Display & Rendering

071011-1
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Human Perception System

- Obtain information about environment through senses:
  - Vision: primary form of perception in most VR
  - Audition: second most common in VR
  - Haptic/Touch: perceptible on through direct contact
  - Olfaction
  - Gustation
  - Vestibular/kinesthetic sense
- VR systems mimics the senses by output of computer-generated stimuli rather than natural stimuli to one or more of these sense.

Vision

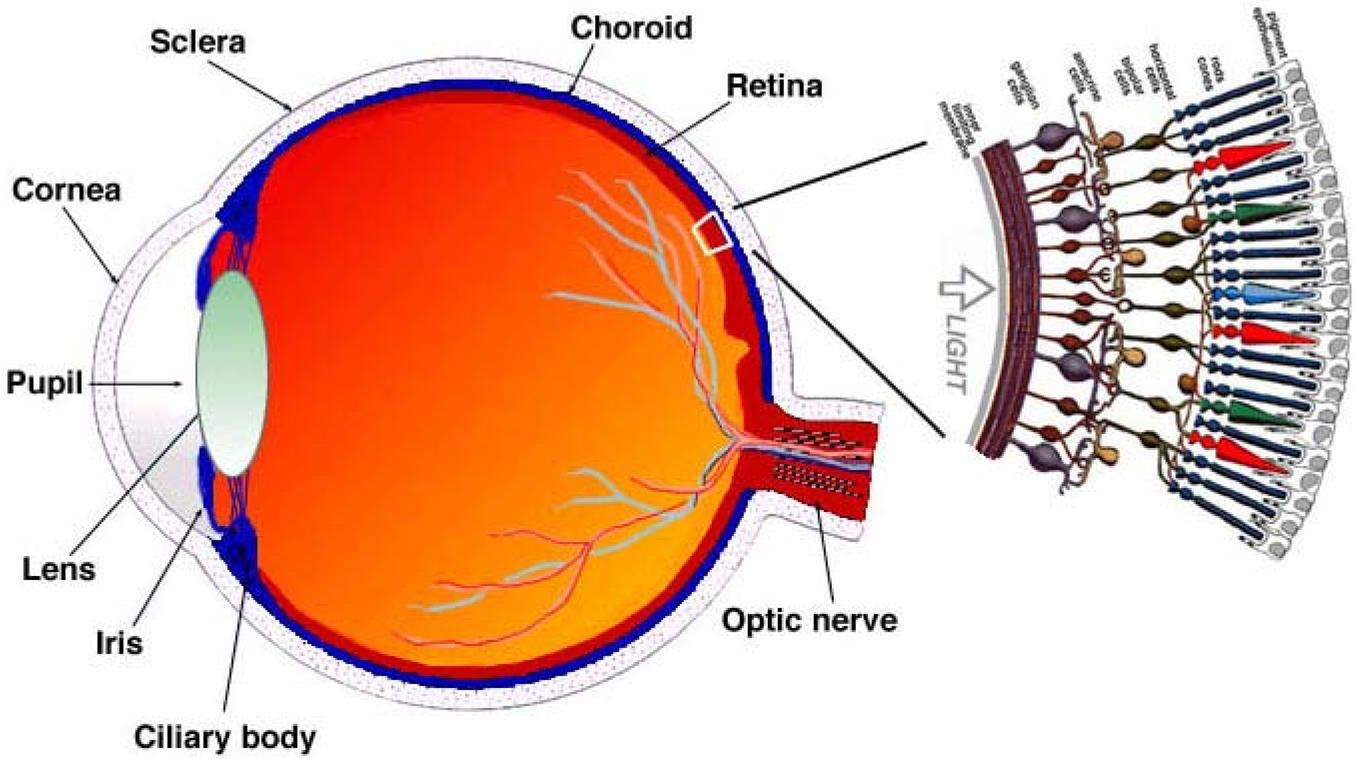


Fig. 1.1. A drawing of a section through the human eye with a schematic enlargement of the retina.

Image from http://webvision.med.utah.edu/sretina.html

Audition

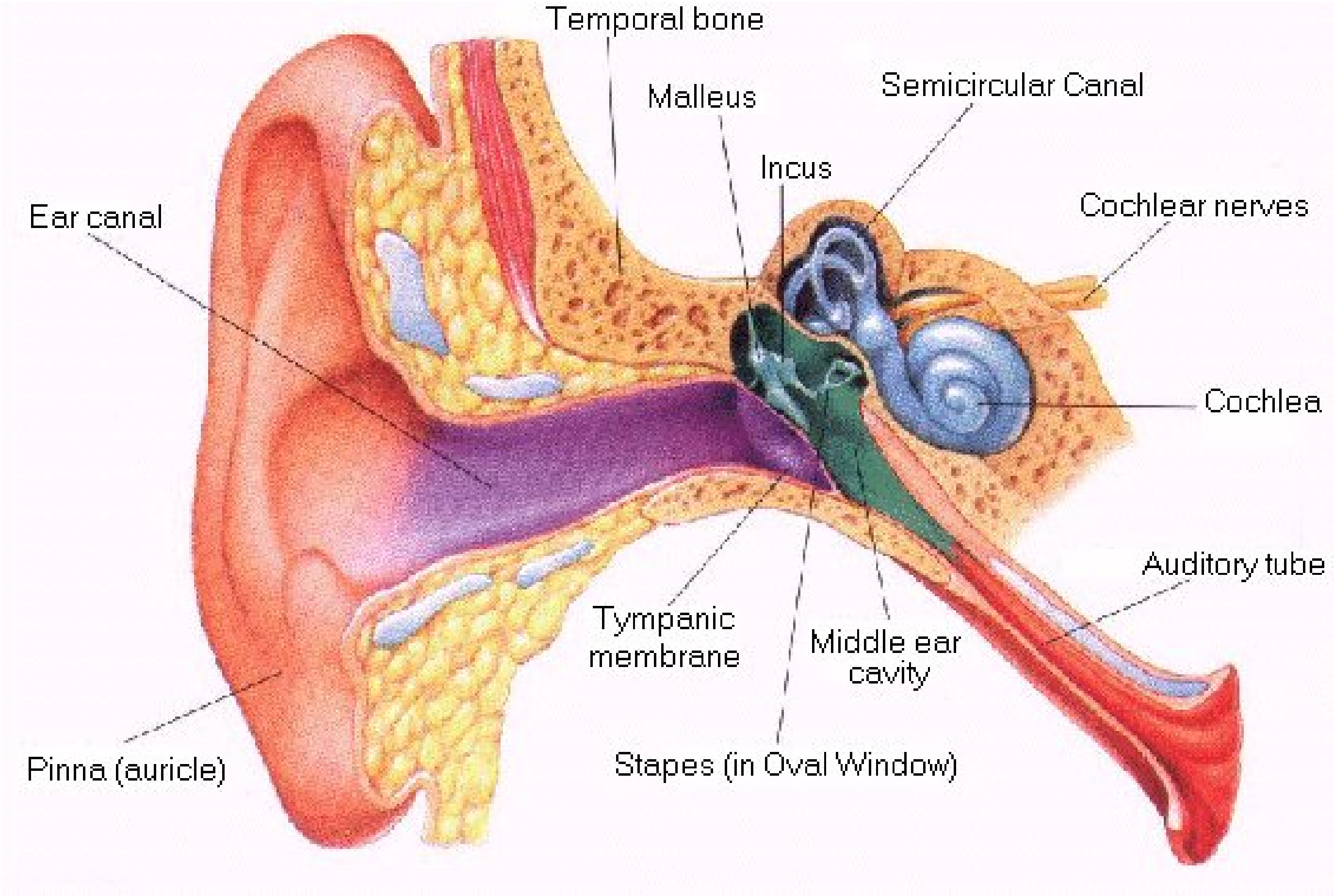


Image from http://www.infj.ulst.ac.uk/~pnic/HumanEar/Andy's%20Stuff/MScProject/workingcode_Local/EarChapter.html

Touch

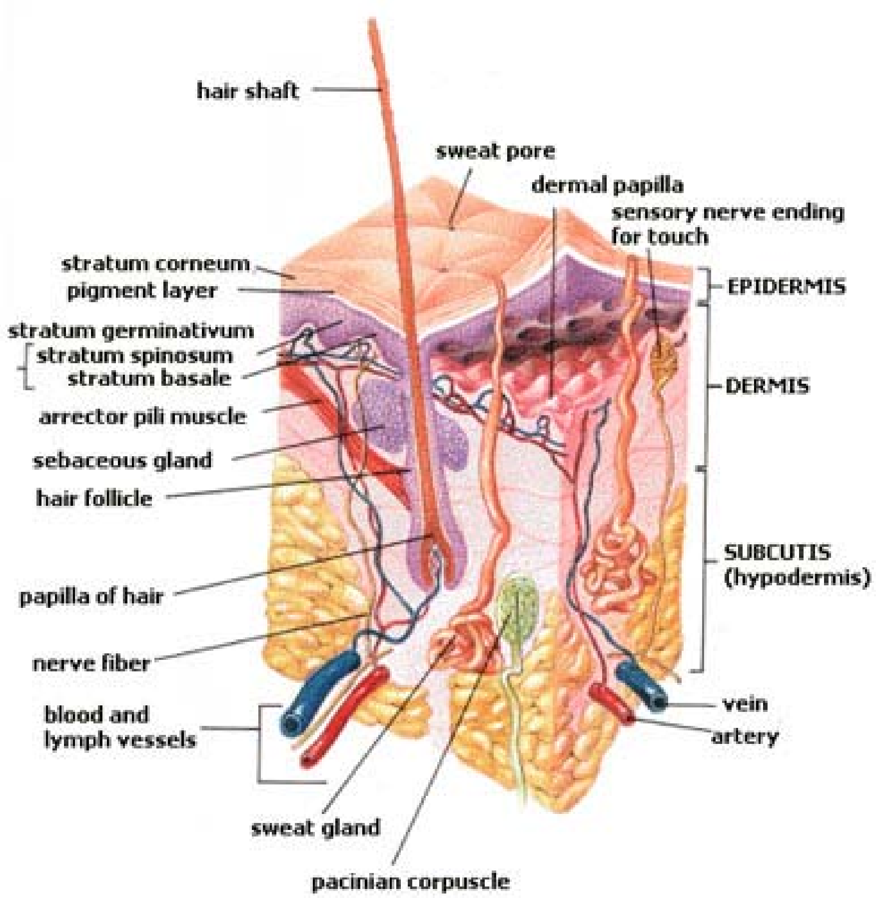


Image from http://en.wikibooks.org/wiki/Human_Physiology/Print_Version

Olfaction

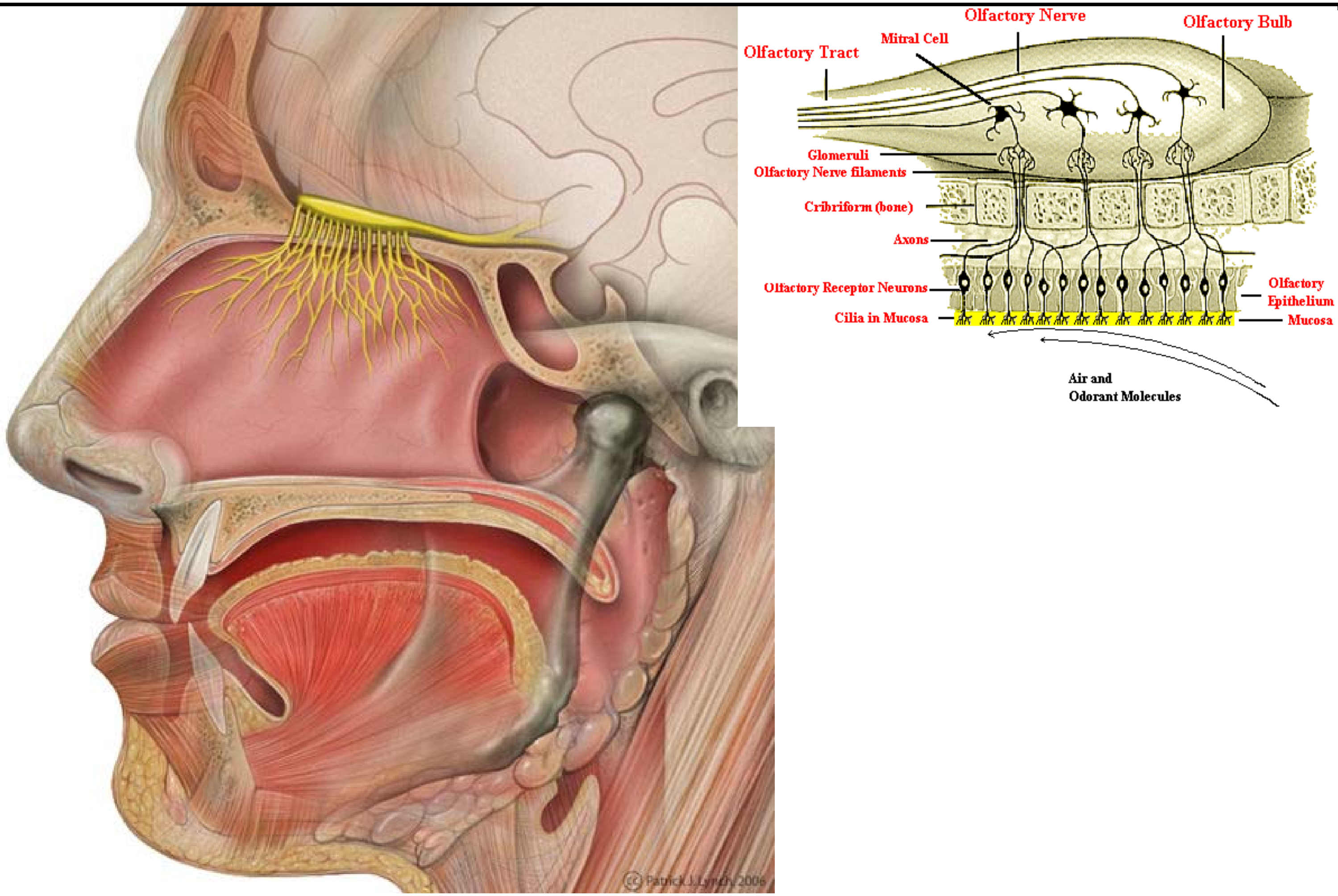


Image from http://en.wikibooks.org/wiki/Human_Physiology/Print_Version

Gustation

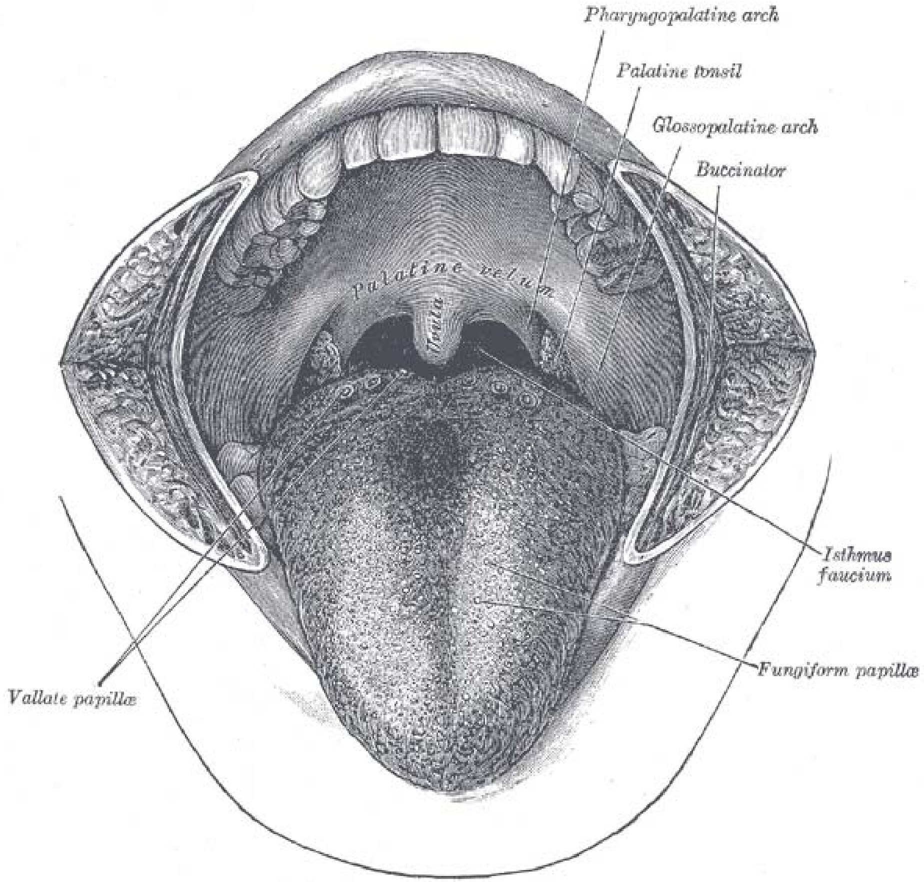


Image from http://en.wikibooks.org/wiki/Human_Physiology/Print_Version

Visual Displays

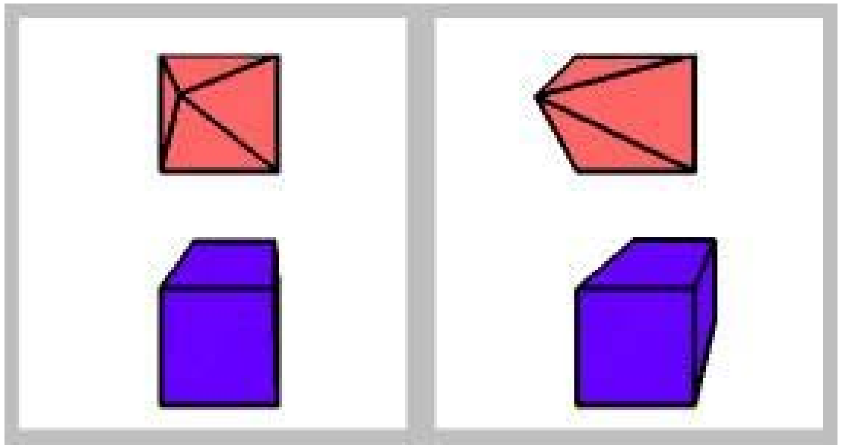
- Fishtank VR stationary display
- Projection VR stationary display
  - Surround-screen displays
  - Tabletop displays
  - Wall displays
- Occlusive head-based display
  - Head-mounted display (HMD)
  - Binocular mono-oriented monitor (BOOM)
- Nonocclusive head-based display
- Hand-coupled display

Visual Display Presentation Qualities

- Color
  - mostly trichromatic color
  - monochromatic color in some displays – e.g. see-through HMD
  - field-sequential color display – overlays the three colors in same location
- Spatial resolution
  - number of pixels
  - pixel density
- Contrast/Brightness
  - dynamic range of the display
  - LCD displays tend to have lower contrast than CRTs
  - See-through HMD requires brighter display

Visual Display Presentation Qualities

- Number of display channels
  - two for stereoscopic displays
  - sometimes two display channels, but the same image on both
  - many ways to transmit multiple channels: color (anaglyph), polarization, time-multiplexing, spatial-multiplexing
  - can combine techniques to introduce more channels (perhaps for two viewers) – e.g. Fakespace DuoView



Visual Display Presentation Qualities

- Focal distance
  - distance at which images seem to appear
  - typically the screen in stationary displays
  - can be infinite via optics in an head-based display
- Opacity
  - occlude the real world or not
  - CAVE does not occlude the real world
  - most HMDs occlude the real world
  - see-through HMD is generally used for AR applications
- Masking
  - hiding things behind an object
  - a problem when a virtual object comes between the viewer's eyes and a physical object
  - physical objects (e.g. user hand) mask virtual objects in stationary displays

Visual Display Presentation Qualities

- Field of view
  - measure of the angular width of user's vision
  - typical HMDs cover about 100 degree FOV with about 60 degree stereo overlap FOV
- Field of regard
  - amount surrounding space where virtual world is displayed
  - HMDs are typically 100%
  - CAVEs are often much less (except for 6-sided CAVEs)
- Head position information
  - typically position trackers monitor six degree of freedom (DOF) of the participant's head
  - 3-DOF orientation is needed for HMDs
  - 3-DOF location is needed for stationary displays

Visual Display Presentation Qualities

- Graphics latency
  - lag between user movements and the update of the display
  - source of causing nausea or headaches
  - lag is very noticable when rotating head in HMD
  - lag is less noticable when rotating head in CAVE
- Temporal resolution (frame rate)
  - image updates per second (measured as FPS or Hz)
  - motion pictures capture 24 FPS
  - 15 Hz is considered marginally acceptable
  - 10 Hz and below causes brain to notice that it is seeing a series of still images

Logical Qualities of Visual Displays

- User mobility
  - can effect on mental immersiveness and usefulness of user VR experience
  - e.g. cables that tether the user, tracking systems with limited range, or screens that prevent further physical movement
- Interface with tracker methods
  - type of displays can influence the selection of tracking methods
- Environment requirements
  - conditions of the surrounding space necessary to provide a good VR experience
  - projection-based displays require low light
  - CAVE requires big rooms

Logical Qualities of Visual Displays

- Associability with other sense displays
  - headphones and HMDs work well together
- Portability
  - large stationary displays are not portable
  - e.g. HMD vs. CAVE

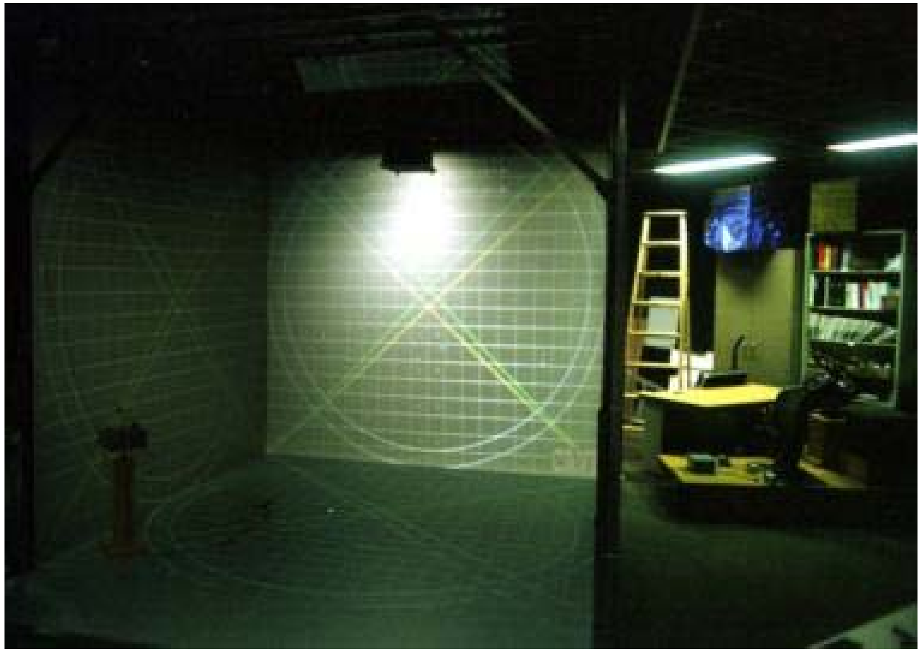
Logical Qualities of Visual Displays

- Throughput
  - HMDs often requires a minute or two to change viewers
  - easier for people to enter and exit a CAVE
- Encumbrance
  - generally more wires associated with HMDs
- Safety
  - eye fatigue and nausea can result from poor optics
  - can’t see what you’re doing in real world in an occlusive HMDs
- Cost
  - generally head-based displays tend to be lower priced than large-screen projection systems
  - CAVE requires more graphics power

Monitor-based or Fishtank VR

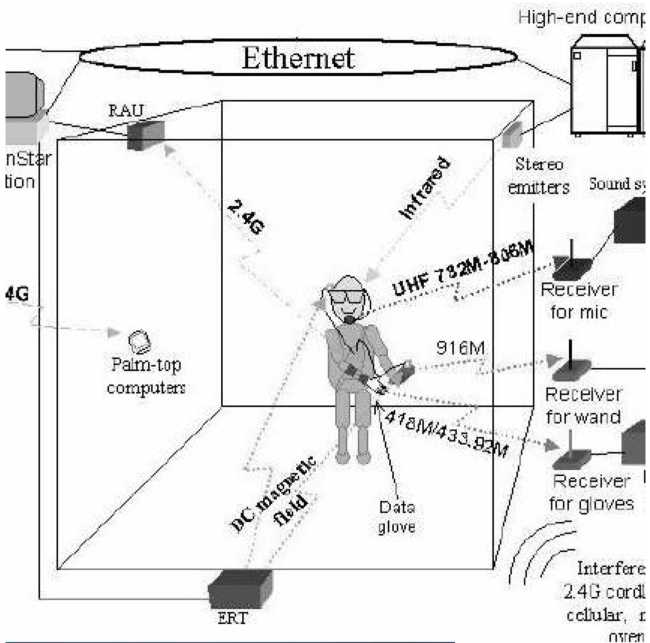
- Use standard computer monitor
- Differ from generic interactive 3D graphics displayed on a monitor because render scenes based on the user's head tracking data
- Fewer components & lower cost
- Standard interface devices available (keyboard, mouse)
- Limited FOV & FOR
- Generally less mentally immersive

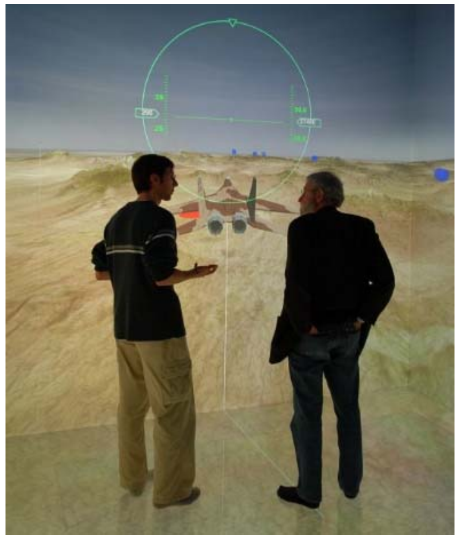
Projection-based VR: Surround-screen displays



- Mostly rear-projected to avoid the participants casting shadows on the screen
- Larger more costly displays
- Longer range tracking systems
- Greater FOV & FOR
- Not isolated from the real world
- Multi-viewers friendly
- Not very encumbering
- Less eye strain
- More space required
- More graphics power required
- Occlusion problem

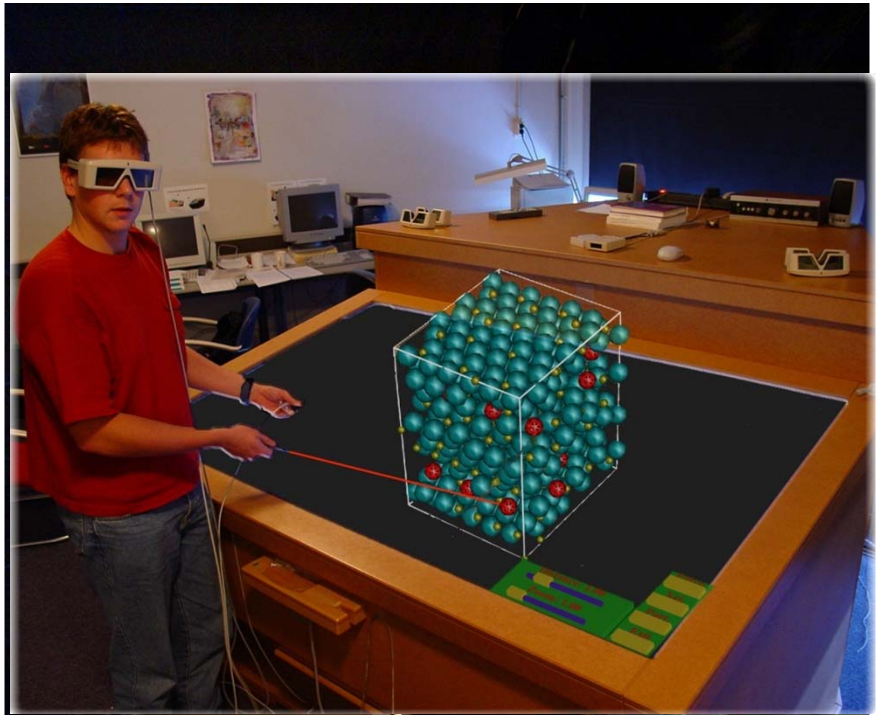
Projection-based VR: 6-sided CAVE





https://www.mechdyne.com/case_study/iowa-state-university/

Projection-based VR: Tabletop displays

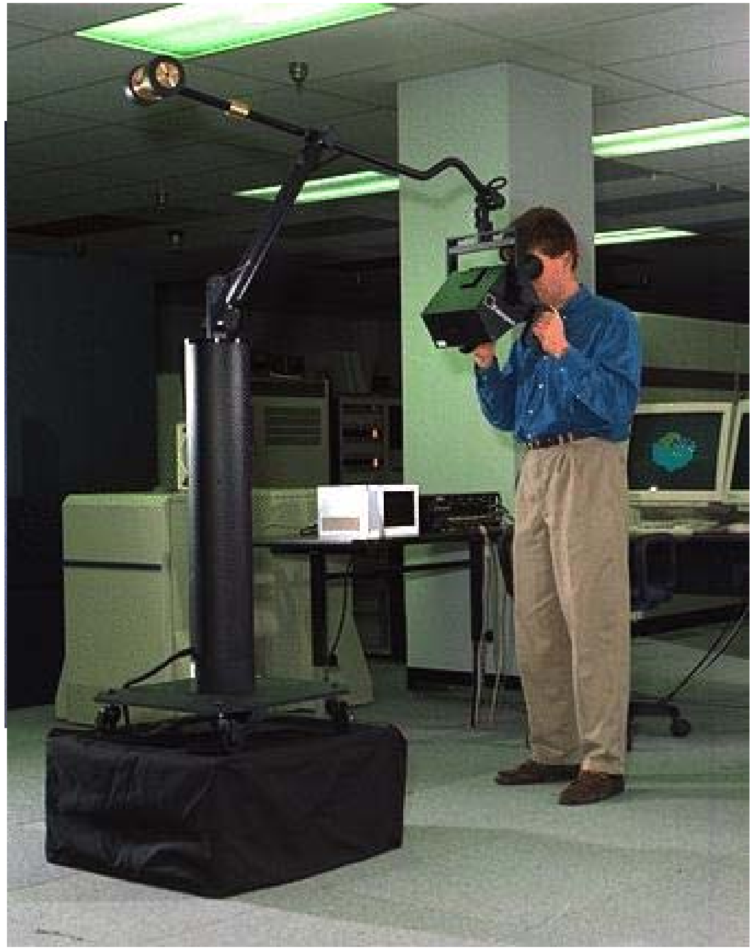


- Good for direct manipulation
- Good for god's eye view
- Good for changing orientation
- Less immersion than surrounded VR displays

Projection-based VR: Wall displays

- 3D movie-like VR displays
- Larger tiled or curved wall displays are suited for larger audiences – larger pixel, need more projectors
- Less immersion than surrounded VR displays
- Problem of seamless integration

Head-based Displays



- Small, lightweight screens
- More portable than stationary VR displays
- More encumbering than stationary VR displays
- Tethering to computer
- 100% FOR
- Limited FOV
- No peripheral vision
- Lag in tracking is detrimental
- Eye fatigue

Head-Mounted Displays (HMD)

- e.g. Sony Glasstron
- HMD Vendors at http://www.faqs.org/faqs/virtual-worlds/visual-faq/section-2.html

Best VR headset for 2020

Oculus Quest, HTC Vive or PSVR? It all depends on who you are and how much you want to spend.

Scott Stein Sept. 8, 2020 7:38 a.m. PT

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Oculus Quest
The best standalone VR
Jump to details
$632 AT AMAZON

Sony PlayStation VR
Still worth it for the games
Jump to details
$245 AT AMAZON

Oculus Rift S
Best easy-to-set-up PC VR
Jump to details
$399 AT LENOVO

Valve Index
Best PC VR to explore the future of VR controllers
Jump to details
$999 AT STEAM

HTC Vive Cosmos
Could be a flexible, modular system
Jump to details
$700 AT AMAZON

Yes, VR is still around, and standalone VR devices have seen a huge spike in interest this year since the March release of Valve's Half-Life: Alyx. But this technology is ever-evolving, and the concept of a VR device in 2020 is in transition. This is because companies such as Qualcomm (which makes the chips inside most self-contained VR headsets, including the popular Oculus Quest) are building new chips that point to a wave of better standalone headsets at lower prices -- including ones that plug into your phone.

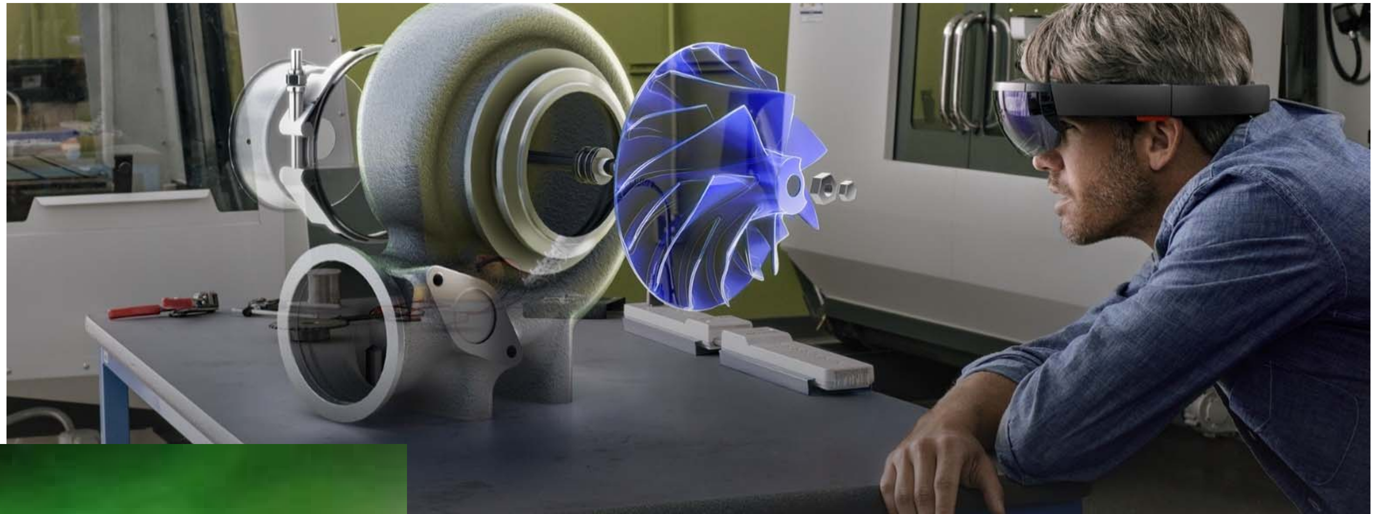
Meanwhile, older mobile VR or phone-based VR headsets, like the Samsung Gear VR and Google Daydream are basically dead. A good number of the current iPhone,

https://www.cnet.com/news/best-vr-headset-for-2020/

See-thru Head-based Displays

- Optical see-through vs. video see-through
- Require 6-DOF tracking
- Registration of tracking with the real world
- Application must live within the restriction of the real world
- Proper rendering of object occlusion is difficult

See-thru Head-based Displays



Handheld VR

- Limited example of handheld VR – e.g. Chameleon, Virtual binoculars
- Used as a magic lens
- Need to track both the screen and the head
- Registration of tracking with the real world
- Can be used in conjunction with projection-based VR displays

Auditory Displays

- Speakers
- Headphones

Aural Display Presentation Qualities

- Number of display channels
  - monophonic
  - stereophonic
  - quadraphonic, octaphonic, 5.1
  - multiple speakers rely on ears to naturally localize sounds
- Sound stage
  - source from which a sound appears to emanate
  - **head-referenced** vs. **world-referenced**
    - head-referenced sound stage moves with the head
    - world-referenced sound stage remains fixed with the world
  - sounds require filtering based on head tracking to reproduce a world-referenced sound stage with headphones

Aural Display Presentation Qualities

- Localization (Spatialization)
  - localization is human brain's ability to determine the location from which a sound is emanating
  - spatialization is technology's ability to make a sound appear to come from particular points in space
  - spatialization is easier with headphones due to direct sound control
- Masking
  - loud sounds mask softer sounds
  - physical objects can mask a sound
  - closed headphones are best for VR experience where the participants is only supposed to hear sounds from the virtual world
- Amplification
  - Need to boost the sounds to hearable levels

Logical Qualities of Aural Displays

- Noise Pollution
  - speakers require quiet and echo free environment
- User mobility
  - wired headphones limit mobility
- Interface with tracker
  - magnets in the speaker/headphones
- Environment requirements
- Associability with other sensors
  - typically stationary with stationary, head-based with head-based
- Portability & Encumbrance
  - speakers generally more comfortable for longer use
- Throughput
  - speakers work better for larger audiences
- Safety & Cost

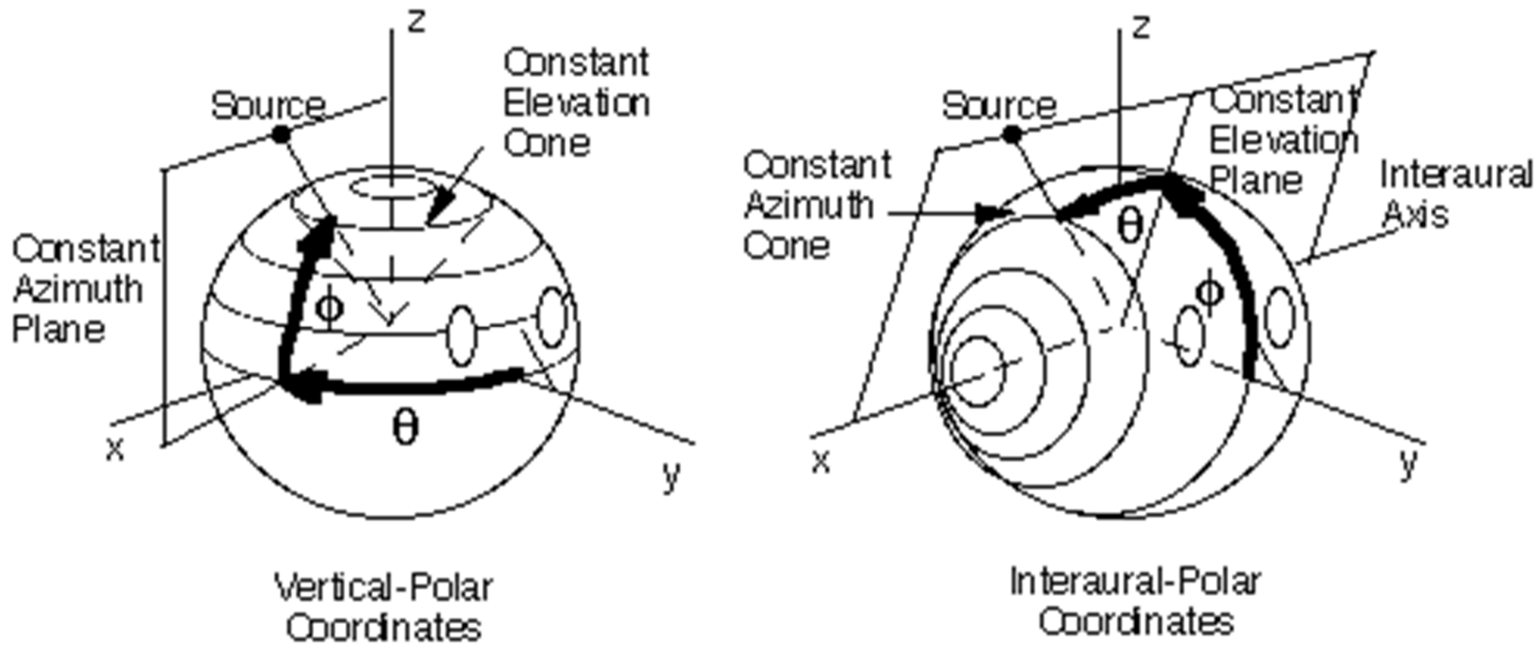
Simple Virtual Environment Audio

- Intensity fall-off
- Headphones also block real-world noises
- Ambient sound in the background
- Subwoofer in seat or platform
- Present speech instead of text

3D Sound Localization

- Spatialization
- Works well in plane of ears
- Based on:
  - Interaural intensity differences (IID)
  - Interaural time differences (ITD)
- Head-Related Transfer Function (HRTF)

Vertical-Polar Coordinate System



θ: azimuth (angle between the nose and a plane containing the source and the vertical axis z)
ϕ: elevation (angle between the horizontal plane by a line passing through the source and the center of the head)
ρ: range (distance to the source measured along this line)

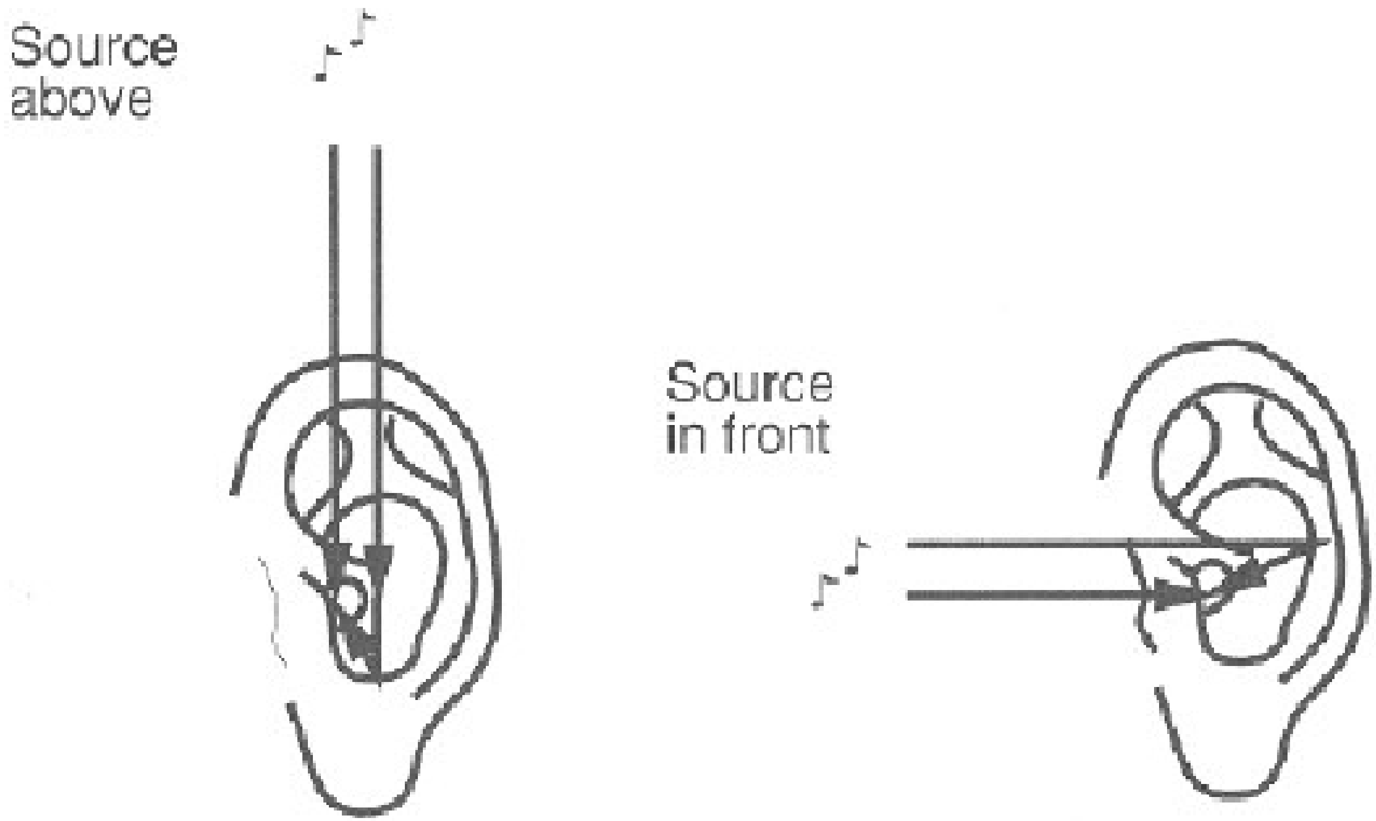
Azimuth Cues

- Interaural time difference (ITD)
  - difference in the arrival time of the sound at the two ears
  - ITD is zero when the azimuth angle is 0 degree, i.e. the source is directly in front of or directly behind the head
  - $ITD = (a/c)(\theta + \sin\theta)$
    - a: the head radius
    - c: the speed of sound (~343 m/s)
    - θ: source azimuth
- Interaural intensity differences (IID)
  - difference in the intensity of sound reaching the ears
  - the closer ear hears a sound with higher intensity
  - detectable for sounds with high frequencies (>1.5kHz)
  - for low frequency, ITD dominates

Elevation Cues

- Different reflections
  - Due to the asymmetry of the outer ear, especially the pinna
  - the path difference between the direct and pinna-reflected sound changes with the elevation angle
  - sound coming from a source located above the user's head has quite a different reflection path than sound coming from a source in front of the user
- Different amplification (and attenuation)
  - by interference between reflected sounds
  - some frequencies are amplified and others are attenuated
- Pinna provides the primary cue for source elevation
  - user's face and shoulders geometry also influences the way the sound is reflected towards the outer ear

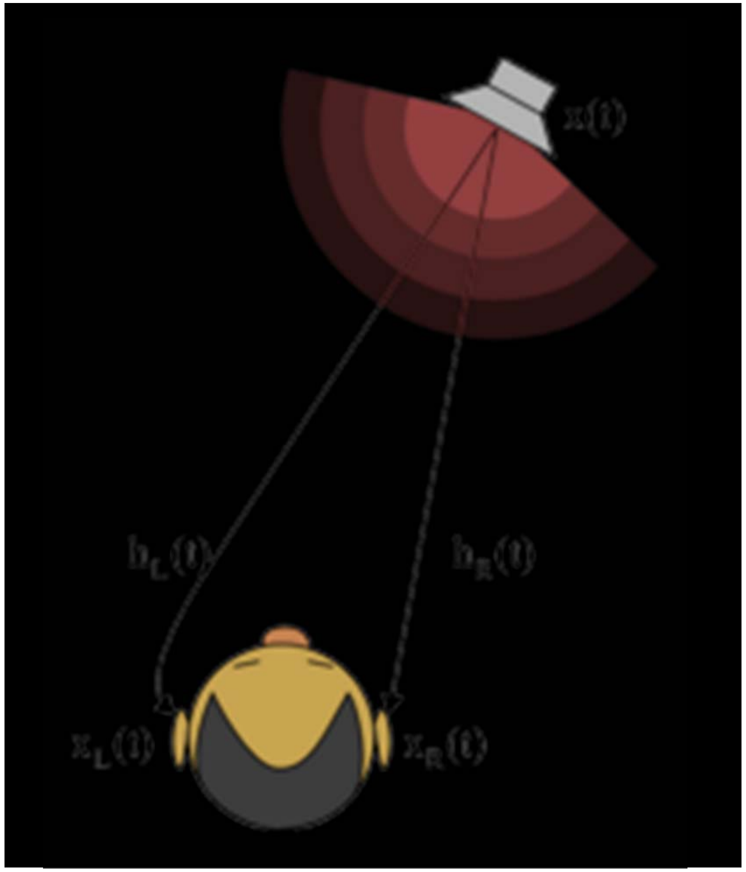
Elevation Cues



Range Cues

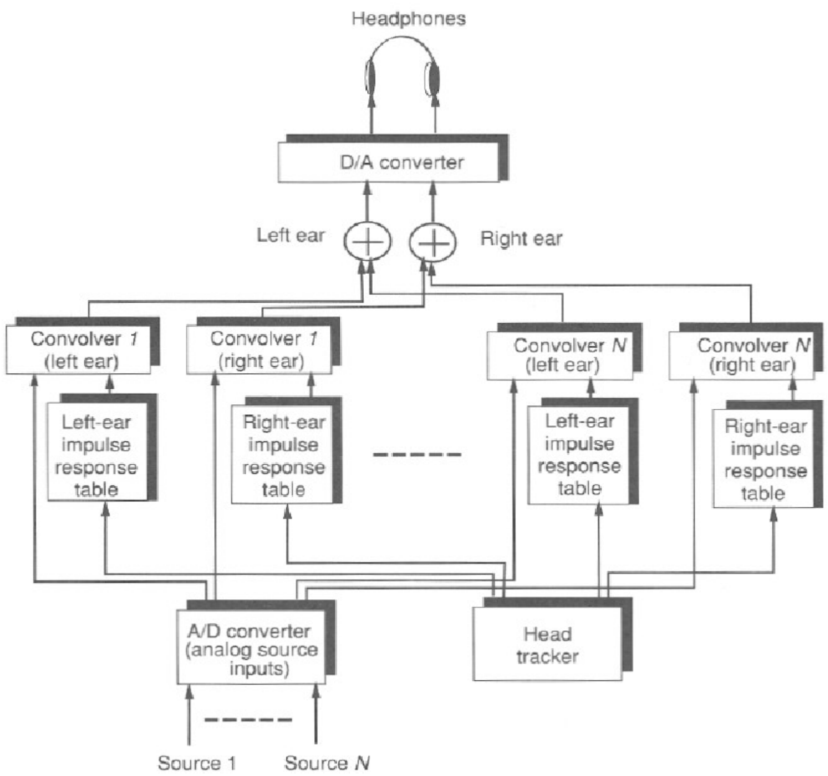
- Perceived loudness
  - prior knowledge of a given sound source
  - faint siren (which is a normally high-energy sound source) is perceived as being distant
  - clear whisper (which is a normally faint sound source) is perceived as being close
- Motion parallax
  - change in sound source azimuth when the user is moving
  - large motion parallax indicates a source nearby
- Ratio between direct and reflected sound
  - energy of the direct sound drops off with the square of the source range
  - energy of the reflected sound does not change much with range

Head-Related Transfer Functions



- HRTF captures all of the physical cues to source localization
- Experimental measurement of transfer function
  - sounds from speakers at different locations
  - tiny microphones in the ears
  - analysis of recordings from both ears
  - head-related impulse responses (HRIRs)
  - head-related transfer functions (HRTFs)
- Each individual has his/her HRTF signature, also called ear print

Convolvotron



- Crystal River Engineering
- HRTF-based spatial audio system
- The system can be customized for a particular individual by measuring and using that person's HRTF
- Echoes and room reverberation can be added by including a room simulation model
- Head motion can be accounted for by combining the absolute location of the source with the outputs of a head tracker to select the appropriate HRTFs

Ambisonics

- Presentation of 3D spatialized sound using multiple stationary speakers
- surrounding sound recording, synthesis and playback system

http://en.wikipedia.org/wiki/Ambisonics

Haptic Displays

- Kinesthetic/Force displays
- Tactile displays
- End-effector displays
- Robotically operated shape displays

Haptic Display Presentation Qualities

- Kinesthetic cues
  - nerve inputs that sense angles of joints, muscle length, tension, and resistance to muscle effort (force) within the body
  - helps us determine firmness, approximate shape, and physical force
- Tactile cues
  - sensory receptors at the skin
  - mechanoreceptor – shape and surface texture
  - thermoreceptor – heat
  - electroreceptor – electric current flow
  - nociceptor – pain
- Grounding
  - force/resistance displays require an anchor
  - self-grounded vs. world-grounded

Haptic Display Presentation Qualities

- Number of display channel
  - how many points of contact with the body
  - 1 channel when Phantom has one point where the user can influence the virtual world
- Degrees of freedom
  - 6-DOF in unconstrained movement
  - 1-DOF display for how far can the thumb be opened/closed
  - 1-DOF display for how far down a tube can you insert a laparoscope camera
  - 2-DOF display for how far down a tube, plus twist
  - 3-DOF display for down, twist, clamping action and resistance
  - 3-DOF display for location of the finger or stylus
  - 6-DOF display for location and orientation

Haptic Display Presentation Qualities

- Form
  - the shape of the physical unit with which the user interacts
  - generic form, such as stick, ball, or plane
  - specific object, such as handgun, or steering wheel
  - amorphous that changes shape to multiple specific representations
- Fidelity
  - how rapidly the system can change to the proper display (force, temperature)
  - can be rated by a maximum stiffness measurement taken in Newtons/meter (Nt/m)
  - a stiffness of 20 Nt/cm as a solid immovable wall
  - 40 Nt/cm is the maximum force that a human finger can exert
  - 10 Nt/cm is the highest force used when doing fine manipulation

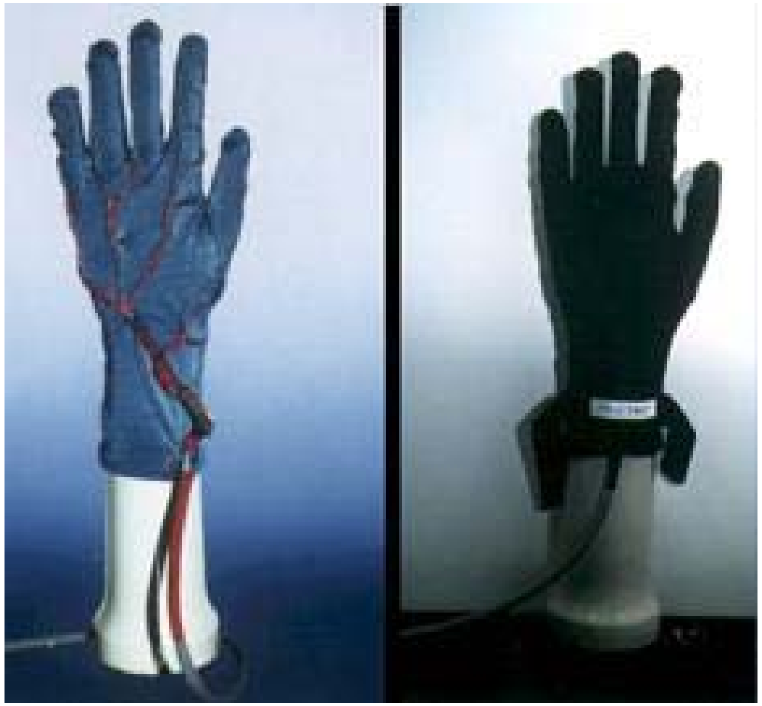
Haptic Display Presentation Qualities

- Spatial resolution
  - higher resolution required at the fingertip
  - fingertips can sense difference 2mm apart
  - 30 mm on the forearm & 70 mm on the back
- Temporal resolution
  - how quickly the system can be updated to new display
  - low frame rate on a force display causes the object to be perceived as shakey
  - 1000 Hz is a good minimum
- Latency tolerance
  - low latency display is crucial, especially for force display
- Size
  - larger displays allow broader range of motion

Logical Qualities of Haptic Displays

- User mobility
  - world-grounded displays require the user to be near the device
- Interface with tracker
  - responsive and accurate tracking system is required
- Environment requirements
- Associability with other sense displays
  - occlusive HMDs often are used in conjunction with haptic displays
- Portability
- Throughput
- Encumbrance
  - self-grounded, exoskeleton-style devices are generally much encumbering
- Safety
  - safety is a significant concern with many haptic displays

Tactile Displays



Teletact Glove

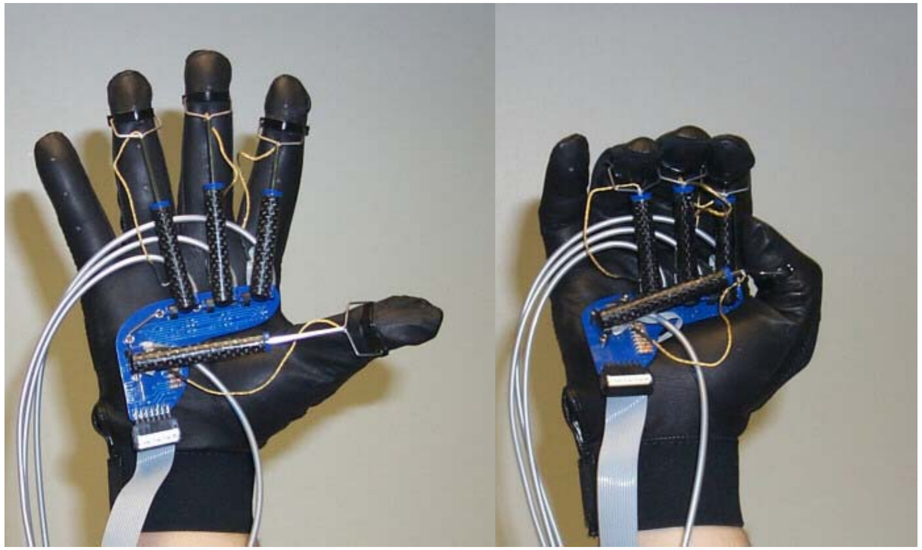
- Sensed by the skin – the largest single organ of the human body
- Actuators mounted generally on the fingers and hand
- Generally no need for world grounding
- Bladder actuators
- Vibrator actuators
- Pin actuators
- Thermo actuators
- Helps in the fine manipulation of virtual objects
- Less expensive & portable

Tactile Displays using Vibrators

Cyberglove

Cricket Prob

End-effector Displays



Rutgers Dextrous Master

- A mechanical device that provides a force to the participant's extremities
- Generally linked to mechanical tracking sensors
- Generally world grounded (exoskeleton method is body-grounded)
- Often operate with respect to a single point in the virtual world
- Fast and accurate tracking is usually built into display

Robotically Operated Shape Displays

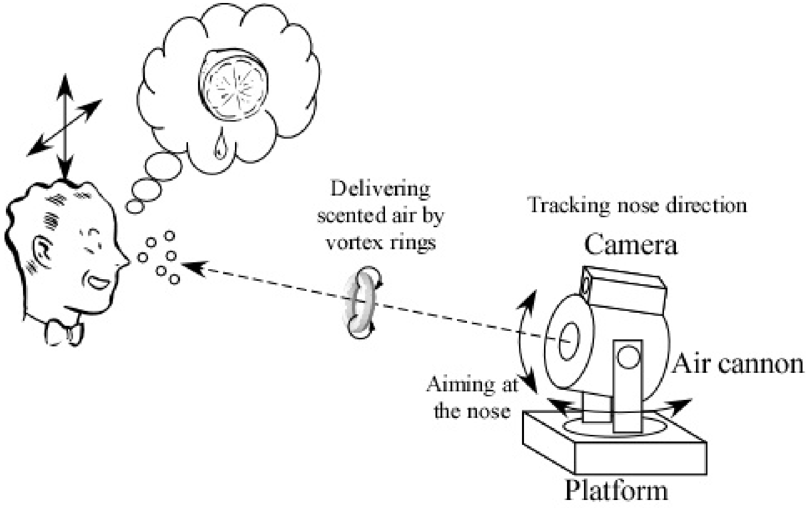
Cybernetic Systems

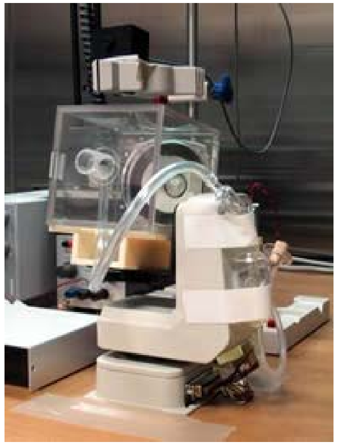
- Use robots to place a representation of the virtual world where the user is reaching
- May be generic (corners and edges) – e.g. Cybernetic Systems
- May be specific (selection of switches) – e.g. Boeing
- Usually uses a finger surrogate for fast tracking
- Can provide a very realistic haptic display
- World-grounded display
- Works with HMDs

Olfactory Displays

- Very little research is done in olfaction
- Lack of effective displays and difficulty in producing broad range of stimuli
- Olfactory events (odor sources) may be near or far, but directional sensitivity is generally poor
- Temporal sensitivity is poor and response times are slow
  - May need 20-60 seconds between stimuli to resolve different smells
  - To control over stimulus decay rate (without significant air circulation)
- Smell synthesis
- Require chemicals
- Olfactometer
- Smell-O-Vision

Olfactory Displays

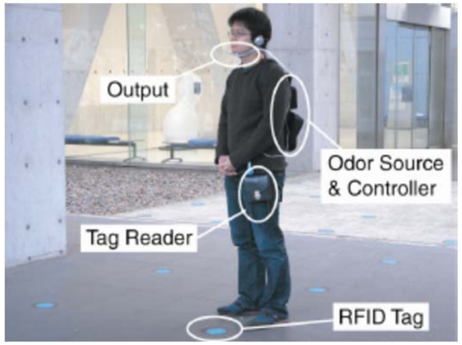


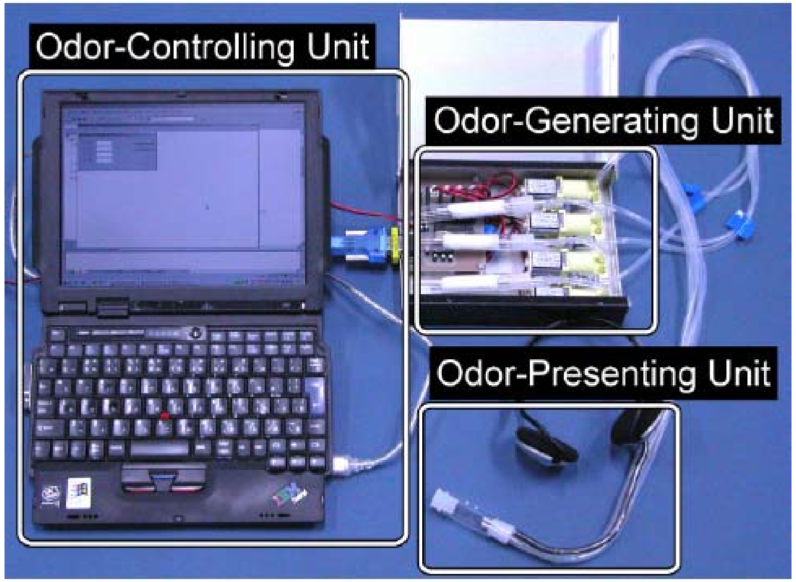


- ATR Scent Projector
  - Projection-based olfactory display with nose tracking
  - Unencumbering: Users do not need to wear any devices or glasses
  - Localized: Scent can be perceived only within a limited range of space at a certain time
  - Composed of “air cannon”, scene generator (aroma diffuser), 2DOF platform and a CCD camera

Image from http://www.mis.atr.jp/past/sem/scent.html

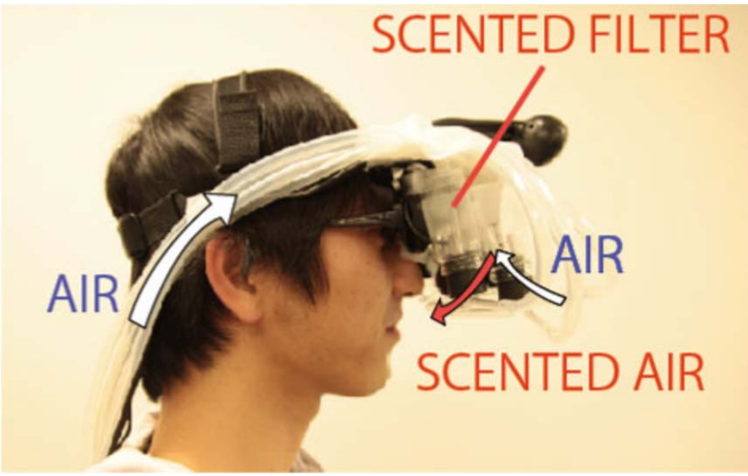
Olfactory Displays





- Wearable Olfactory Display by U. of Tokyo
  - odor-generating unit (air-pump & odor filters)
  - odor-controlling unit (a notebook PC and a device controller)
  - odor-presenting unit (to present the mixing of odor air)

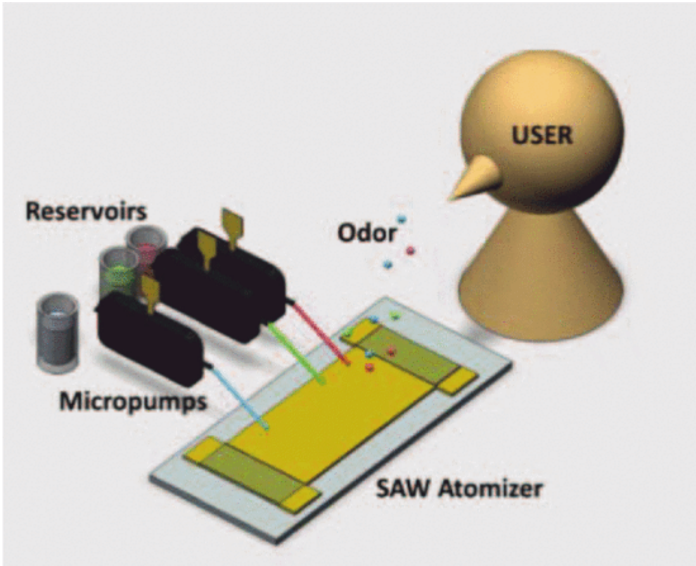
Olfactory Displays



- Meta Cookie @ University of Tokyo – Air-pump type head-mounted olfactory display (2011)

https://www.exploratorium.edu/blogs/fabricated-realities/meta-cookie-olfactory-gustatory-augmented-reality

Olfactory Displays



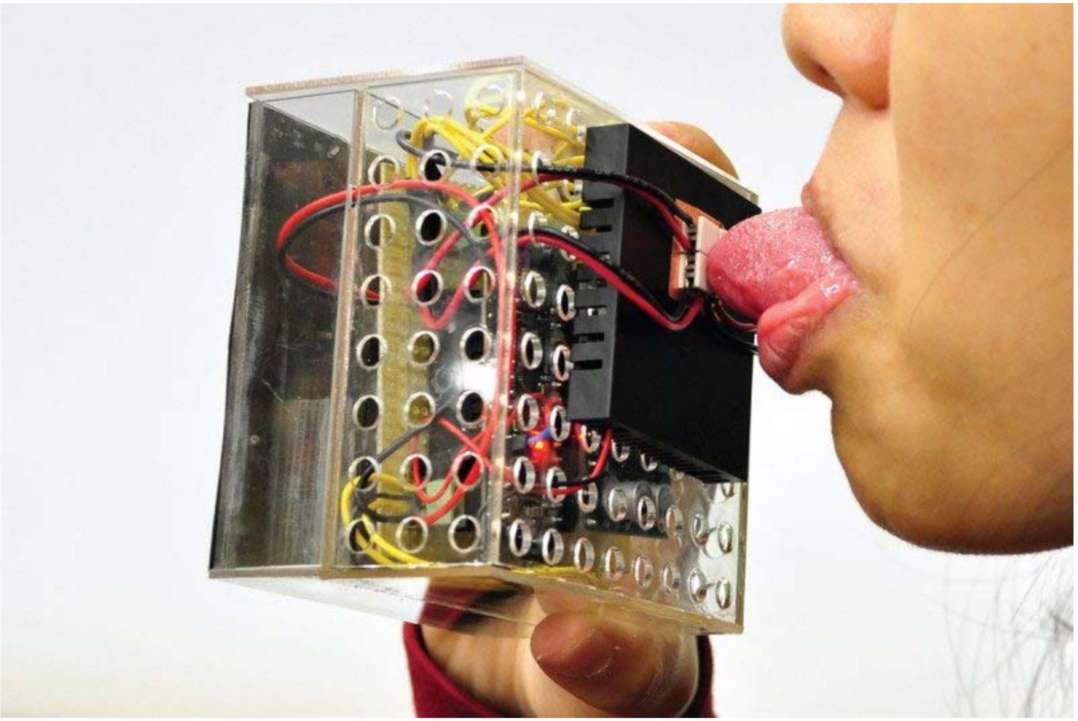
VR Oculus Rift Olfactory Display @ Tokyo Institute of Technology (2016)
https://hackaday.com/2017/03/21/your-vr-doesnt-stink-yet/
https://www.youtube.com/watch?v=LCYe4euI3TA

Gustatory Displays

- Affected by other senses – strong influence of smell on taste
- Need more than flavor – e.g. texture
- Basic elements of taste – salt, sour, bitter, sweet, umami, smell

Food Simulator 2003
Image from http://www.siggraph.org/s2003/conference/etech/food.html

Gustatory Displays



Unreal: this tastes delicious (2016)
https://www.newscientist.com/article/2111371-face-electrodes-let-you-taste-and-chew-in-virtual-reality/

Vestibular Displays

- Physically move the user – e.g. motion platform
- Sense of body movements or acceleration
- Vestibular information works together with visual and kinesthetic information
- Virtual body representation
- Can “display” to these senses by stimulating the proper parts of the brain

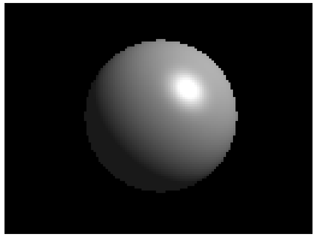
Rendering Systems

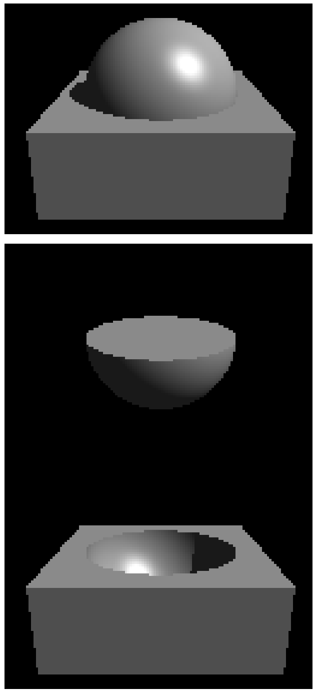
- Visual
- Aural
- Haptic

Visual Rendering Systems

- Computer graphics
  - generating visual imagery
- Software rendering
  - graphical rendering routines
- Object presentation schemes
  - Geometrically based (polygons, NURBS, CSG)
  - Non-geometric forms (volumetric rendering, particle systems)

Geometrically-based Representations





CSG

- Polygons
- Constructive Solid Geometry (CSG)
- Non-Uniform Rational B-Splines (NURBS)
- Other representations are often converted to polygons for hardware rendering

Non-geometrically-based Representations

- Volume rendering
- Particle systems

Techniques for rendering complex visual scenes

- Shading
- Reducing polygons:
  - Texture mapping
  - View culling
  - Level of Detail (LOD)
  - Atmospheric effect, e.g., fog
- Multiplexing multiple renderers to one screen:
  - Added cost of additional rendering systems
  - Decrease average image latency for each frame
  - Does not decrease onset latency
  - Reduces the maximum delay between the input and the response

Internal Computer Representation

- Most hardware graphics rendering engines are optimized for polygonal representation
- 3D models created by a model package, Alias, SoftImage, AutoCAD, VRML
- A scene graph is a mathematical graph that allows objects and object properties (colors, materials, textures) to be related to one another in a hierarchical fashion.

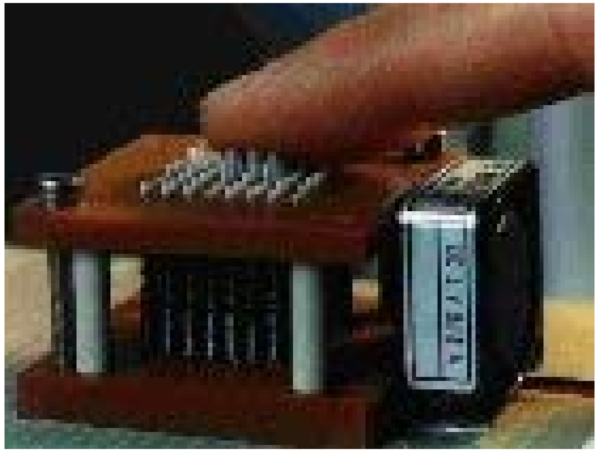
Aural Rendering Systems

- Sampling
  - A common way of producing sounds
  - Playback of digitally recorded samples of physical world sounds
  - 8 KHz telephone, 44 KHz CD, 96 KHz DVD quality
- Sound synthesis
  - Spectral method using sound wave's frequency spectrum
  - Physical model using physics of the object generating sound
  - Abstract synthesis is to create sound using some numerical system

Techniques for Rendering Complex Sounds

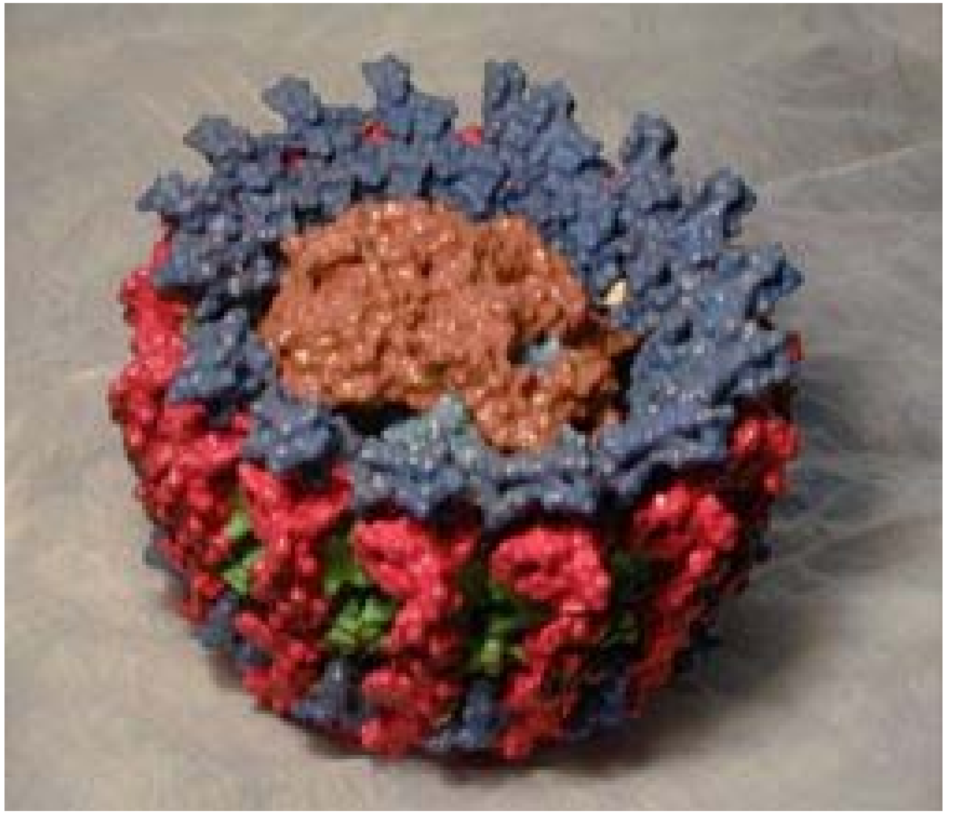
- Frequency modulation (FM)
- Algorithmic additive and subtractive techniques
- Granular synthesis
  - Combining the sound of a single drop of water falling to produce the sound of a waterfall
- Sonic effects
  - Convolution – making a sound appear to come from a particular location
  - Reverberation – using reflections of the sound
  - Chorusing – mixing sounds

Haptic Rendering Systems



- Thermal rendering – usually used on Peltier thermoelectric coolers
- Pin-based rendering
- Kinesthetic rendering using force display
- Robotically operated shape display
- Physical object rendering -3D hardcopy, aka stereolithography

Stereolithography



http://en.wikipedia.org/wiki/Stereolithography

Techniques for rendering complex haptic scenes with force displays

Laparoscopic surgery interface

- Single point of contact with an object
  - E.g. to a fingertip or tip of a stylus
  - Required 3-DOF force display
- Single point of contact with torque
  - Required 6-DOF force display
- Constraint of movement
  - E.g. laparoscopic
- Two points of contact (pinching)
- Multiple points of contact (grasping)

Haptic Rendering Techniques

- Spring and dashpot
  - controls direction, tension, and damping
- Point and plane & Multiple plane
  - interaction between a probe stylus and a surface by placing a virtual planer surface tangential to the probe's tip
- Point to point
- Multi-springs
  - adds torque to any of the other haptic representations
- Inertial and resistant effects
  - resistive forces to add friction and viscosity
  - inertial force to add momentum
- Vibration
  - a signal indicating when the display should vibrate and at what frequency and amplitude

Reference

- An Interactive Introduction to Splines
  http://www.ibiblio.org/e-notes/Splines/Intro.htm
- Haptic Community Web Site http://haptic.mech.northwestern.edu/
- 3D audio http://www.dcs.gla.ac.uk/research/gaag/dell/report.htm
- VR audio http://vrlab.epfl.ch/~thalmann/VR/VRcourse_Audio.pdf
- Scent http://www.mis.atr.jp/past/sem/scent.html