

Display & Rendering

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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

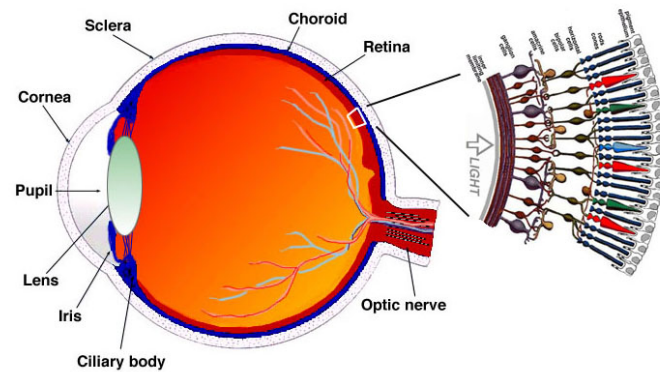


Fig. 1.1. A drawing of a section through the human eye with a schematic enlargement of the retina.

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

Audition

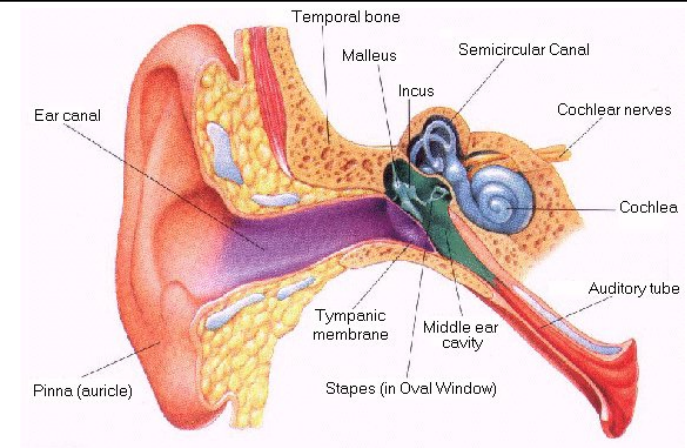


Image from http://www.infj.ulst.ac.uk/~pnjc/HumanEar/Andy's%20Stuff/MScProject/workingcode_Local/EarChapter.html

Touch

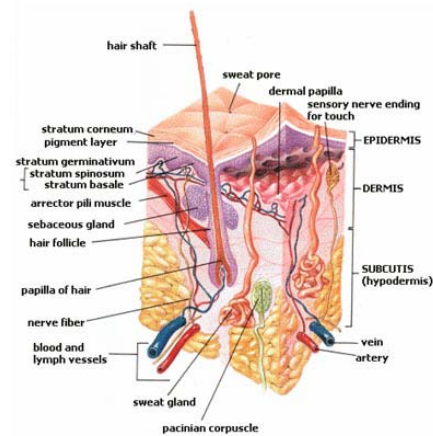


Image from http://en.wikibooks.org/wiki/Human_Physiology/Print_Version

Olfaction

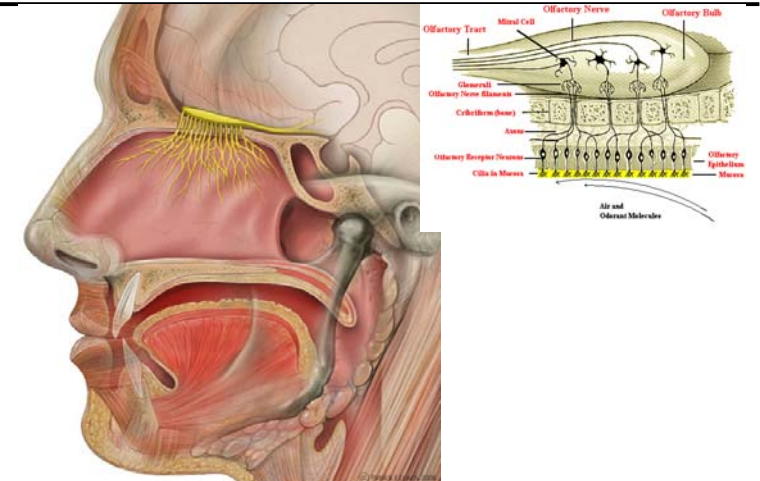


Image from http://en.wikibooks.org/wiki/Human_Physiology/Print_Version

Gustation

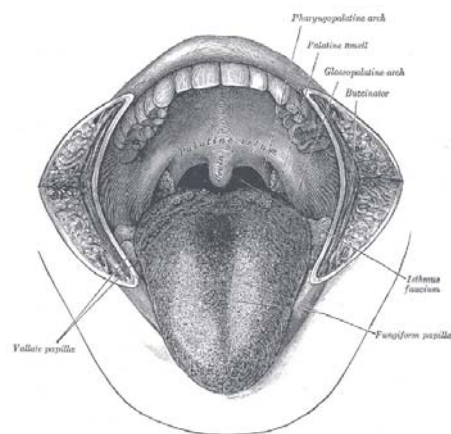


Image from http://en.wikibooks.org/wiki/Human_Physiology/Print_Version

Visual Displays

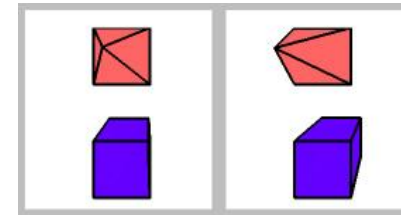
- ❑ Fishtank VR stationary display
- ❑ Projection VR stationary display
 - Surround-screen displays
 - Tabletop displays
 - Wall displays
- ❑ Occlusive head-based display
 - Head-mounted display (HMD)
 - Binocular mono-oriented monitor (BOOM)
- ❑ Nonocclusive head-based display
- ❑ Hand-coupled display

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



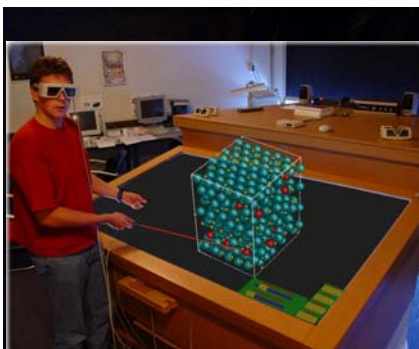
- ❑ Use standard computer monitor
- ❑ Differ from generic interactive 3D graphics displayed on a monitor because render scenes based on the user's head tracking data
- ❑ Fewer components & lower cost
- ❑ Standard interface devices available (keyboard, mouse)
- ❑ Limited FOV & FOR
- ❑ Generally less mentally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



- ❑ 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

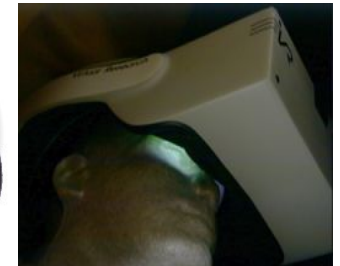
Head-based Displays



- ❑ 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

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



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

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

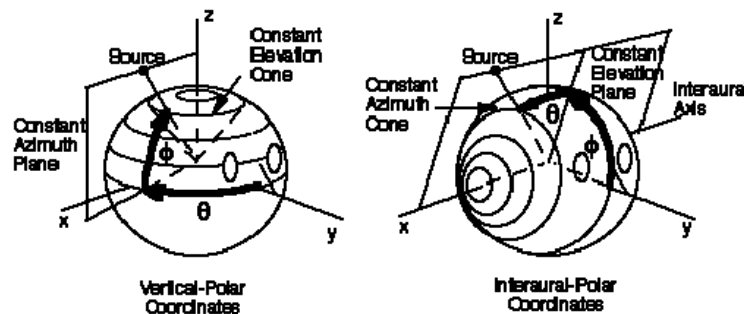
Simple Virtual Environment Audio

- 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)

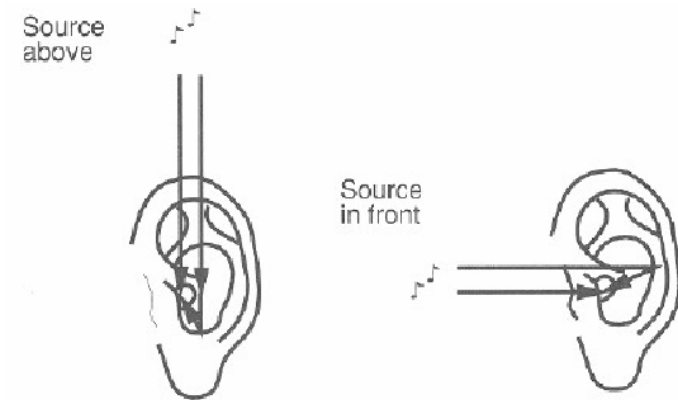
Azimuth Cues

- 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 (>1.5 kHz)
 - 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

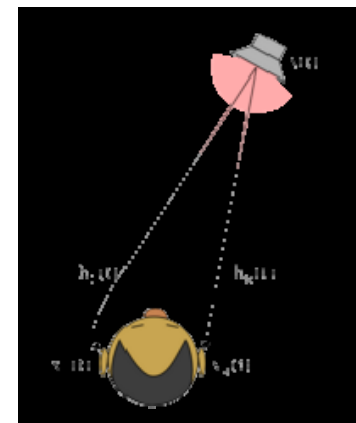
Elevation Cues



Range Cues

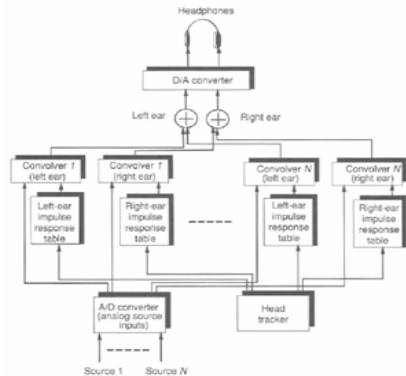
- ❑ Perceived loudness
 - prior knowledge of a given sound source
 - faint siren (which is a normally high-energy sound source) is perceived as being distant
 - clear whisper (which is a normally faint sound source) is perceived as being close
- ❑ Motion parallax
 - change in sound source azimuth when 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

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

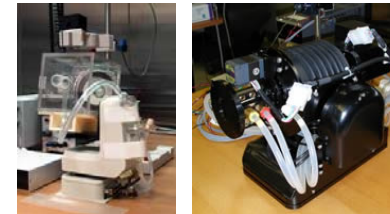
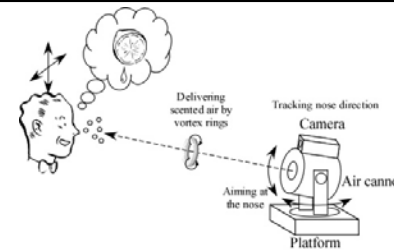
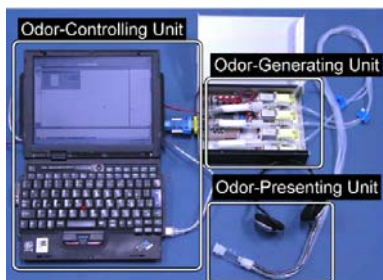


Image from <http://www.mis.atr.jp/past/sem/scent.html>

❑ 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

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)

Gustatory Displays



Food Simulator

Image from <http://www.siggraph.org/s2003/conference/etech/food.html>

- ❑ 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

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

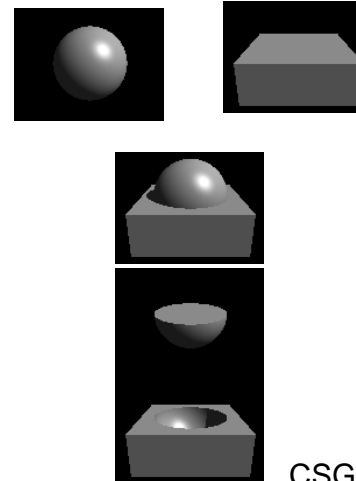
Rendering Systems

- ▣ 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



- ▣ 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



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>