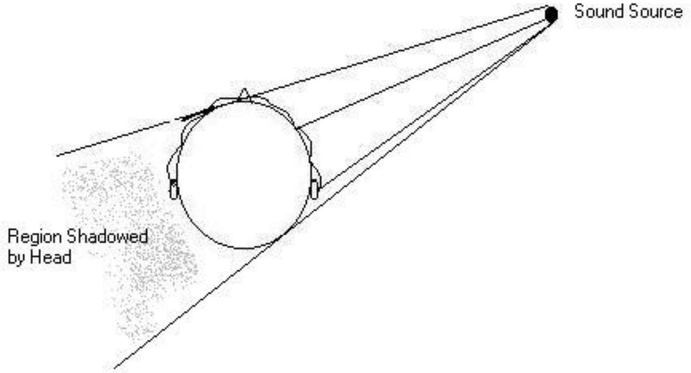
THE BASICS OF VR ACOUSTICS

In the virtual world we can talk of an auditory world, which reproduced the characteristics of the real, and it is composed by:

- **The auditory actor**: Entity emitting sounds through its interface.
- **The auditory space**: The environment that has to be modeled. Sound is reflected, attenuated, refracted and also diffract around objects. An auditory space object models the geometry of the enclosures in the world.
- **The listener**: They move around and orientate in the world, capable of perceiving the sounds.

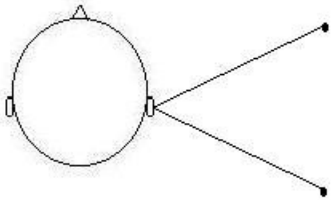
The Listener

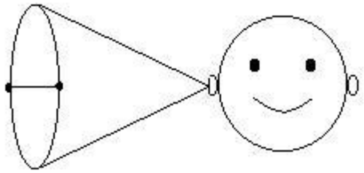
Calculating position of sound would be "trivial" if we didn't have our head blocking one of the ears (or both)



Simple model

- Tries to model how sound is perceived using two ears "mounted" on a solid sphere...
- Solving the equations for wave propagation around this rigid sphere
- Problematic as
  - First, ILDs are not linear with frequency
  - For frequencies > 1500Hz, ITD becomes ambiguous
  - Cone of Confusion—Multiple positions have identical ILD, ITD





AUDITORY SPACE

As sound waves does not only move directly from the source to the listener, it gets colored and diffracted on its way from the source to the listener.

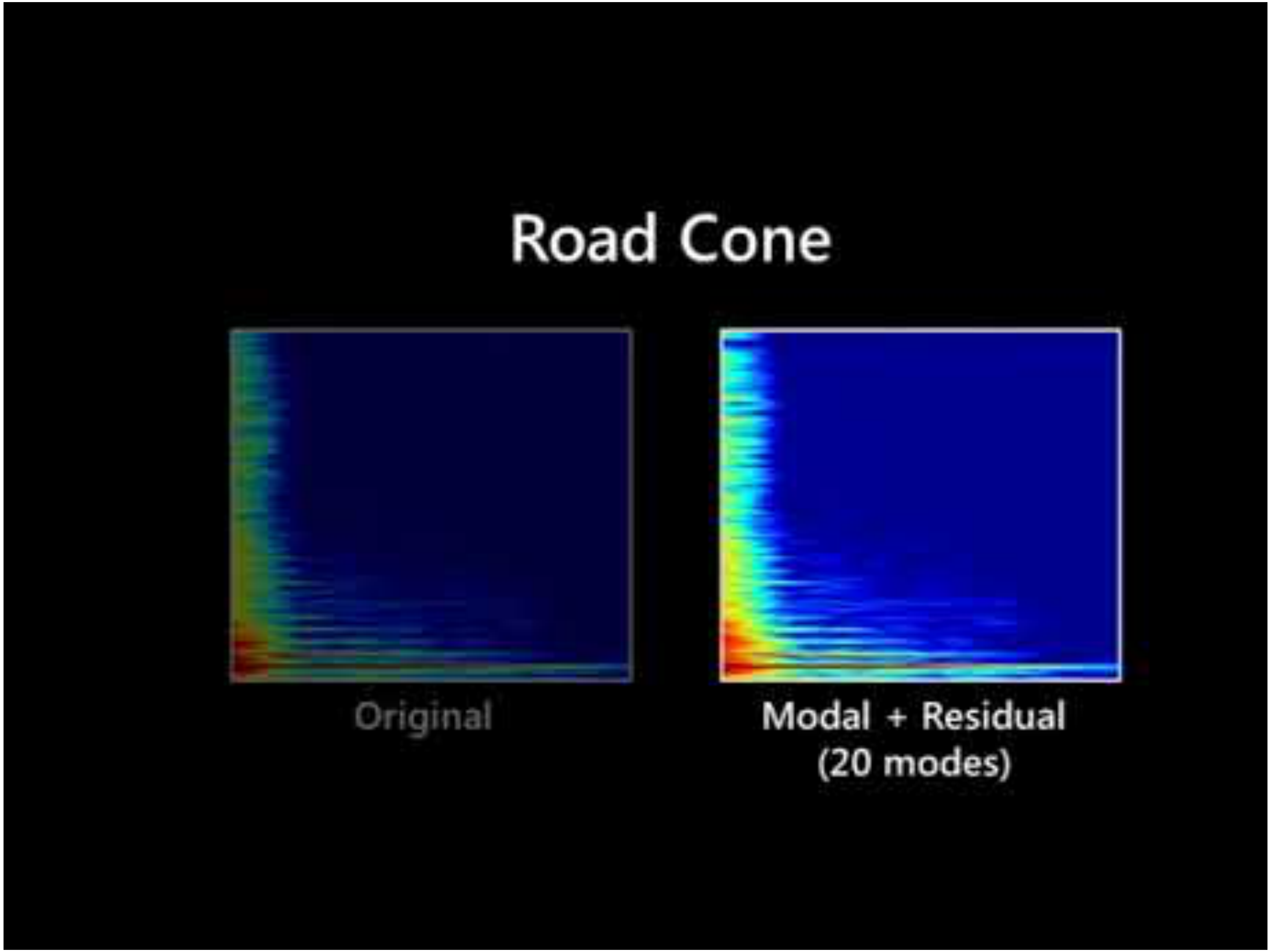
Using GPU for calculating raytracing for sound paths.

- Walls are given material properties
- Uses purely specular model (no diffraction, refraction, diffusion)
- Preprocesses mesh
  - Remove invalid geometry
  - Portal calculation
  - Build BSP
- Propagation of rays through portals and reflecting them from walls
- Using echogram to generate spatial sound

AUDITORY ACTOR

Sound can be sampled or synthetic:

- Sampled sounds are digital recordings of a sound that are temporally mapped and played back on demand.
- Synthetic sounds are created from arbitrary parameters. Approaches used for generating sounds: Fourier synthesis, signal multiplication, filtering, frequency modulation, timbre trees (in which parameters of motion will determine the parameters of generation)...
  - Generating sounds is a difficult task.



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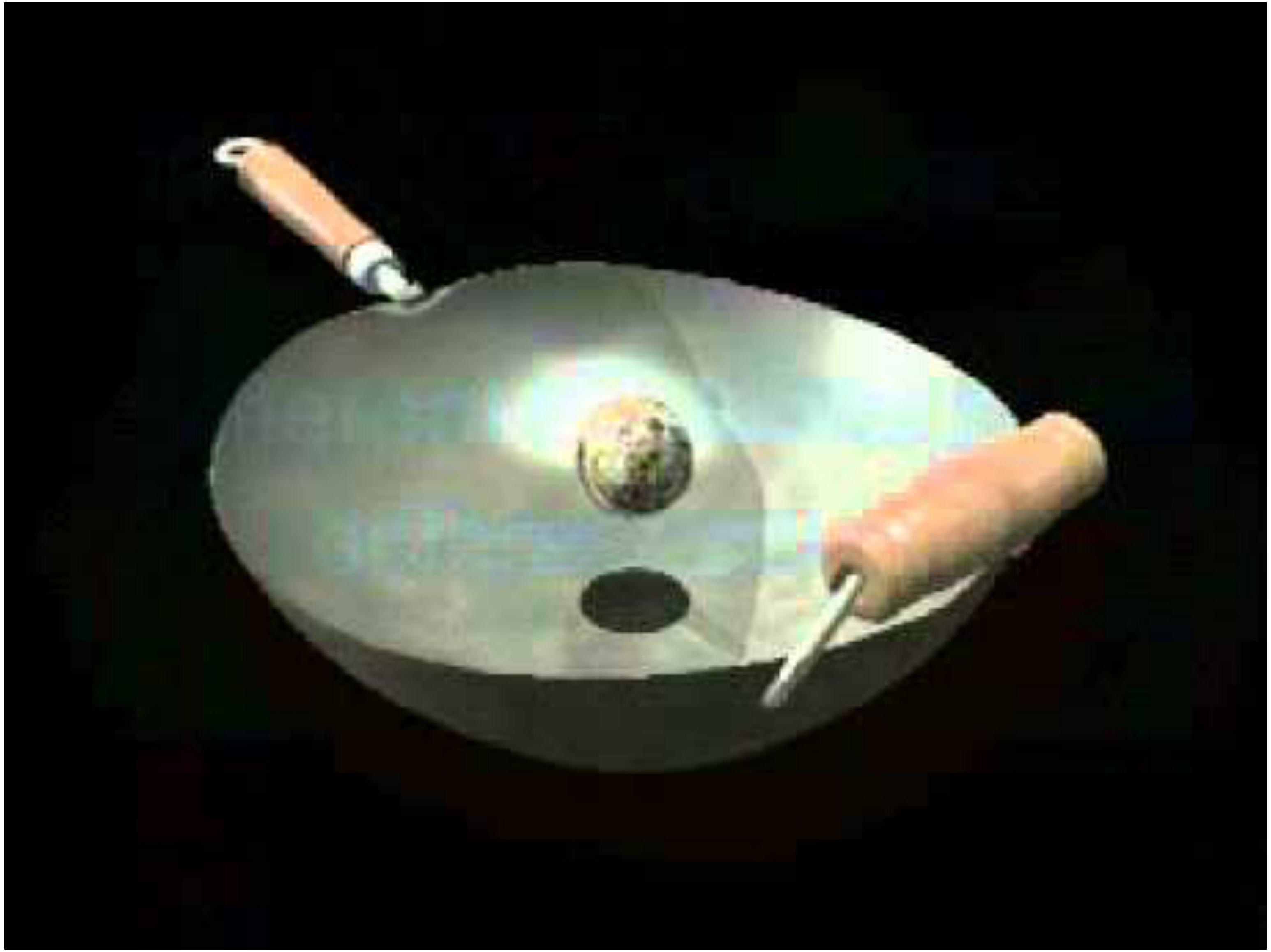
Real-time synthesis of sound-effects



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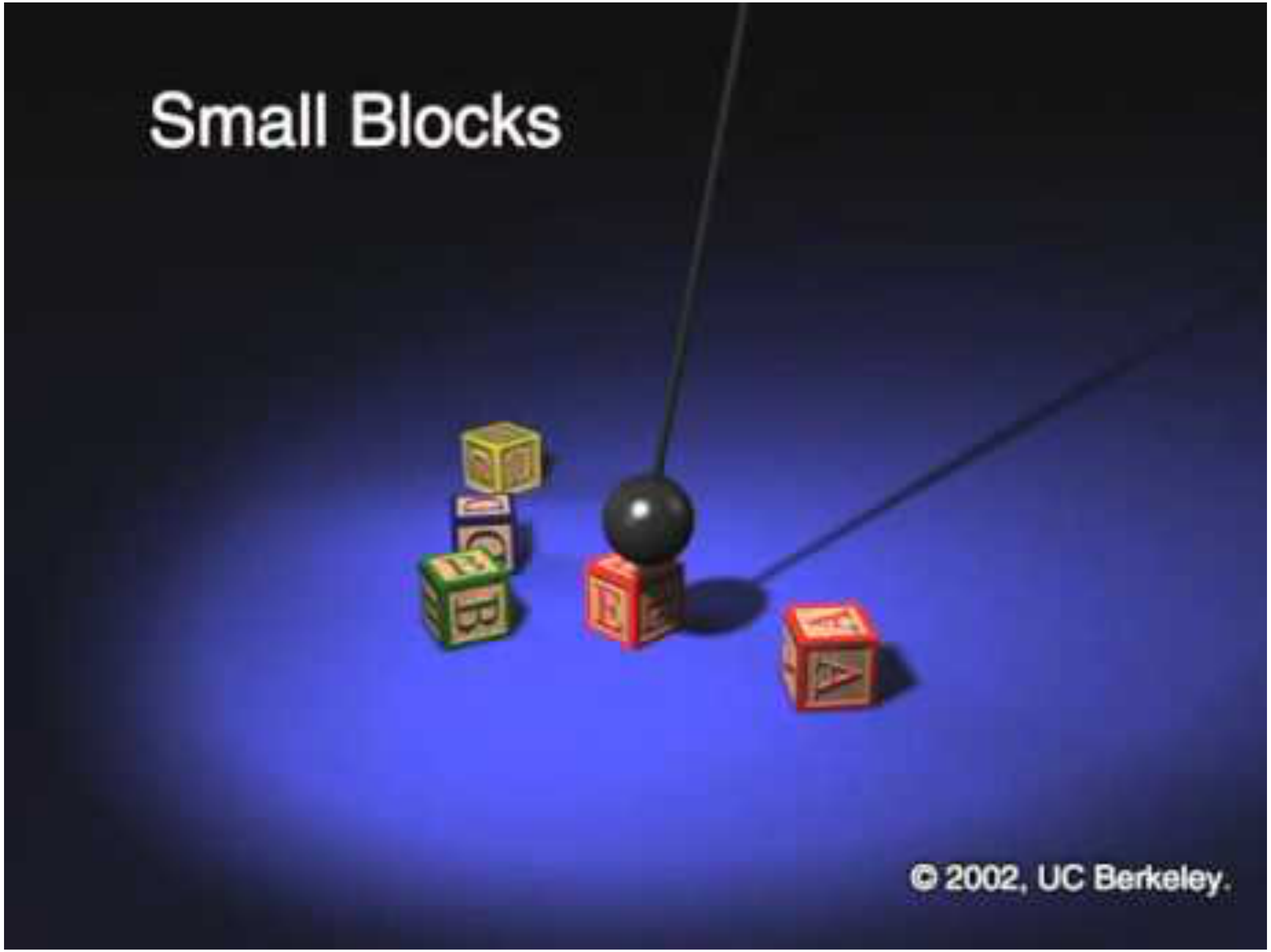
Synthesizing Sound from Rigid-Body simulations



https://youtu.be/-vo84AxF4R4

Sounding Liquids: Automatic Sound Synthesis from Fluid Simulation

https://youtu.be/MHBViinfmKo

AUDIO-VISUAL SYNERGY

Together, synchronized 3D audio and 3D visual cues provide a very strong immersion experience.

3D audio removes a lot of requirements on the visual part

- The graphics don’t have to be as nice!

It is needed a single framework that integrates arbitrary sounds and motions for virtual environments. This is done when audio parameters are taken from motion parameters, and motion and audio are synchronized.

Head Movement and Audio

- Audio cues change dramatically when a listener tilts or rotates his head. The ears alert the brain about an event outside of the area that the eyes are currently focused on, and we automatically turn to redirect our attention.
- Interactive audio is much better than prerecorded audio because it allows the listeners head motion be properly simulated.

TOUCH

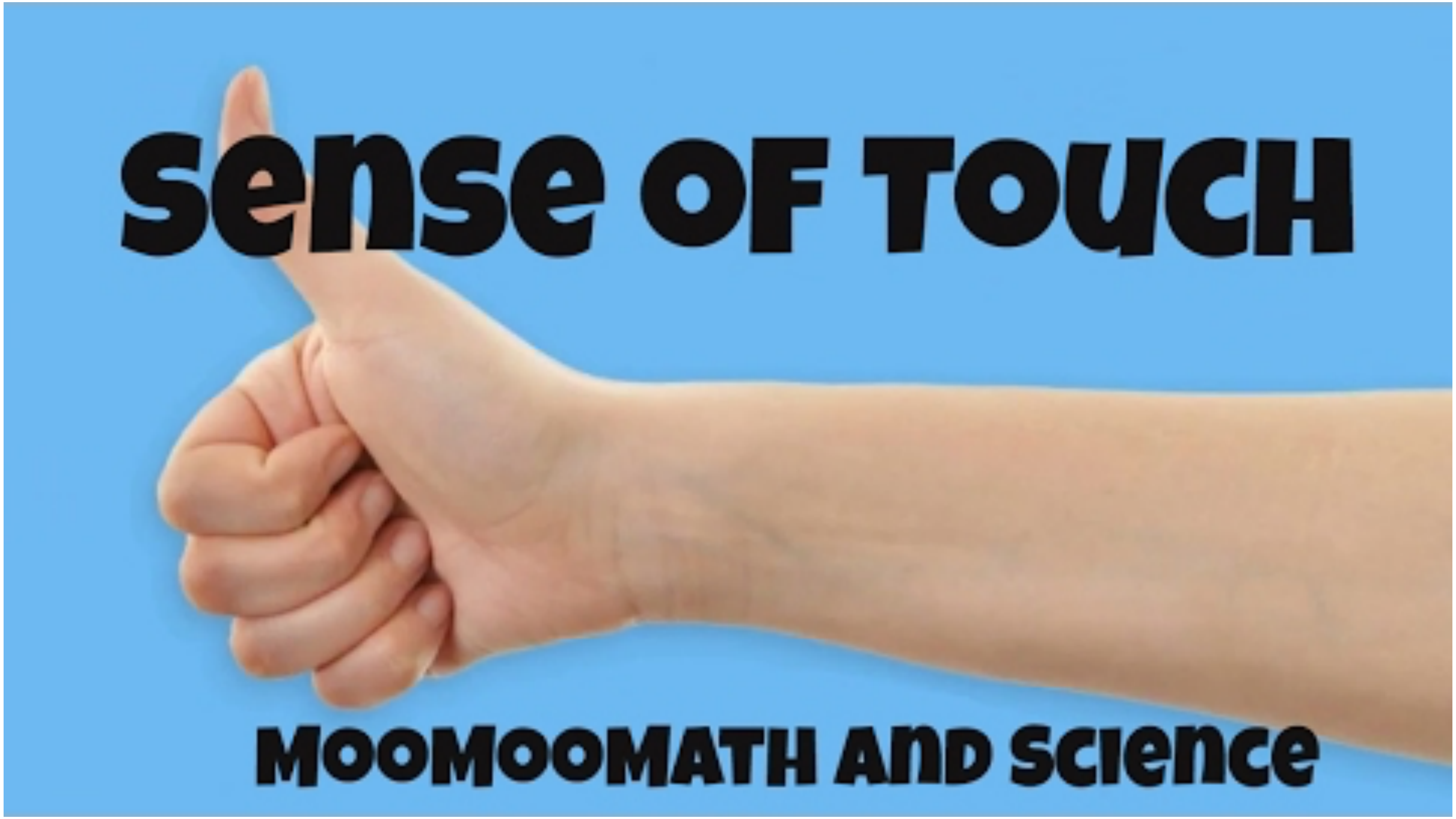
TOUCH

Actually a range of skin senses

- touch / pressure
- hot / cold
- pain

Useful for object identification & understanding

How touch works



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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

TOUCH

Uses

- Medicine
- Virtual Prototyping
- General UI enhancement

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

Tactile Feedback Interfaces

Goal: Stimulate skin tactile receptors

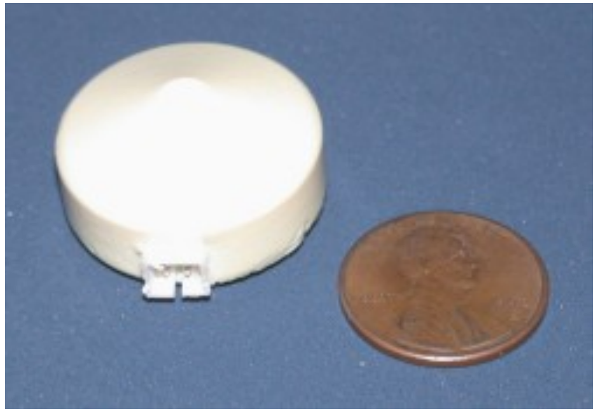
Using different technologies

- 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

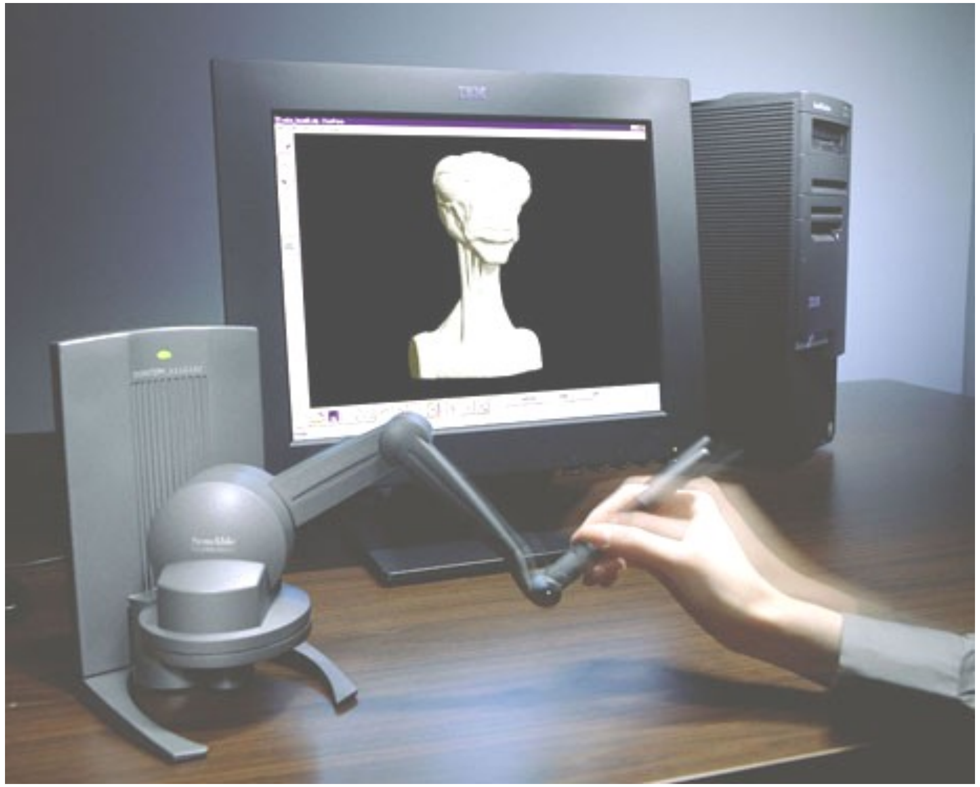
Example: HaptX Glove

https://youtu.be/4K-MLVqD1_A

EXAMPLE: PHANTOM OMNI

Combined stylus input/haptic output

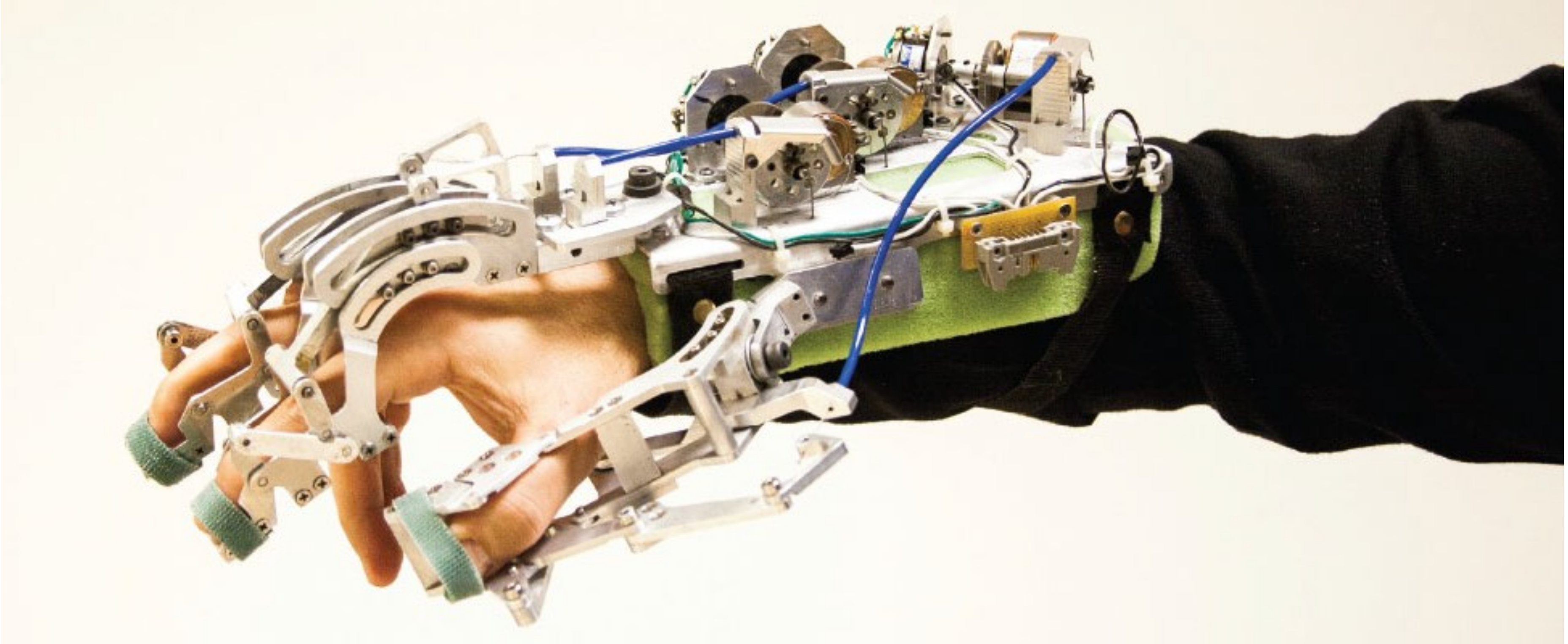
6 DOF haptic feedback



Phantom Omni Demo

https://youtu.be/REA97hRX0WQ

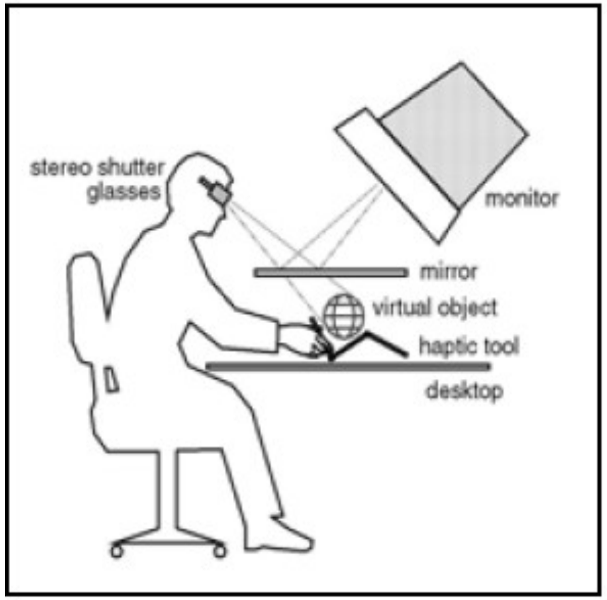
HAPTIC GLOVE



Many examples of haptic gloves

Typically use mechanical device to provide haptic feedback

HAPTIC INPUT



AR Haptic Workbench

- CSIRO 2003 – Adcock et. al.

PHANTOM

Sensable Technologies (www.sensable.com)

6 DOF Force Feedback Device

EXAMPLE: HAPTIC AUGMENTED REALITY

HTTPS://YOUTU.BE/3MEALLE8KZS

PASSIVE HAPTICS

Not controlled by system

- Use real props

Pros

- Cheap
- Large scale
- Accurate

Cons

- Not dynamic
- Limited use

NEAR-FIELD (PASSIVE) HAPTICS

Use of props - “poor man’s” haptic display

Grounding in VE

Examples:

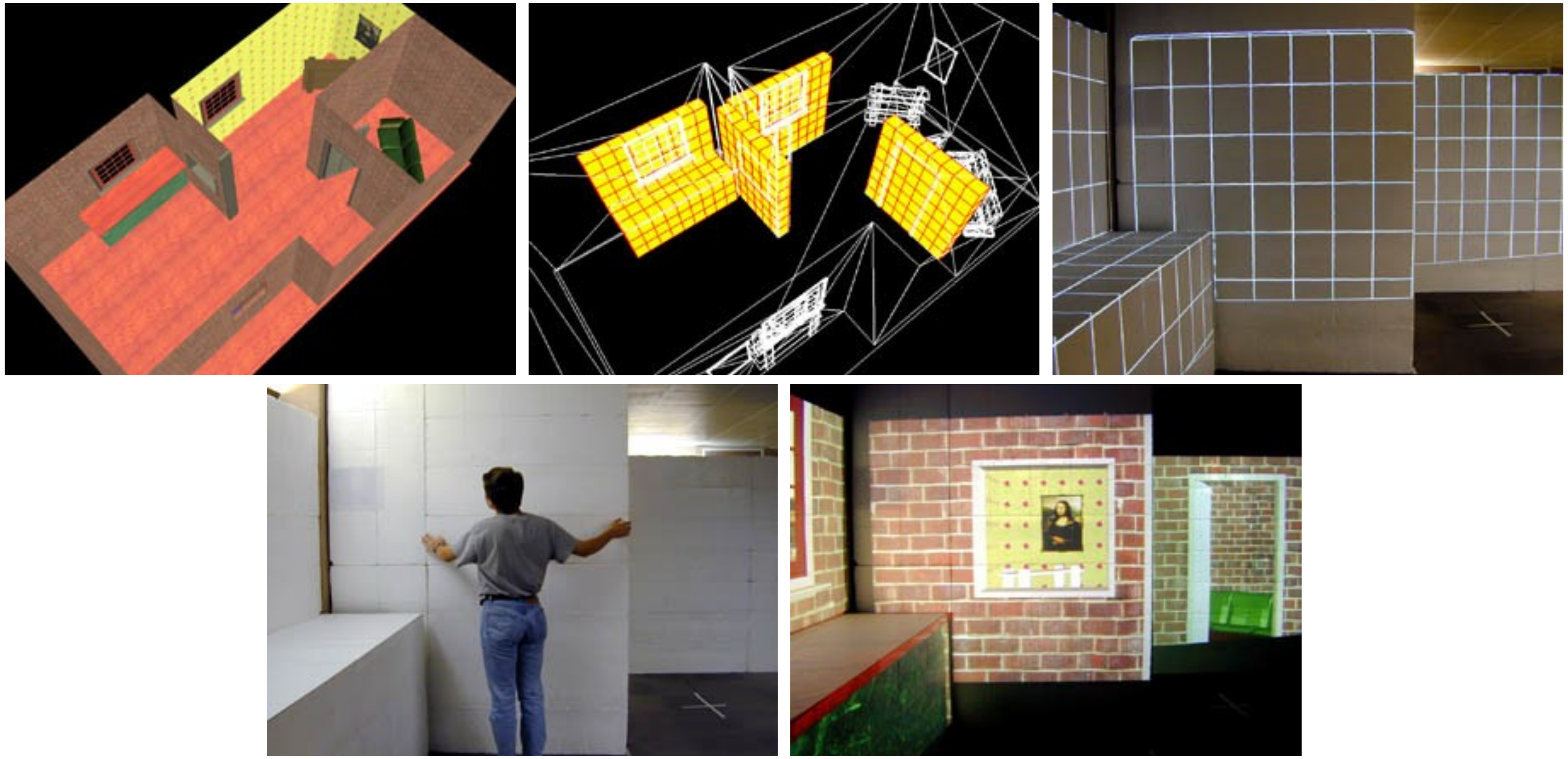
- pen & tablet
- GM: plastic cup
- hairy spider
- airplane cockpit

Displaying to other skin senses

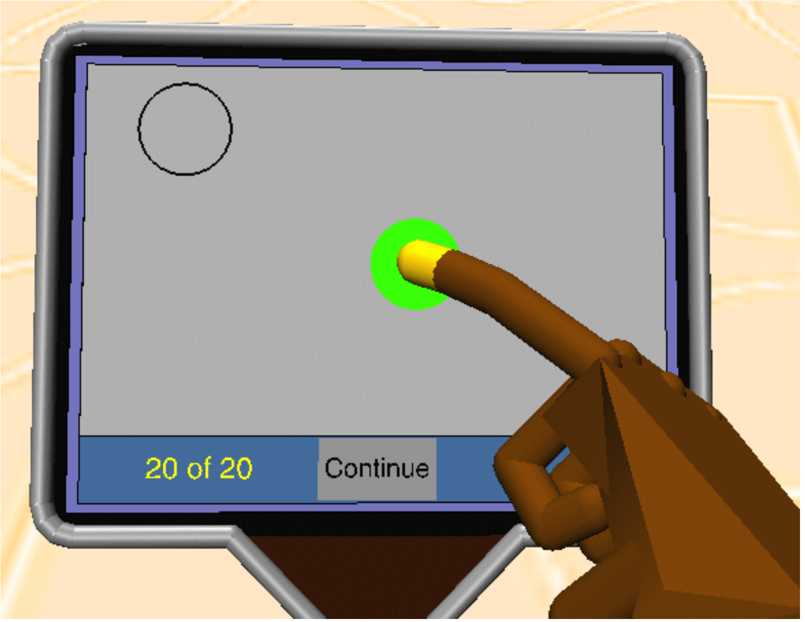
Simple, special-purpose "displays" for temperature, air movement, etc.

- Fan
- Heat lamp

UNC Being There Project



PASSIVE HAPTIC PADDLE



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

Large format displays

There are many large physical displays that help provide realism

- Think aircraft simulator containing real looking aircraft controls

The Virtual Palpitator

Simulate touch of bovine reproductive system

Addresses these issues (from Virtalis website)

- difficult to guide students when the instructor can’t see what they are palpating inside the cow/horse.
- students can’t see what the instructor is doing, so can’t copy.
- little quality feedback from "the patient"
- concerns for animal welfare

Shape Displays

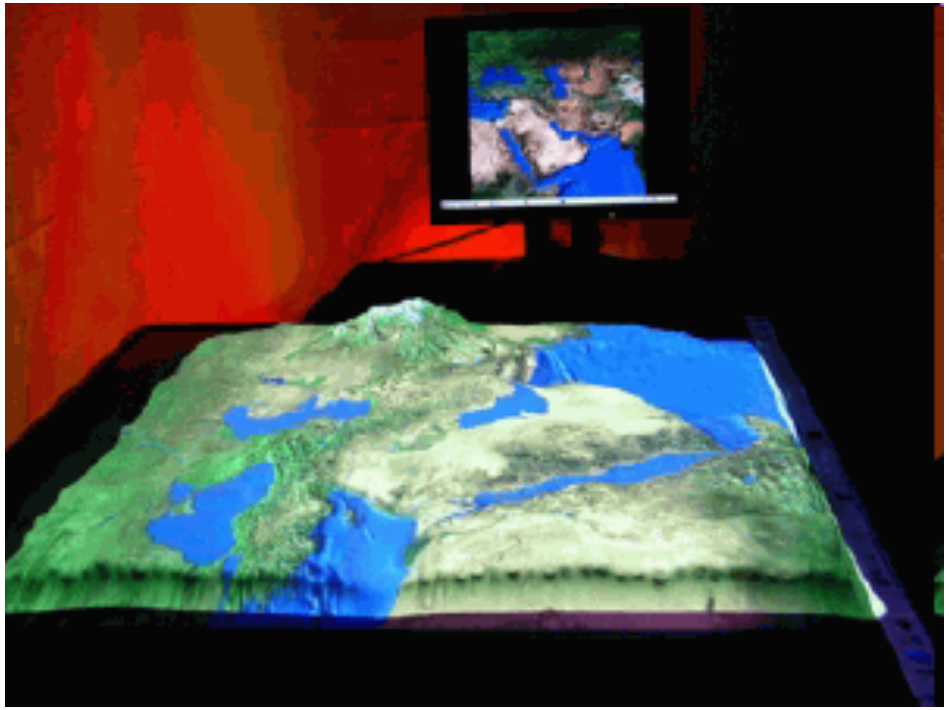
Combine tactile and force feedback

- Project FEELEX

https://youtu.be/EOL7N0sqs14?t=14

A cool DARPA project

Dynamic sand table



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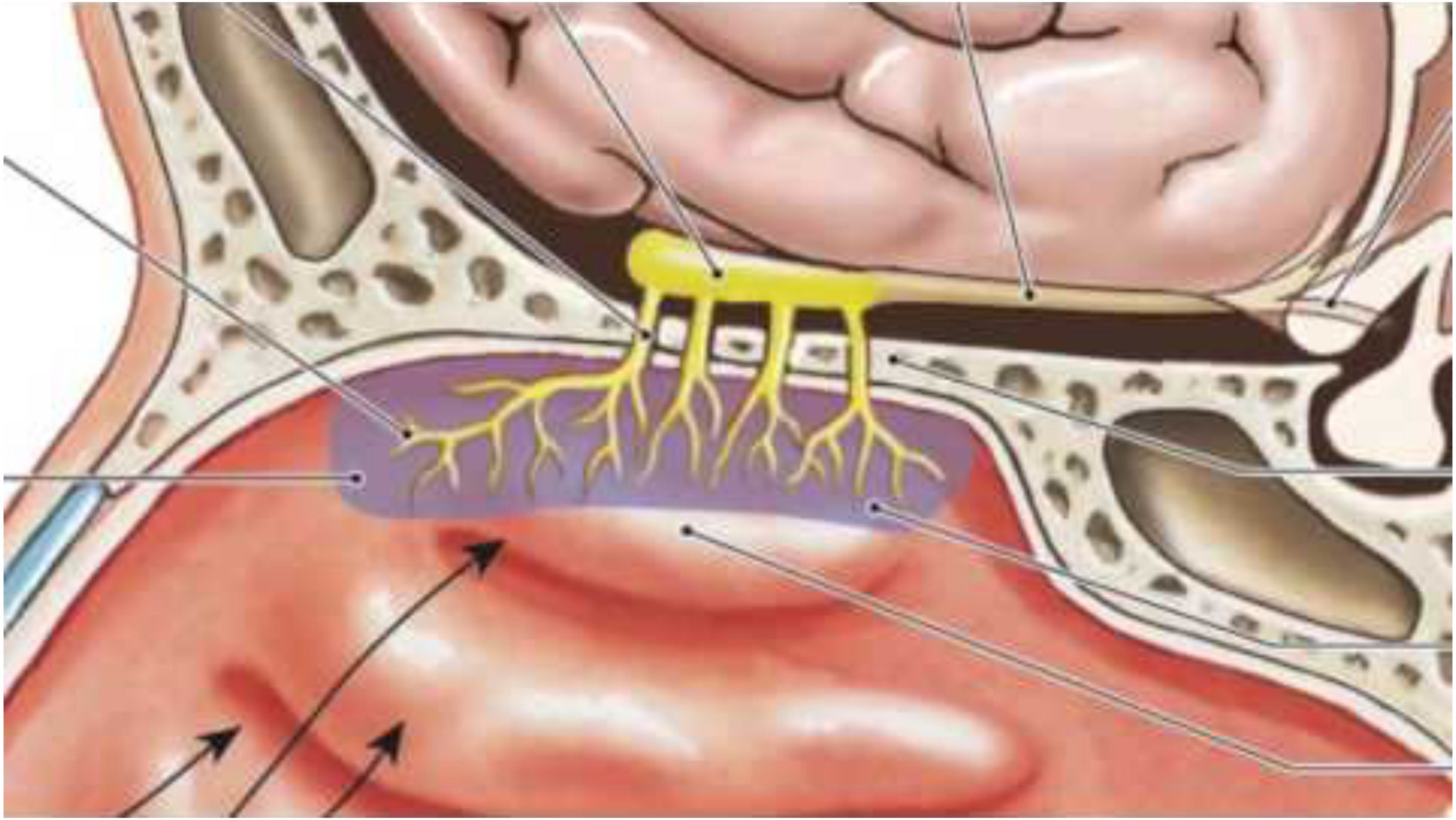
Smell

How the Nose Works



https://youtu.be/zaHR2MAxywg

Olfactory Mechanisms

Air with molecules pass by olfactory nerve endings

- How to increase smell throughput?

How many smells are there?

- Can distinguish around 10,000 smells
- Maybe around 400K smells out there
- Numbers provide an analogue to true color visual at 16M colors
  - But how many basis functions?

Olfactory Interfaces

- Increased immersion
- Task-specific information (e.g., Fire-fighting)

Smell Classification

Basic units of smell are caprylic, fragrant, acid, and burnt (Cater, 1992). Other terms that have been used are fruity, spicy, floral, and green.

Six category prism (Henning 1915)

Perfumery (Curtis and Williams 1994)

- set of three letter codes, often trade-secret

Domain specific

- beer, wine, and spirits

PERCEPTUAL LIMITS

10 degrees in the horizontal plane, as well as having a field of smell subtending about 130 degrees

- Von Bekesy 1964

concentration range sensitivity spanning three orders of magnitude

- Dravnieks 1975

Without cues from the other senses subjects in a study failed for two out of three odors to make the correct identification

- Zellner, Bartoli, and Eckhard 1991; Youngblut et al. 1996

It is not uncommon to have a high rate of false detection and report the existence of smells that in fact are not present

- Richardson and Zucco 1989; Barfield and Danas 1995

STORAGE MEDIA

Liquid, gel or waxy solids

Microencapsulate odorants

- Scratch and sniff

Drops of liquids encapsulated in gelatin

Olfactory Displays

DIVEpak

- Computer controlled scratch and sniff

iSmell DigiScents (bankrupt)

- smell index (100-200 smells)

TriSenx (bankrupt)

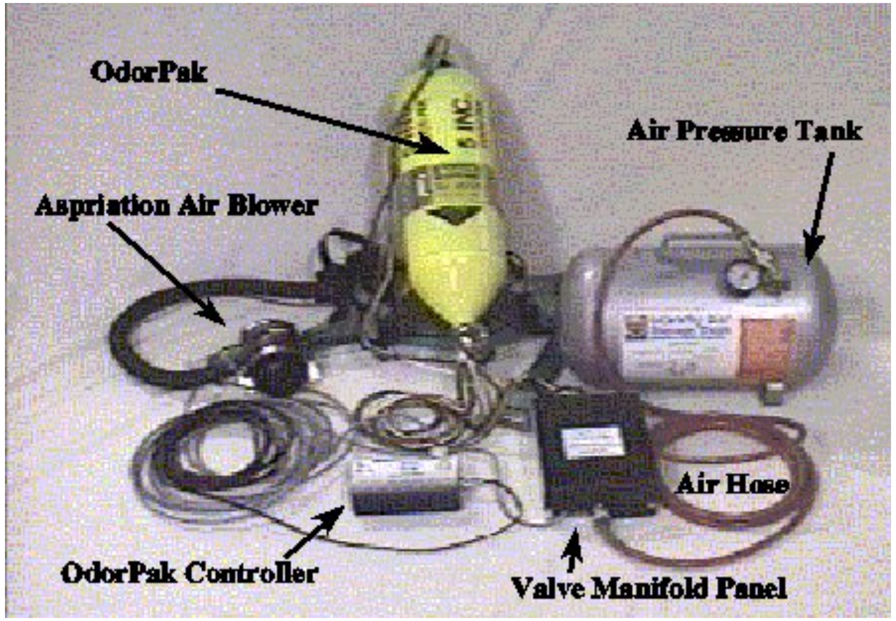
- single smell controlled by serial port

Smell-o-Vision (K Opticom)

- 6 gels, USB controlled

FIRE TRAINER

Odors range from burning wood, grease and rubber to sulfur, oil and diesel exhaust.



Air Force + 5,Inc.

Okado Laboratory – Olfactory system

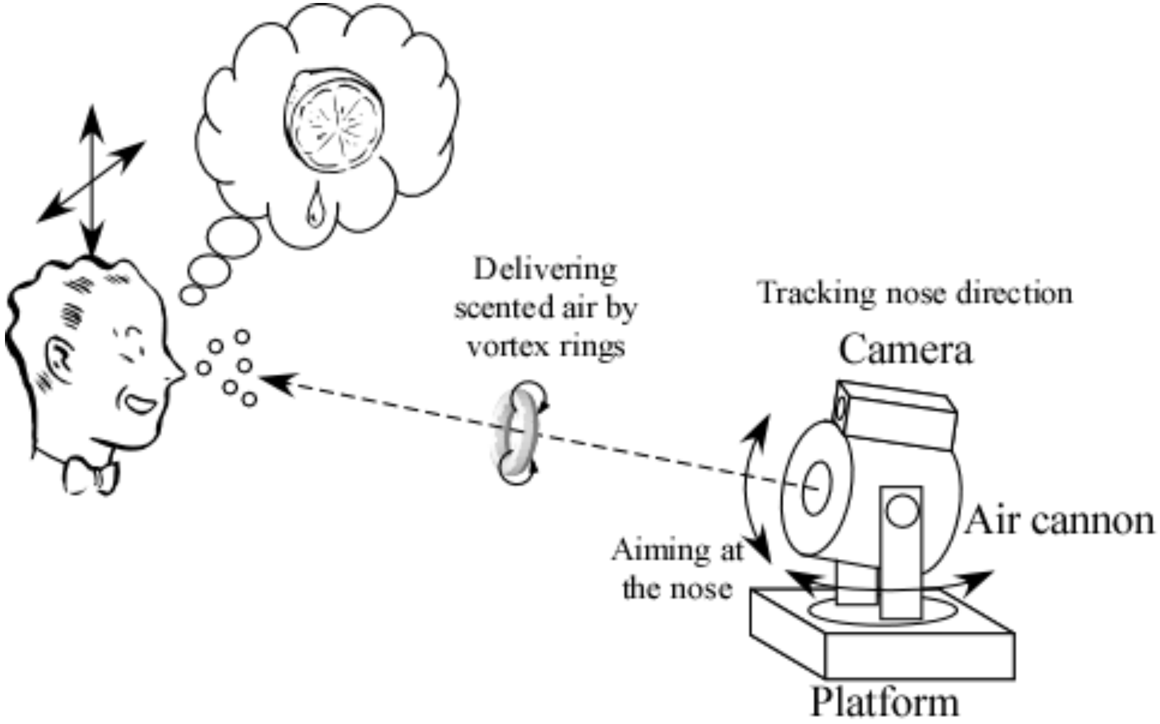
https://youtu.be/p7FEf03OraQ

Smell Cannon

Track target with camera

Aim below eyes

Prerecorded smells



Olfactory Displays

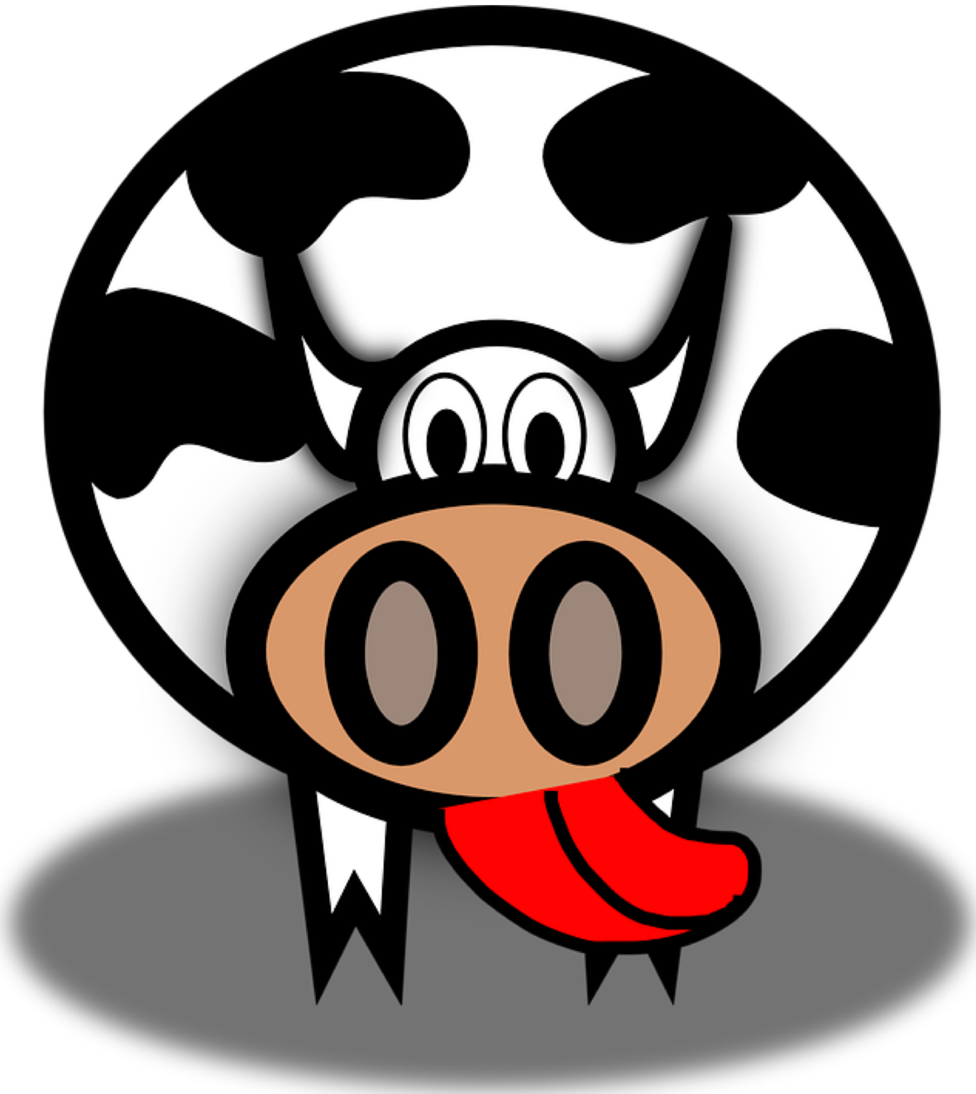
Challenges

- clean air input
- evacuate air
- clean output air

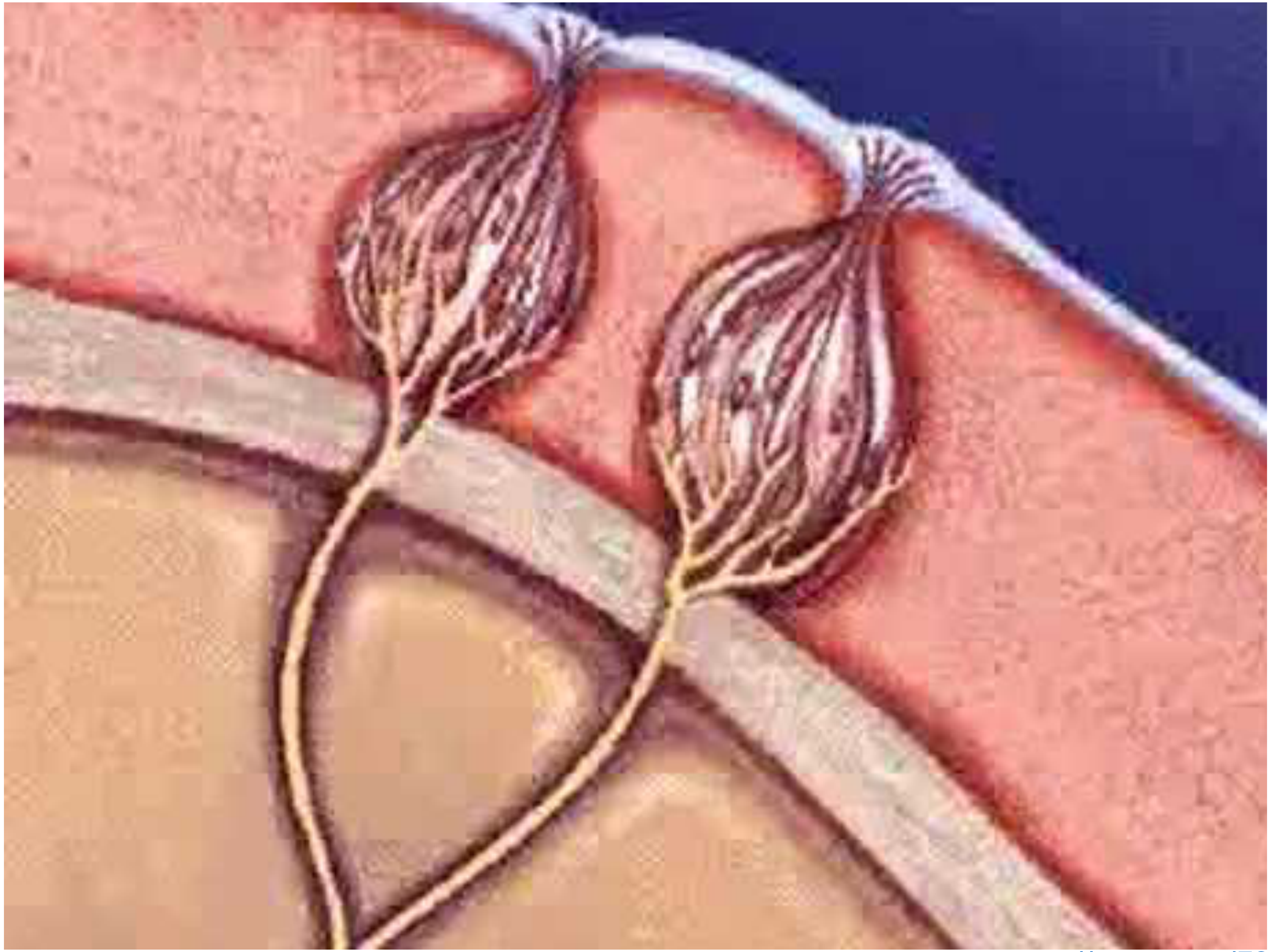
How to control breathing space

- sealed room with air filtration
- air control in front of and behind user
- sealed pod
- tethered mask
- tubes into an HMD from pack
- built into HMD

TASTE



Sense of Taste



https://youtu.be/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

Flavor 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.

Gustatory Displays

Simulate the experience of eating

Iwata food simulator

Capture forces of eating

Playback

Combine flavors

- five basic taste sensations: sweet, sour, bitter, salty and umami