Why study perception?
• Important to understand human abilities and limits
• Determine appropriate range for input and output (frame rate, resolution, etc)
• Understand that different senses have different ranges and abilities
• Determine appropriate sensory channel to use to transfer information
• Avoid sickness and injury

Human Perceptual Systems
• Visual
• Vestibular
• Auditory
• Olfactory
• Haptic
• Gustatory
**Visual Perception**

- Visual information is often considered the primary feature of virtual environments, we gather large amounts of information with vision in everyday life.
- The visual channel generally can process much larger bandwidth than other senses.
- This channel is also sensitive to very small anomalies, especially when motion is involved.

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**Eye Geometry**

- Each eye rotates around its center, which is usually about 13mm behind the front of the cornea.
- *Inter-pupillary distance/inter-ocular distance*: can vary greatly, adults usually around 50-70mm (2.5 inches).
- *Accommodation* is the change that occurs within the eye to focus images by changing the shape/thickness of the lens.
Retina

- The retina is the photosensitive lining at the rear of the eye
- Photoreceptors called rods and cones trigger nerve impulses which are carried to the optic nerve and on to the brain
  - Rods are unevenly distributed, none are in the fovea
  - Rods react to lower intensity levels of light than cones and take about 35 min of exposure to reach maximum sensitivity
  - Cones are sensitive to bright light, respond quickly, and are responsible for sensing color and details
  - Cones are most dense in the fovea and become less dense towards the edges of the retina

Blind Spot

- The area where all the nerve fibers join together to leave the retina has no receptors and is referred to as the blind spot
- The blind spot is roughly circular with a diameter of about 5°
- Binocular vision (using 2 eyes) helps compensate for the blind spot

Field of View

[Diagram showing various fields of view with labels for monocular and binocular fields, head movements, and eye movements.
Adapted from Stanney p31]
Resolution/Acuity

- Not constant throughout the viewing area. Best in the foveal area.
- Also affected by brightness and contrast
- Many different studies give results in the range .5 – 30 sec of arc. 1 min arc = able to detect detail of .01 inch from a distance of 3 feet.
- Most current VR displays (HMD and projection based) do not approach the capabilities of the human visual system

Brightness/Contrast

- Humans can adapt to a wide range of intensities, but adaptation time is very long for low intensities.
- Performance is usually best with higher contrast
- At very high intensities, damage to the eye can occur.
- Scotopic region: rods only
- Mesopic region: rods and cones
- Photopic region: cones only

<table>
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<th>Light intensity (candela/meter²)</th>
<th>Light intensity (millilamberts)</th>
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<tbody>
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<td>3.18x10⁶</td>
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- Photopic Vision
  - Sun’s surface at noon
- Mesopic Vision
  - Tungsten filament
  - White paper in sunlight
  - Comfortable reading
- Scotopic Vision
  - Cone threshold
  - White paper in moonlight
  - White paper in starlight
  - Absolute threshold
  - White paper in starlight

- Damaging
- Discomfort
- Rod saturation
- Absolute threshold
**Color**

- Color is largely due to the wavelength of the light.

![Color Wavelength Diagram](Image)

- We have 3 types of cones, each type is sensitive to a different range of wavelengths.
- Current displays (including monitors) provide a wide range of colors, but still produce only a small part of the range of colors we can see.
- Additionally, many display devices do not produce stable colors, or uniform color (or brightness/contrast) across the entire display.
- Colorblindness: 8% of males, 1% of females

**Mono Depth Cues**

- Interposition/Occlusion
- Linear perspective
- Textural gradient

Images from StereoGraphics' Developers' Handbook
• Aerial perspective (atmosphere)

• Shadows
• Shading
• Highlighting
• Size
• Past experience
• Height relative to horizon (lower=closer)

• Note that many of these factors are usually present at the same time (see previous slide)
• Accommodation and differences in sharpness may also act as depth cues

**Binocular & Stereo Vision**

• *binocular disparity or stereopsis*: each eye sees a different view of the world due to distance between the eyes
• Stereo is the feature most often associated with virtual reality. It's one of the strongest depth cues, particularly for near objects (~10m).
• About 5-12% of the population cannot see stereo correctly.
• Problem images that can’t be fused can result in *binocular rivalry*. (ex. hole in hand)
**Motion Parallax**

- When either the scene or the observer moves relative to the other, objects close to the observer will appear to change/move more quickly than objects farther away.
- This effect gives a very strong depth cue, even with no-stereo images

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**Vergence**

- Each eye will rotate to point at the object being focused on, so that the lines of sight intersect at the object being focused on

- In everyday experiences, vergence and accommodation are linked

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**Vergence/Accommodation Conflict**

- When viewing computer generated stereo scenes, the physical display surface and the virtual object may be at different depths, resulting in a conflict between them

- This relationship is learned and can be overcome, but can cause eyestrain and other undesirable effects when large differences are present
**Tips on Visual Perception**

- Wider FOV is usually better
- Use caution with large amounts of disparity
- Use caution with motion, especially when it is fast, or wide FOV is used, or *looming* is involved
- Consider that some simple depth cues may be much easier or cheaper to implement and result in only a slight decline in performance

**Auditory Perception**

- Audio in VEs is often absent or implemented poorly (only as an afterthought). But the entertainment industry recognizes that sound is vital to creating ambience and emotion.
- Sound can also be used to transmit useful and important information
- Senses such as visual must be directed at the stimulus to receive information — the auditory channel is continually receiving information.
- When sound is done poorly, the brain notices!

*Your ear is not just a microphone!*
Process

• Sound is transmitted through the air as vibrations (waves)
• The shape of the outer ear affects how the waves are passed into the ear.
• The middle ear converts the air waves to mechanical vibrations and passes them through tiny bones to the inner ear
• Fluid in the inner ear passes the vibrations along to hair cells, which creates nerve impulses passed to the brain

Properties

• Waves consist of amplitude (magnitude of the pressure change) and frequency (rate of pressure change)
  – Amplitude roughly similar to “loudness”
  – Frequency roughly similar to “pitch”
• Our auditory systems are sensitive to a wide range of sounds:
  – Frequencies between about 20 Hz and 22,000 Hz

• The pain threshold is usually in the range of 110-130 dB, but damage can start to occur at even lower levels (85-90 dB)
• 16 bits generally adequate to represent amplitude
• Masking/interference – multiple sounds presented simultaneously or in close succession can interfere with each other and prevent one or more from being heard
  – Both forward and backward masking can occur
• Humans are sensitive to temporal fluctuations and react very quickly (approximately 20% faster than visual channel)
**Spatial Hearing**

- Spatial acuity of auditory system far worse than visual
  - Best resolution about 1°
  - worst 10° or more
- Listeners can judge relative changes in distance better than absolute distance
- Several cues provide information:
  - Time difference
  - Level difference
  - Phase difference
  - Reverberation
  - Dynamic cues

**Interaural Time Difference**

Generally, \( t_1 \neq t_2 \), so the sound reaches one ear before the other. Sound travels “slow” enough you can detect this difference.

**Interaural Level Difference**

- Intensity of a sound decreases as it moves through the medium (air)
- So, for 2 receivers (ears) at different distances from the emitter, the intensity at the closest receiver will be greater
Phase Difference

Reverberation

Reverberation confuses direction information and ability to extract information (such as speech processing), but improves distance estimation and provides environmental information.

Dynamic Cues

- Motion can help to resolve location and motion information
- Ex. Turning your head to hear a sound better or make comparisons
- A moving source can also produce the Doppler shift/effect where sound waves “bunch up” or spread apart to increase/decrease frequency
HRTFs
• For each person, the unique shape of their head and ears slightly transforms the waves that reach the inner ear, allowing the hearer to determine additional information on direction and distance.
• This unique function is called the head-related transfer function.
• HRTFs can be measured using probe microphones
• It is unknown what happens when people are presented auditory information based on an HRTF that is not their own.

Vestibular System
• Senses movements/accelerations of the head/body.
• Primary organs used are:
  – Three vestibular canals (rotations)
  – Otolith organs: Utricle and saccule (gravity and linear accelerations)
  – These organs are connected
Vestibular Sense

- We generally use information from this sense without conscious thought. We usually aware of it only when something is wrong.
- Vestibular information works together with visual and kinesthetic information to maintain posture. These senses are also tightly coupled.
- This sense is a major factor in motion sickness and cybersickness – people without a working vestibular system do not experience these phenomenon.
• There are many possible methods for creating the perception of acceleration, including both accelerating the user and keeping the user stationary while stimulating other senses such as the visual field.
• This sense is vulnerable to many types of illusions (both good and bad).
• For example, it is often possible to combine real physical movement with other inputs to create the perception that other movements happened (such as motion platforms having fewer than 6 degrees of freedom).

UNC Study
• University of North Carolina, Chapel Hill. Eurographics 2001.

Summary
• This lecture touched briefly on the 3 senses of vision, hearing, and vestibular
• Proper stimulation of these senses enhances a VR experience
• Improper stimulation can result in a range of consequences from mild (lack of enjoyment) to unpleasant (cybersickness) to dangerous (severe and/or permanent damage to a person.
• Always keep these factors in mind when designing and creating a virtual environment.