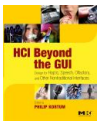
Human Senses, 3D Audio

Lecture 2

The human senses

- Understanding the human senses and properties is required for designing VR devices to deceive senses. Several senses:
- Vision
- Hearing
- Touch
- Smell
- Taste
- Equilibrioception, the vestibular sense (balance, acceleration)
- Thermoception (heat, cold)
- Nociception (physiological pain)
- Proprioception, the kinesthetic sense
  - The sensation of movement or strain in muscles, tendons, and joints; muscle sense
  - Provides feedback solely on the status of the body internally. It is the sense that indicates whether the body is moving with required effort, as well as where the various parts of the body are located in relation to each other
- Non-human animal senses:
  - Electroception: the ability to detect electric fields
  - Echolocation: the ability to determine orientation to other objects through interpretation of reflected sound (e.g. bats)
  - Magnetoception: the ability to detect fluctuations in magnetic fields (birds, bees)
  - Pressure detection uses the lateral line, which is a pressure-sensing system of hairs found in fish and some aquatic amphibians. It is used primarily for navigation, hunting, and schooling
  - Polarized light direction / detection is used by bees to orient themselves, especially on cloudy days



Sensations

- Stimulus
  - The signal
- Sensation
  - Experiences associated with simple stimuli
- Perception
  - The integration and meaningful interpretation of sensations
- Stimulus threshold
- Sensitivity range is limited
- Our data processing is both electrical and chemical
  - Extremely delicate, complex and meticulously designed system
  - Human eye complexity: http://www.detectingdesign.com/humaneye.html
- You can measure the energy, but not the sensed perception

Minimum stimulus

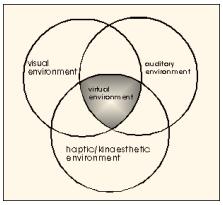
- Weber's Law: Just noticeable difference
  - Vision .08
  - Audition .05
  - Kinesthesis .02
- Vision
  - A candle flame seen at 48 km on a dark, clear night
- Hearing
  - The tick of a clock at 6 m under quiet conditions
- Taste
  - One teaspoon of sugar in 7.6 liter of water
- Smell
  - One drop of perfume diffused into entire volume of six rooms
- Touch
  - The wing of a fly falling on your cheek from the distance of 1 cm

Artificial sensations

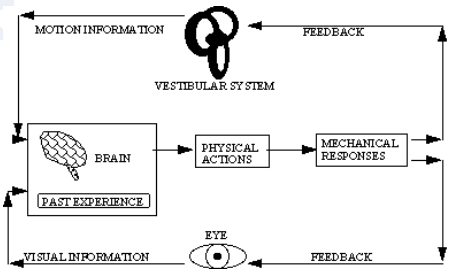
- Deceiving the senses
  - A perfect illusion?
  - Hardly possible
- Immersion
  - Entering the image
- Interaction
- Multimodality
  - Human-computer communication using multiple senses
  - Human friendly, close to senses
- The quality of stimuli and amount of the devices depend on the task and the budget
- Also background music and other non-realistic issues are important in entertainment applications

Fooling the human senses

- Try to find the shortcuts and cheatings
  - Approximation, essence
- The best cues are unnoticeable
- All cues together, synchronized
  - Visual system
  - Sound system
  - Haptic system
  - Balance system
    - Balance and acceleration
  - Other senses



Creating artificial sensations



Auditory System

- Primary channel for communication and music
- Along with vision, audio is our major means of obtaining information about the environment
- Outer ear is visible and is made of folds of skin and cartilage
  - Collects sound waves, which travel down the auditory canal and vibrate the eardrum
- Middle ear, containing eardrum
- Inner ear analyzes sound waves and contains an apparatus that maintains the body's balance
- Parts of the brain process signals
- Connecting neural pathways

Sound

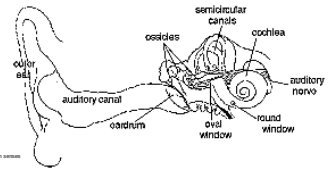
- SGN Digital audio (SGN-4200, 4010, 4106)
- Sound is pressure changes, a wave movement
- In air 340 m/s (temperature-dependent)
- Infra/ultrasounds
- Audio: speech, music, noise
- Intensity (psycholog. loudness), dB
- Wavelength (psycholog. pitch), Hz
- Computer music, speech processing, acoustics
- Multimedia, user interfaces, VR
- Sonification (data visualization with sound)
- "Auralization" partly at books.google.com
- SGN audio: http://www.cs.tut.fi/sgn/arg/
- HUT audio: http://www.acoustics.hut.fi/research/
  - PhD: http://www.acoustics.hut.fi/~ruba/pubs/drtech05112000.pdf

Aspects of sound

- Originates from the motion or vibration of an object
  - Air molecules push other molecules and then return to original position
- Speed of sound varies
  - Speed in air about 340 m/s, depends on matter and temperature
- Pitch
  - The frequency of the sound. Human frequency range 20 to 20,000 Hz
- Loudness
  - An attribute which is proportional to the amplitude of the sound
  - The power of sound, specified in decibels (+10 dB = 10x sound power)
- Timbre
  - Our experience of the complexity of a sound
  - Different instruments vary in timbre despite having the same pitch and loudness
  - Combination of frequencies, harmonics
  - Pure tone has one frequency, sine wave

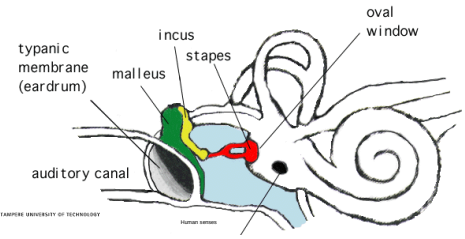
Outer ear

- Auricle gathers, filters
  - Diffraction, dispersion, reflection, resonance etc.
- Auditory canal
- Sound arrives also from elsewhere
  - Through the tissues, bone conduction

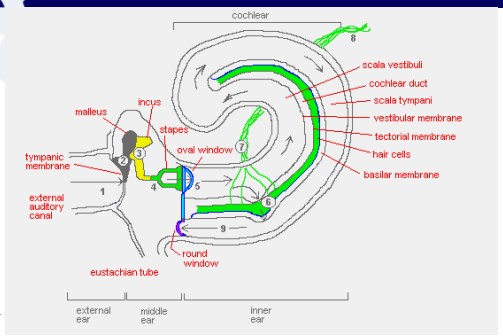


Middle ear

- The ear drum
- Oval window
- The ear bones amplify sounds
  - Eardrum area = 15 x oval Window

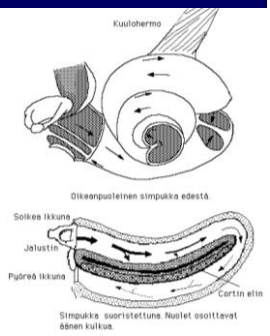


Middle and inner ear structure

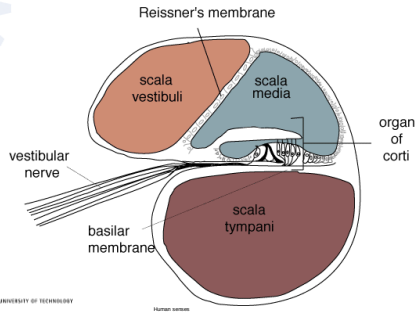


Inner ear, cochlea

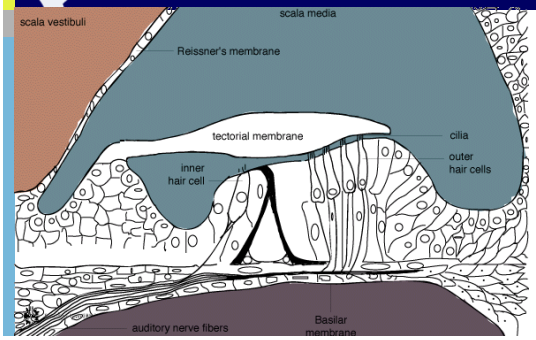
- Cochlea, like gastripod
- Fluid is vibrating
- The receptors are there
- 16000 hair cells sense movements
- 31000 auditory neurons produce electrical impulses
- Various frequencies are sensed in different places and different ways
- Connection to the auditory nerve



Inner ear, cross section

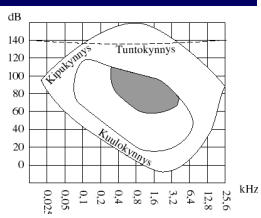


Inner ear, hair cells



Sense on hearing

- 20-20,000 Hz
  - Bats -150 kHz
  - Moles 1 Hz -
- The most sensitive:
  - 2-5 kHz
- Dynamic range 10^{12}
- 120 dB pain, even loss of hearing
- 16,000 hair cells are not replaceable
- Speech
  - 50-10,000 Hz
  - 60 dB
- Soft whisper (at 5m): 30dB, normal conversation: 60dB, busy traffic: 70dB, average factory: 80dB, stadium: 117dB



Hearing stimulus

- The sensed volume depends on frequency
- Hearing adapts easily
- Masking: close-by frequencies are cut off (c.f., coding in MP3, GSM)
- A strong sound is also felt. Deaf people can listen to music by touch
- Complements visual
- The hearing recognizes the short-living sound spectrum
  - Formants: the resonant frequencies of the vocal tract for vowels
  - Frequency spectrum
  - The harmony of spectrum
- The sound impression of a space
  - Blind persons can navigate with their hearing using echoes
  - Bats also send ultrasound

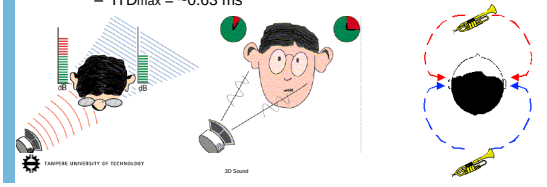
Direction of the sound

- Two ears help to point the direction of sound in space
  - Binaural = hearing using two ears
- Human perception system relies on three major methods of locating sounds
- **1. Amplitude difference** between ears
- **2. Time difference** between ears, when sound arrives
- **3. HRTF** (Head-related transfer function)
  - Reflections depending on form of the outer ear, shoulders etc.
- Also other cues

Locating Sounds

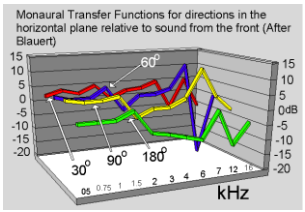
1. Intensity (high frequencies, >1.5 kHz)
   - Inter-aural Intensity Difference, IID (or ILD), binaural cue
   - Not linear with frequency
2. Time (low frequencies, <1.5 kHz, ~ ms)
   - Inter-aural Time Difference, ITD, binaural cue
   - ITD_{max} = ~0.63 ms

ITD = IID => confused direction



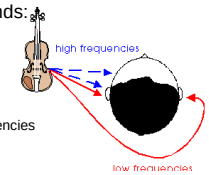
Locating Sounds

3. Head Related Transfer Function
   - Spectral cues result from the effects of a sound signal reflecting off of the listener's head, shoulders, and pinnae (outer ears)
   - Non binaural
   - HRTF is a personal transform function of a sound based on the forms of ears, shoulders, etc.
   - Personal filtering effect, varies, averages often used
   - HRTF dummy head: http://sound.media.mit.edu/resources/KEMAR.html



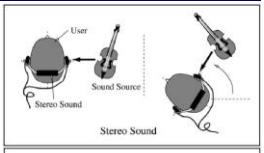
Other Cues for Locating Sound

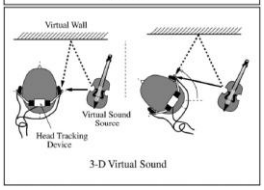
- Visual confirmation and unambiguity
- The room acoustics and reflections
- Head movements
- Differences in frequency spectrum between signals from the ears
- The precision of locating sounds:
  - Front 3.5° / back 5.5°
  - On the sides 10°
  - Elevation 10-25° (6 kHz)
  - Depends on frequency
    - Direction not exact in low frequencies



3D Sound

- Binaural audio, spatialized sound, virtual acoustics, auralization
- World-referenced 3D audio space with tracking
- Fairly low-cost to implement
- Stereo or surround sound is not the same as 3D sound
- The user expects the sounds to have fixed position in VEs
  - In immersive VEs, the sound is modified to compensate user's movement (tracking is needed except in wave field synthesis)





3D Sound

- Artificial 3D sound environment
  - Direction, volume, reflections, etc. of sounds
- Latency and lag are less of a concern with the audio component of a VR display than the visual component
- Ears are more sensitive to drop-outs (interruptions) and small synchronization inconsistencies than eyes
- The sound space should support the visual element in a synchronized manner
  - Direction
    - Depends on frequency. Low sounds are hard to locate
  - Distance (?)
- No echoes: Perception errors
- Real time, accurate impression of sound space is computationally heavy
- Doppler effect

Sound environment design

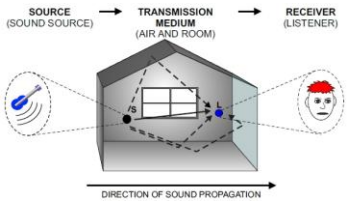
- A loud sound can mask soft sound
- Both with headphones and speakers
- Objects blocking the path of sound from the speaker to the ear
  - For example, loudspeakers can be behind the screen
  - Objects don't completely block sound, they filter it
  - High frequency sounds are masked more easily than low frequencies
- Masking out unwanted real-world sounds
  - Can be done with closed-ear headphones
  - Placing a noisy computer in another room etc.
- Preventing circulation when communicating with microphones
  - Problem when using loudspeakers and microphones together
  - Normally an irritating high-frequency pitch sound

Spatialization

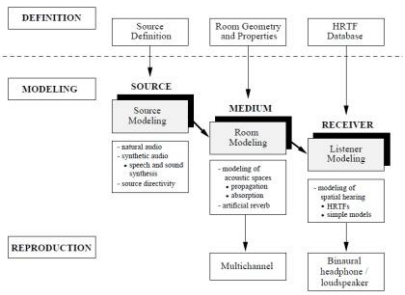
- Spatialization, auralization
- The process of making a sound seem to come from a particular location in space
  - Realistic synthesis is complex
- Individual sounds can be processed by a computer and made seem to come from the appropriate spot
- Using artificial head with microphones placed in the ears
  - The problem is that people have different heads, so their HRTF varies
- 3D effect can be faked using sound-effect processors with reverberation and delay effects
- Reverb effects can be used to create a perceptual cue indicating the size of the space the participant is in
  - Longer delays - larger space

Auralisation

- Source, medium, receiver modeling

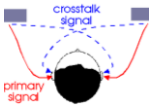


Spatialization, auralisation

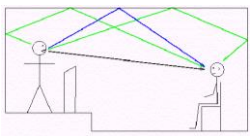


Aural rendering

- Create the illusion of sound sources anywhere in 3D space
  - including behind, above or below the listener
  - cross-talk cancellation with loudspeakers
- Playback of recorded waveform sampled
- Postprocessing of existing sound signals
- Synthesis, algorithmic rendering
  - Spectral methods
    - Observing a sound wave's frequency spectrum and re-creating that spectrum to mimic original
  - Physical models
    - The physics of the sound source is simulated
  - Abstract synthesis
    - Generating the sound algorithmically

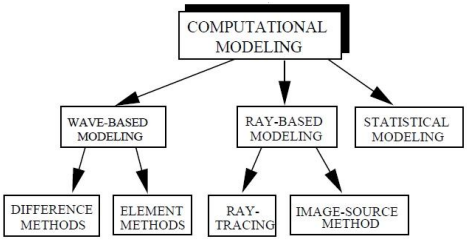


Room acoustics



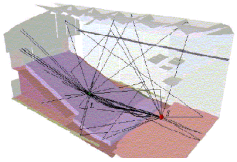
- Direct sound
- 1. and 2. reflections
- Later reflections
  - Reverberation
  - Attenuates exponentially
- Sound waves are absorbed, reflected, refracted and diffracted in different ways depending on their frequency, and material and geometry of the environment
- Perceptual acoustics modeling
  - No 3D model used, fast calculation, shortcuts
- Physical acoustics modeling
  - The exact progression of sound in an environment
  - Suitable for virtual environments, but heavy calculation

Modeling of room acoustics



Modeling methods

- Wave-based
  - Suitable for low frequencies
- Ray-based
  - Suitable for high frequencies



Aural Displays

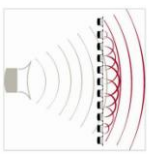
- Stationary: loudspeakers
- Head-based: headphones (easier to 3D spatialize)
  - Also bone conduction headsets (bonephones)
- Wave field synthesis
- Not only stereo or surround, but localized 3D sound!
  - Monophonic: one sound channel
  - Stereophonic: two sound channels
  - Multi-channel: multiple sound channels
- Together, synchronized 3D audio and 3D visual cues provide a very strong immersion
- Noise from the other VR equipment can spoil the audio experience (computers, projectors etc.)
- Binaural virtual haircut (no head tracking, of course)
  - http://www.youtube.com/watch?v=8lXm6SuUigI

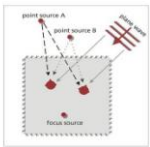
Multi-channel speaker setups

- At least 2-channel (stereo) in most systems
- 2.1 system: stereo pair + subwoofer
- 5.1 system: front: L+C+R, back: L+R, subwoofer
- 7.1 system: added center L+R
- Surround sound is not interactive 3D audio

Special multi-channel setups

- 8 channels in the corners of CAVE + subwoofer
- Wave field synthesis, e.g. Uni-Ilmenau
  - Produces "artificial" wave fronts synthesized by a large number of individually driven speakers. Wave fronts seem to originate from a virtual starting point
  - Localization of virtual sources does not depend on or change with the listener's position





Speakers vs. headphones

- Benefits of loudspeakers
  - Works well with stationary visual displays
  - Greater user mobility
  - Little encumbrance
  - Multi-user access means faster throughput
- Benefits of headphones
  - Works well with head-mounted displays
  - Easier to implement spatialized 3D sound fields
  - Masks real-world noise
  - Better portability
  - Private, personal
  - No sweet spots, works allover the space

3D Audio APIs and Hardware

37

- Audio APIs: sounds behave naturally as the user moves through the VE. Programmer needs to make very little work to make this happen in an OpenGL-based 3D app
- Games are one driving force
- DirectX Directsound3D is common
  - Crystal River Engineering for NASA's VIEW in the 1980's
  - Crystal River products: Convolvotron and the Acoustetron
  - Aureal acquired Crystal River and rebranded it to A3D
  - Aureal A3D, extension to DS3D, bought by Creative Labs
  - Creative's environmental audio extensions (EAX)
  - Hardware acceleration for DS3D was dropped in Win Vista
- OpenAL, OpenAL++
  - free cross-platform audio API, by Creative Labs
- Creative Labs Audio Blaster, Turtle Beach Montego cards
- Other audio APIs: Advanced Multimedia Supplements (JSR-234), Java3D, OpenSL ES, JASS

Audio logistic qualities

38

- Noise pollution
  - Goes both ways
  - Multiple participants in HMDs sharing the same room
  - Echoes
- Environment requirements
  - Square room (like a CAVE) can be a problem for speaker displays
  - Hard-surfaced square room even worse
- User mobility, encumbrance, portability
  - Speakers generally more comfortable for lengthy periods of time
  - Wired headphones limit mobility
  - Headphones obviously more portable than speakers
- Interference with trackers
  - Magnets in the speakers/headphones. Headphone magnets smaller, but closer to the tracker receiver (problem for electromagnetic trackers)
  - Loud sounds from speakers may interfere with ultrasonic trackers

Audio logistic qualities

39

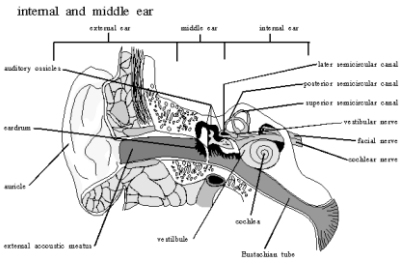
- Associability with other sense displays
  - Typically, stationary w/ stationary & head-based w/ head-based
  - Headphones easily incorporated with the visual head-based display
- Safety
  - Hearing damage is possible through both speakers and headphones
  - Wires to headphones are a potential tripping hazard
  - Hygiene
- Throughput
  - Headphones require a separate pair for all immersed participants
  - Speakers work much better for larger groups (but not so personal)
- Cost
  - High-quality headphones more expensive than high-quality speakers
  - But cost per listener may be less with speakers
  - Amplification system for speakers adds to the cost

Orientation Senses

- Vestibular system
  - Balance (orientation, movement)
- Inner ear
  - Sense of balance, movement, acceleration, rotational acceleration
- A sensation is a combination of many sensing components
- Sight and kinesthetic senses affect also to our sense of orientation and balance
  - Strongly interconnected in the brains
  - A strong visual stimulus (e.g., in a CAVE) can bring us down

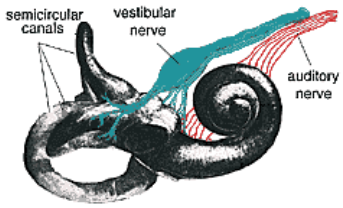
Vestibular system

- Controls the sense of movement and balance
- Sense of equilibrium



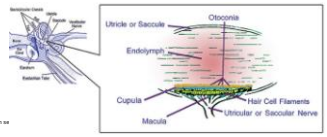
Inner ear, vestibular system

- 3 semicircular liquid-filled channels perpendicular to each other
- Cochlea
- Sensing cells
- Auditory nerve
- Brains



Inner ear, vestibular system

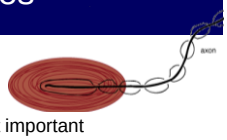
- Viscous liquid
- The liquid moves when the head moves
- The movement is recognized by small hairs and a flexible valve in the inner ear
- Sensitive to rotations and tilting
- Otolith (statoconium, otoconium) two per ear
  - Sensitive to gravity and linear acceleration, like jelly
- Vestibular system helps the eyes to compensate the head movements



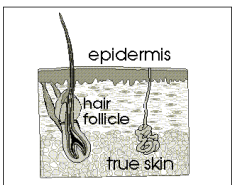
Skin Senses, Receptors

- Thermoreceptors
  - respond to heat and/or cold
- Nociceptors
  - respond to intense pressure, heat and pain
- Mechanoreceptors
  - respond to mechanical stress, pressure

Skin senses

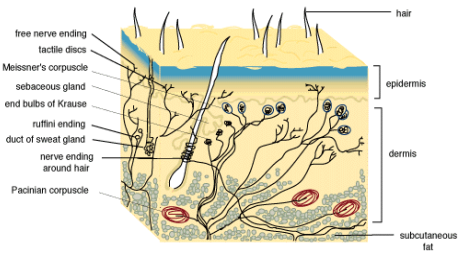


- Tactile = touch-, skin senses
- (Kinesthesis = force)
- Sensory adaptation
- Touch (pressure, pain) is the most important
- Hot, cold (15-45° C, Δ 0.001°/s)
- Electricity
- Chemical substances
- The tip of a finger
  - The most sensitive
  - Even 20 nm movement



The structure of skin

- Lots of nerves in skin, density varies



The structure of skin

- Free nerve endings
  - Pain, many senses of touching
- Meissner's corpuscle
  - Precise location, fast changes
- Merkel's discs
  - Precise location, slow adaptation
- Skin hair
  - Short-lasting movements outside skin
- Ruffini's endings
  - Deeper under the skin, static pressure/orientation
- Pacinian corpuscle
  - Fast vibrations (30-700 Hz)

Pressure

- Lips, nose and cheek most sensitive
- The big toe least sensitive
- Differences related to a number of receptors
- 5 mg can be noticed in sensitive areas
- Identifying familiar objects and surfaces
- Not aware of steady pressure on the entire body (like air pressure)
- Adaptation

Temperature

- Receptors are neurons just under the skin
- Cold receptors notice decrease in skin temperature
  - Also respond to very high temperatures
- Warm receptors notice increase in skin temperature
- Very hot stimulus activate both warm and cold receptors
- Can detect warming of 0.4° C
- Can detect cooling of 0.15° C
- Adapts to temperature in a few minutes

Pain

- Any stimulus that is intense enough to cause tissue damage is a stimulus for pain
- Pressure, temperature, electric shock, etc.
- Phasic pain
  - The pain immediately upon suffering an injury
  - Typically sharp and brief in duration
- Tonic pain
  - The pain after the injury has occurred
  - Typically dull and long-lasting
- Pain is as much matter of mind as of sensory receptors
  - A "neural gate" must be open to allow pain signals from the receptors to pass the brain

Touch and orientation senses

- Kinesthesis = the orientation of body
- Many different sensors
  - Muscles: force, orientation
  - Joints: orientation
  - Inner organs: pain, good/bad feeling

Table 12. Variability of Forces Exerted in Human Grasping

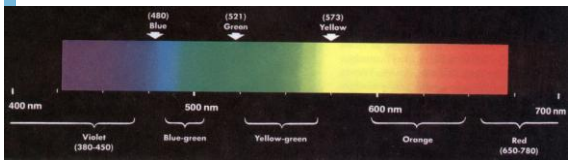
						
5% Female	53 lbs	53 lbs	7.5 lbs[71]	7.5 lbs	9 lbs	4 lbs[73]
95% Male	147 lbs	147 lbs	30 lbs[71]	30 lbs	32 lbs	13 lbs[71]
Torque Capability	Excellent	Excellent	Good	Poor	Some	Excellent
Endurance @25% Load	Good	Good	Poor	Fair	Fair	Good

Vision

- The most important sense for VEs
- The most finely tuned sense in humans
- Only vision, audition and smell are capable of obtaining information that is at distance from us
- Physical stimulus is light
  - Emanates mostly from the sun in nature
  - In modern society also artificial light sources are very important and ubiquitous
  - A form of electromagnetic radiation
    - A very narrow human wavelength range
    - Richards: Alien Vision - Exploring the Electromagnetic Spectrum with Imaging Technology. SPIE
      - imaging in all possible wavelengths + auditory imaging

Spectrum of light

- Intensity, W
- Wavelength, nm
  - Around 380-750 nm
  - The energy of light quantum: 1.6 – 3.3 eV
  - Dynamic range even from 1 photon to 10^{12}



The human visual system

- Visual system consists of the eyes, several parts of the brain, and the pathways connecting them
- Sight processes over 1000 megapixels / sec.!
- The eye contains
  - A system for forming the image
    - Like optics in camera
  - A system for transforming the image into electrical impulses
    - A little like a CCD or CMOS chip in digital camera

Image formation in the eye

- Basically it works like a camera
- Focuses light reflected from objects and forms an image at the back of the eyeball

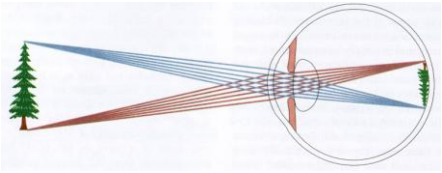
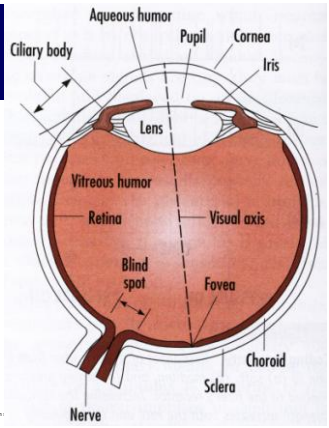


Image forming system

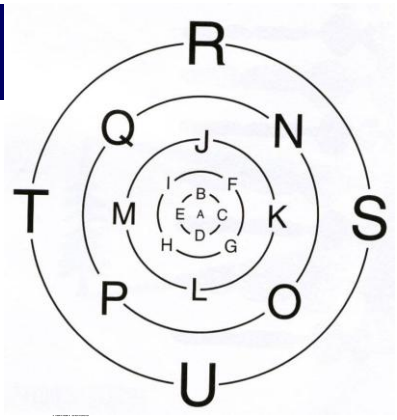
- Consists of the cornea, the pupil and the lens
- The cornea
  - The transparent front surface of the eye
- The lens
  - Completes the process of focusing the light
  - Can focus on objects at different distances
  - More spherical for near objects and flatter for faraway objects
- The pupil
  - A circular opening that varies in diameter in response to the light level
  - Largest in dim light, smallest in bright light
  - Like the aperture control (f-stops) in cameras

The eye

- The image is focused on the retina
- Fovea, the center of the retina is ”the sharp seeing region”

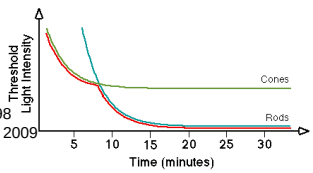


- Letter sizes have been scaled so that when the central A is looked at directly, all the other letters are approximately equally easy to read.



Retina

- The area of precise sight (fovea)
  - 0.2 mm = 1(- 5) degrees
  - Receptors are plentiful and closely packed
- Blind spot, no photoreceptors on the retina (optic nerve)
  - Masked by brain, so not noticed
- Two (four) types of receptor cells
  - Rods
    - Light sensitive
    - No color, only b/w
  - Cones
    - Needs much light
    - Colors
  - Melanopsin, found in 1998
  - Horizontal cells, found in 2009



From light to neural impulses

- The rods and cones contain photopigments, chemicals that absorb light
- The product of the process is a neural impulse
- The responses transmit to bipolar cells
- Then they transmit to ganglion cells
- Then to brain using the optic nerve
  - The blind spot is connection to the optic nerve
- Optical nerve
  - Combines nerve cells
  - 1 million axons form the optic nerve
    - Data compression 100x
  - The signals go to visual cortex in the brain

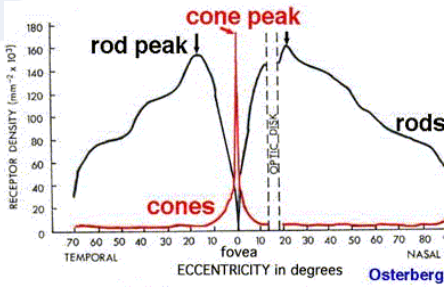
Rods

- No color
- Sensitive to light
  - Rhodopsine
- 120 million
- Uneven distribution, not in fovea
  - Night vision is like seeing past a dark star
- Max. sensitivity at about 510 nm
- Dark sight
  - Adapts to dark in 20-30 minutes
  - In sunlight they are less sensitive
- Dark/light adaptation 1:10^6
- Several rods in one nerve

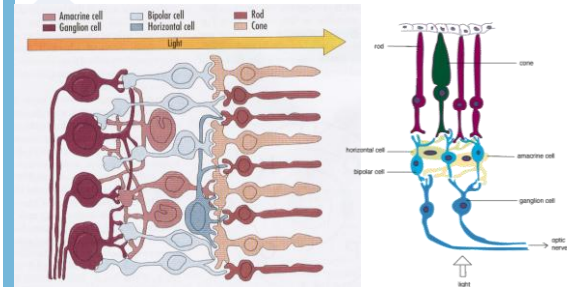
Cones

- Colors
- Not very sensitive
- Daylight (photopic)
- 7 million
- Centered near fovea
- Three types
  - Red, green and blue: 420, 534, 564 nm
  - B is less common
  - Color blindness: some of these is missing
- Dedicated nerves

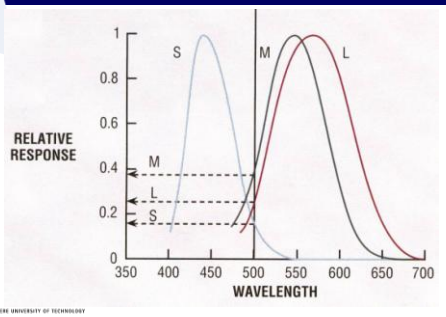
Cone/rod distribution



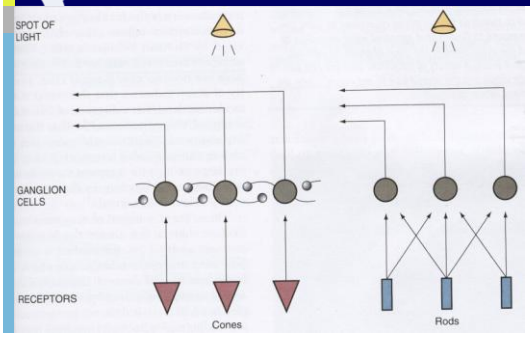
Schematic pictures of the retina



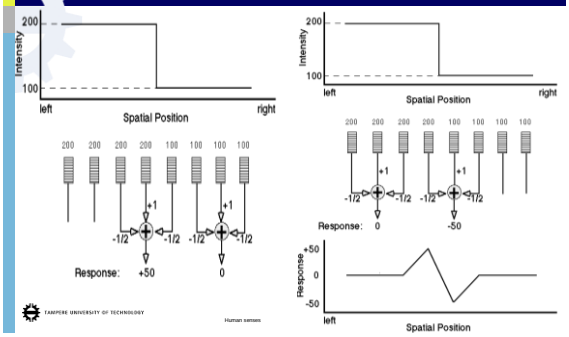
Spectral responses of cones



How cones and rods connect to ganglion cells

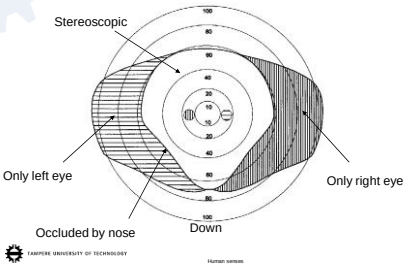


Connections of the neurons



Field of view

- Maximum horizontal ~200^{O}, vertical ~120^{O}, varies among humans
- Overlapping stereoscopic area somewhat smaller



A fish

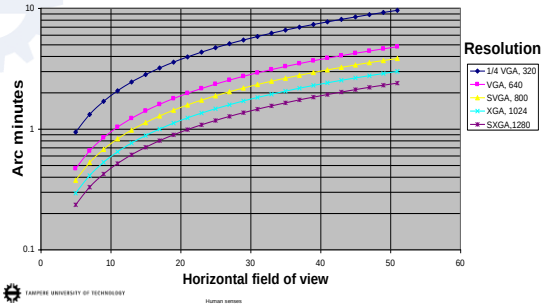
Field of View

- Angular width of a user's vision that is covered by the display at any given time
- The common field of view of the eyes is smaller
- Stereopsis: both eyes get their own images
- Difficult to attain:
  - Wide, fast, hi-res image
  - Optics that is distortion-free, light & wide FOV
  - Requires calculation
- 120^{O} x 60^{O} sufficient?
- Wide FOV:
  - Better immersion
  - More prone to sim sickness
  - Less resolution
- Field of regard: the amount of space surrounding the user
  - HMD = 100%, CAVE = usually less

Sight

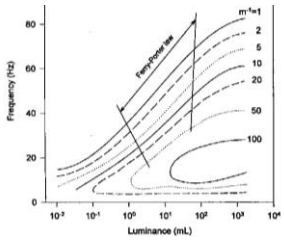
- Sight system is sensitive to
  - Edges, colors, distance, movement
- In the center of retina
  - Precise sight, ~ ½-1 arc min
  - Resolution depends on illumination, contrast, etc.
  - Good differentiation of colors
- Near the edges of retina
  - Movement
  - Changes in illumination
- In theory, the changing resolution of the eye could be taken advantage of in designing HMDs, but is difficult to implement
- Sight processes over 1000 megapixels per second

The Resolution of Displays



Flicker

- Flicker at high luminance: 50-60 Hz
- Flicker at very low luminance: 5 Hz

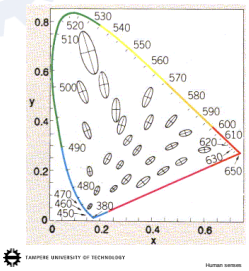


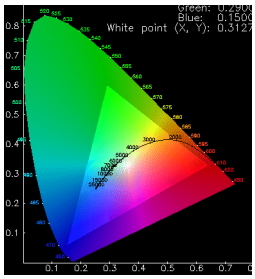
Seeing color

- All light is alike except for wavelength
- The eye turns the wavelength into a perceived color
- Different combinations on wavelengths give more colors
- The eye can distinguish among about 150 wavelengths
  - Wavelengths only 2 nanometers apart
- The origin of color sensation is usually an object that reflects light when illuminated by a light source
- All subjective colors can be made by 3 suitably chosen colors
- Not all colors can be created with any given 3 colors
  - No display can show all the wavelengths and colors
- Luminance = ΣL_i
- Color perception mechanism is not completely clear
- No wavelengths, but ratios of them. Eye adapts to various lights
  - We can discriminate among different wavelengths because they lead to different responses in three receptors

The ability to differentiate colors

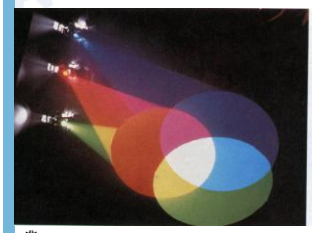
- Varies for different colors





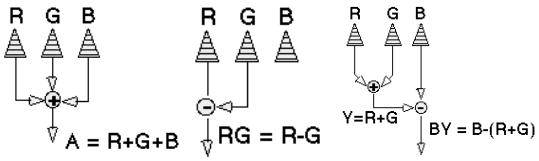
Mixing colors

- Additive — Subtractive
  - Light, light emitting displays — Printing



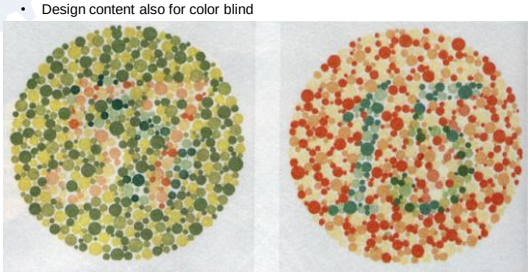
The color connections on neurons

- Black-white -channel
- Red-green -channel
- Blue-yellow -channel



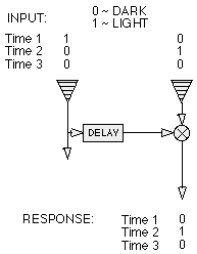
Color blindness

- A test pattern to test vision for colors
- 2 of 3 primary colors can be separated (dichromate)
- In some cases the vision is black and white (monochromes)
- Design content also for color blind



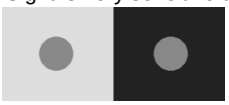
Perception of movement

- In collaboration with other senses
- The perception of edges and colors is insensitive to movement
- A dot light moving to right:
  - Movement in time
  - Delay

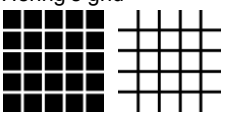


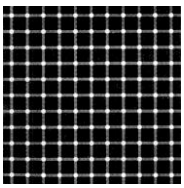
Contrast

- Sight is very sensitive to contrast



- Hering's grid





The Effects of Contrast

- Mach band

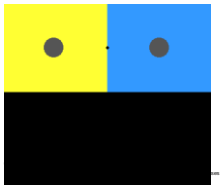
  - Near the edges, the perceived illumination changes
  - The visual system seeks for differences

The Eye Adapts

- The eye adapts to continuous stimuli

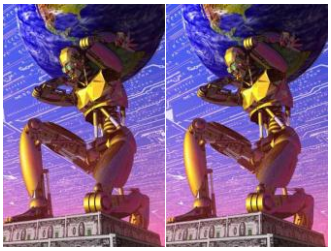
Colour Contrast

- The visual system compares colors
- Adapts, no absolute values
- Complementary afterimages



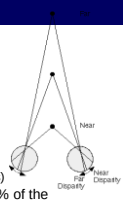
Depth, Distance Perception

- Numerous cues
- Not the same priority
- Binocular cues
  - Stereopsis
  - Convergence
- Monocular cues
  - Interposition
  - Shading
  - Size
  - Linear perspective
  - Surface texture gradient
  - Height in visual field
  - Atmospheric effects
  - Brightness
  - Motion depth cues
  - Accommodation



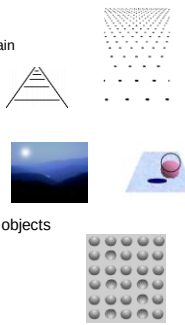
Binocular Depth Cues

- Binocular = seeing with two eyes
- Stereopsis, stereo sight, < 50 m
  - Typically dominant depth cue
  - Binocular disparity
  - Inter-pupillary Distance, IPD
  - Only near the center of FOV
  - Brains merge 2 images into one with distance information
    - Images near each other, otherwise diplopia (different images)
  - Approximately 6% of the population is stereo-blind. 25-30% of the population is stereoanomalous, meaning that they reverse depth with short exposures to stereo, which may affect the stereo displays market
- Convergence: simultaneous inward movement of both eyes toward each other, usually in an effort to maintain single binocular vision when viewing an object, at less than 10 m distance



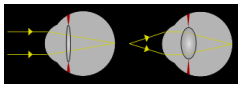
Monocular Depth Cues

- Monocular cues
  - One eye is enough. Interpreted in the brain
- Perspective
- Textures
- Atmospheric effects (e.g., fog)
- Brightness
- Motion parallax
  - Nearby objects move faster
  - Very dominant
- Optical flow: apparent motion of moving objects
- Shading
  - Lights and shadows
  - A shadow can also create illusions



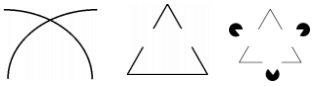
Monocular Depth Cues

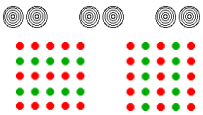
- Interposition, relationships
  - Occlusion: a strong cue
- Known object height
- The size in retina
- Accommodation
  - The focusing of eye muscles to a certain distance
  - Only under ~3 m distances
  - Error in accommodation, or a difference between accommodation and convergence can cause nausea or simulator sickness



Pattern Recognition

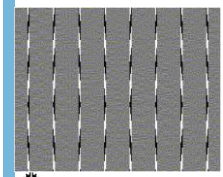
- Background and image
- Grouping
  - Proximity
  - Similarity
  - Continuity
  - Enclosure
  - Moving together



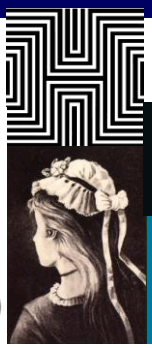


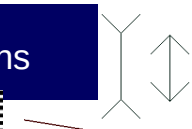
Pattern Recognition

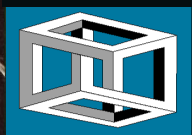
- The brains supplement the real view
  - What you see is what you expect

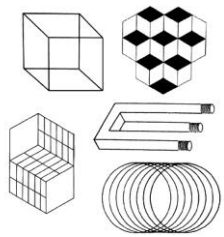


Optical Illusions





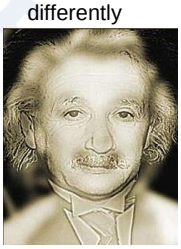




Optical Illusions

Edge Filtering

- The visual system filters sharp and soft edges differently

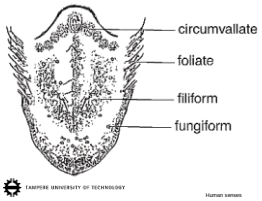


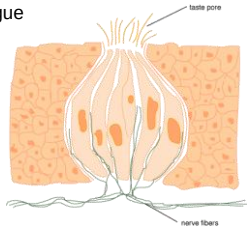
The Perfect Display

- The resolution of the eye
  - 50 arc sec => 213 Mpixel
  - 20 arc sec => 1300 Mpixel (x 25 Hz!)
  - The area of precise sight is small, but the movement of eyes can be very fast, and the sight near the edges of FOV is very sensitive to movement
- Levels of depth
  - 10 => (50"=2 Gvoxel, 20"=13 Gvoxel)
  - 1000 => (50"=214 Gvoxel, 20"=1300 Gvoxel)
- 0.01 - 100,000 lux etc.
- 30 Mpixel * 48 Hz => 35 Gb/s, 1 petaB
  - Hi-end SGI Onyx2: 6 Gvoxel/s, 0.2 TB => 20 years

Taste

- 10,000 taste buds on the tongue
- Four different types
  - Sweet, sour, salty, bitter
  - In different parts of the tongue





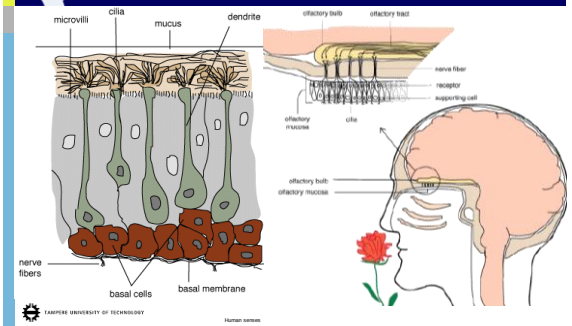
Taste (gustation)

- The gustatory system includes receptors in tongue, throat and roof of the mouth
- Most sensitive to salty and sweet
- Taste buds
  - Bumps of the tongue and around the mouth
  - Clusters of receptors
  - Short, hair-like receptors
    - Create electrical impulses

Smell (olfaction)

- Needed for the detection of gas, spoiled food, etc.
- Sensorama 1960, Smellitzer 1984
- Responsible also for most taste sensations!
- Volatile molecules (related to C, H, O, N, P, S, Cl, Br, I) given off by a substance are the stimulus for smell
- No primary odors, or at least 350 of them (receptor proteins)
  - Mice have ~1000 types of receptor proteins (Nobel Prize 2004)
- Receptors in nasal passage
  - Hair-like structure, about 10,000,000 of them
    - Dogs have 1 billion, butterflies can smell each other from 1 km away
  - Contact with volatile molecules cause an electrical impulse
- Humans are less sensitive to smell than most animals
  - Can detect 400,000, distinguish thousands. Personal variation
  - Directional localization aided by internostril comparisons

Olfactory Receptors



Direct Nerve or Brain Stimulation?

- Cyborg: extended human, half-human, half-robot
- Prof. Kevin Warwick and also ADS inc.: chip implants
- Electricity into spine / nerves
  - Ear implants for hear impaired. Sight implants coming?
  - Orgasm stimulator: US Pat 6169924
- Chemicals, electricity into brain, etc. can generate artificial sensations and recover forgotten memories
  - Silicon implant into brains? Cyborg rats (NYSU)
  - The function of the brains is not fully known
  - The same stimulation for the same people can result in different ways
  - Variation also among people
  - The generation of desired artificial sensations is practically impossible currently
- Transcranial magnetic stimulation (TMS)