IMGD 3xxx - HCI for Real, Virtual, and Teleoperated Environments:

Human Hearing and Audio Display Technologies

by
Robert W. Lindeman
gogo@wpi.edu

Motivation

- Most of the focus in gaming is on the visual feel
  - GPUs (Nvidia & ATI) continue to drive the field
  - Gamers want more
    - More realism
    - More complexity
    - More speed
- Sound can significantly enhance realism
  - Example: Mood music in horror games

Audio Displays

- Spatialization vs. Localization
- *Spatialization* is the processing of sound signals to make them emanate from a point in space
  - This is a *technical* topic
- *Localization* is the ability of people to identify the source position of a sound
  - This is a *human* topic, i.e., some people are better at it than others.

Audio Display Properties

Presentation Properties

- Number of channels
- Sound stage
- Localization
- Masking
- Amplification

Logistical Properties

- Noise pollution
- User mobility
- Interface with tracking
- Environmental requirements
- Integration
- Portability
- Throughput
- Cumber
- Safety
- Cost

Channels & Masking

- Number of channels
  - Stereo vs. mono vs. quadrophonic
  - 2.1, 5.1, 7.1
- Two kinds of masking
  - Louder sounds mask softer ones
    - We have too many things vying for our audio attention these days!
  - Physical objects mask sound signals
    - Happens with speakers, but not with headphones

Audio Displays: Head-worn

Ear Buds

On Ear

Open Back

Closed

Bone Conduction

Audio Displays: Room Mounted

- Stereo, 5.1, 7.1
- What is the ".1"?
- Sound cube

Types of Sound

- Music
  - Opening/Closing
  - Area-based music
  - Function-based music
  - Character-based music
  - Story-line-based music
- Speech
  - NPC speech
  - Your thoughts
- Non-speech audio

Music in Games

- Opening/closing music
  - Can help set the stage for a game
  - Can be "forever linked" to the game
  - You must remember some…

- Area-based music
  - Each level (or scene) of a game has different music
  - Country vs. city
  - Indoor vs. outdoor

Music in Games (cont.)

- Function-based music
  - Music changes based on what you are doing
  - Fighting
  - Walking around
- This can be a very good cue that someone is attacking
  - If they are behind you, for example

Music in Games (cont.)

- Character-based music
  - Each playable character has his/her own "theme" music
  - Many RPGs use this
  - Film uses this too 
- Story-line-based music
  - As in film
  - Music contains a recurring theme
  - Used for continuity
  - Used to build suspense

Speech

- Player
  - Used to communicate with others
  - Used to hear your own thoughts
- Non-player characters
  - Used to convey information to you/others
- More and more "voice talent" being used
  - Big money
  - Return of radio?
- Often accompanied by subtitles

Non-Speech Audio

- Used to enhance the story
- Similar to Foley artists in film
  - The art of recreating incidental sound effects (such as footsteps) in synchronization with the visual component of a movie. Named after early practitioner **Jack Foley**, foley artists sometimes use bizarre objects and methods to achieve sound effects, *e.g.*, snapping celery to mimic bones being broken. The sounds are often exaggerated for extra effect - fight sequences are almost always accompanied by loud foley-added thuds and slaps.

    (Source: www.imdb.com)
- Typically used to mimic (hyper-)reality

Non-Speech Audio (cont.)

- Some examples:
  - Footsteps
    - Vary depending on flooring, shoe type, or gait
  - Explosions:
    - Vary depending on what is exploding
  - Bumping into things
    - Walls, bushes, *etc.*
  - Objects in the scene
    - Vehicles, weapon loading/firing, machinery
  - Animals
  - Anything that works!

Non-Speech Audio (cont.)

- Real examples
  - The screech of a TIE Fighter is a drastically altered elephant bellow, a woman screaming, and more
  - Wookie sounds are constructed out of walrus and other animal sounds
  - Laser blasts are taken from the sound of a hammer on an antenna tower guide wire
  - Light saber hum taken from a TV set and an old 35 mm projector to create the hum

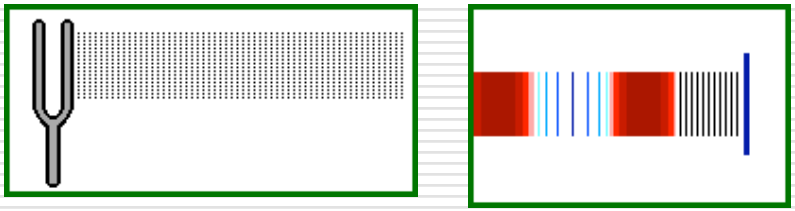
http://www.filmsound.org/starwars/#burtt

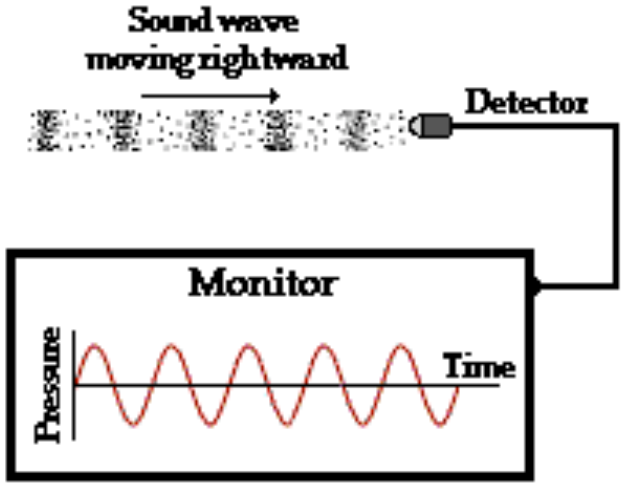
Non-Speech Audio (cont.)

- State of the character
  - Breathing, heartbeat
- Synchronized spatialized video and audio can increase immersion
- Confirmation of user action
  - Reload
  - Menu-item “ping”
  - Unlock a door

Structure of Sound

- Made up of pressure waves in the air



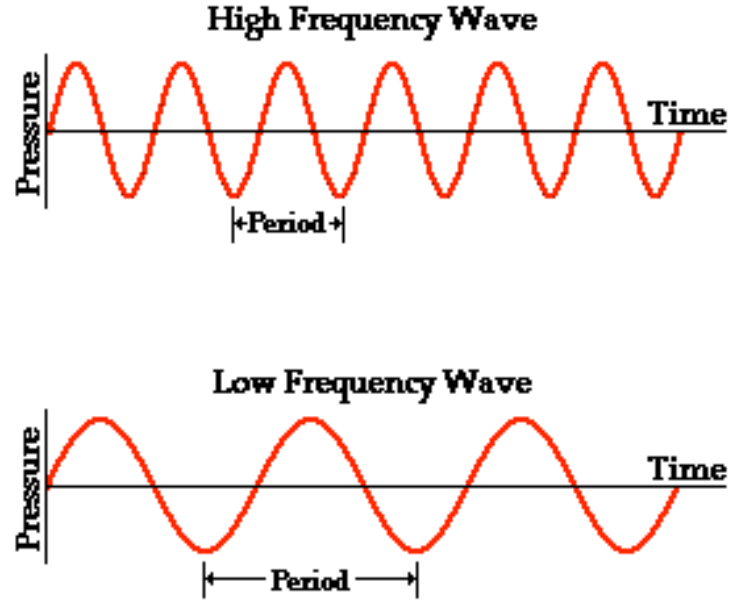


- Sound is a **longitudinal wave**
  - Vibration is in the same direction (or opposite) of travel

(http://www.glenbrook.k12.il.us/GBSSCI/PHYS/CLASS/sound/soundtoc.html)

Frequency and Amplitude

- Frequency determines the *pitch* of the sound
- Amplitude relates to intensity of the sound
  - Loudness is a subjective measure of intensity
- High frequency = short period
- Low frequency = long period

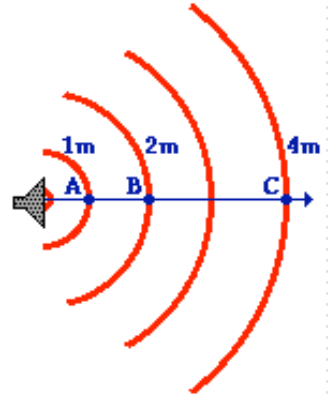


Distance to Listener

- Relationship between sound intensity and distance to the listener

  Inverse-square law

  - The intensity varies inversely with the square of the distance from the source. So if the distance from the source is doubled (increased by a factor of 2), then the intensity is quartered (decreased by a factor of 4).



Audio Processing

- Audio is made up of a *source* and a *listener*
- Music is typically source-less
  - May be 5.1 surround sound, *etc.*
- Sound undergoes changes as it travels from source to listener
  - Reflects off of objects
  - Absorbed by objects
  - Occluded by objects
- Does this sound familiar?

Audio Processing (cont.)

- Just like light, different materials affect different parts of a sound signal
  - Low frequencies vs. high frequencies
- We can trace the path of sound from source to listener just like we trace light
  - But, we are less tolerant of discontinuities in sound
  - It is more expensive to process "correctly"
- So, we cheat (as always ;-)

Source of Sounds

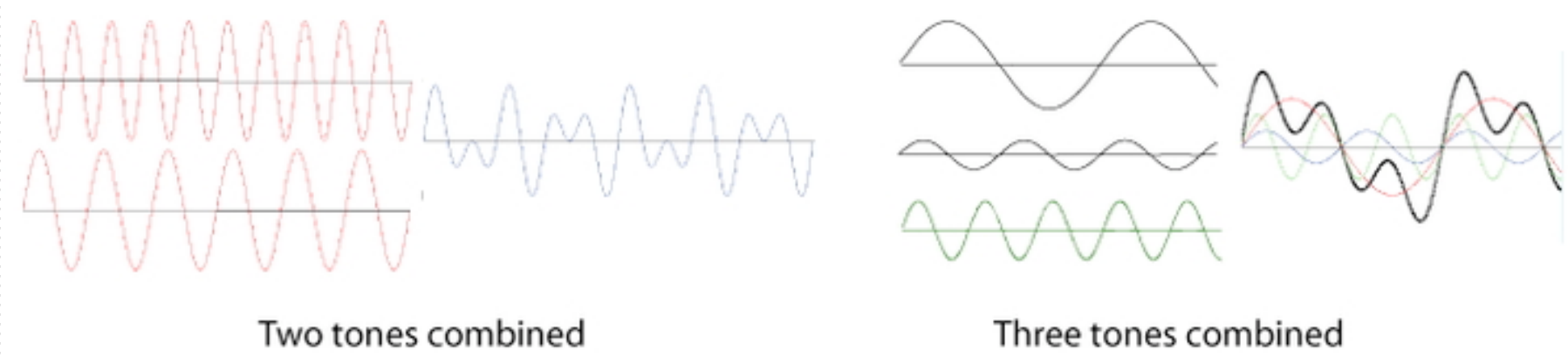
- Like textures, sounds can be captured from nature (*sampled*) or synthesized computationally
  - High-quality sampled sounds are
    - Cheap to play
    - Easy to create realism
    - Expensive to store and load
    - Difficult to manipulate for expressiveness
  - Synthetic sounds are
    - Cheap to store and load
    - Easy to manipulate
    - Expensive to compute before playing
    - Difficult to create realism

Synthetic Sounds

- Complex sounds are built from simple waveforms (*e.g.*, sawtooth, sine) and combined using operators
- Waveform parameters (frequency, amplitude) could be taken from motion data, such as object velocity
- Can combine wave forms in various ways
  - This is what classic synthesizers do
- Works well for many non-speech sounds

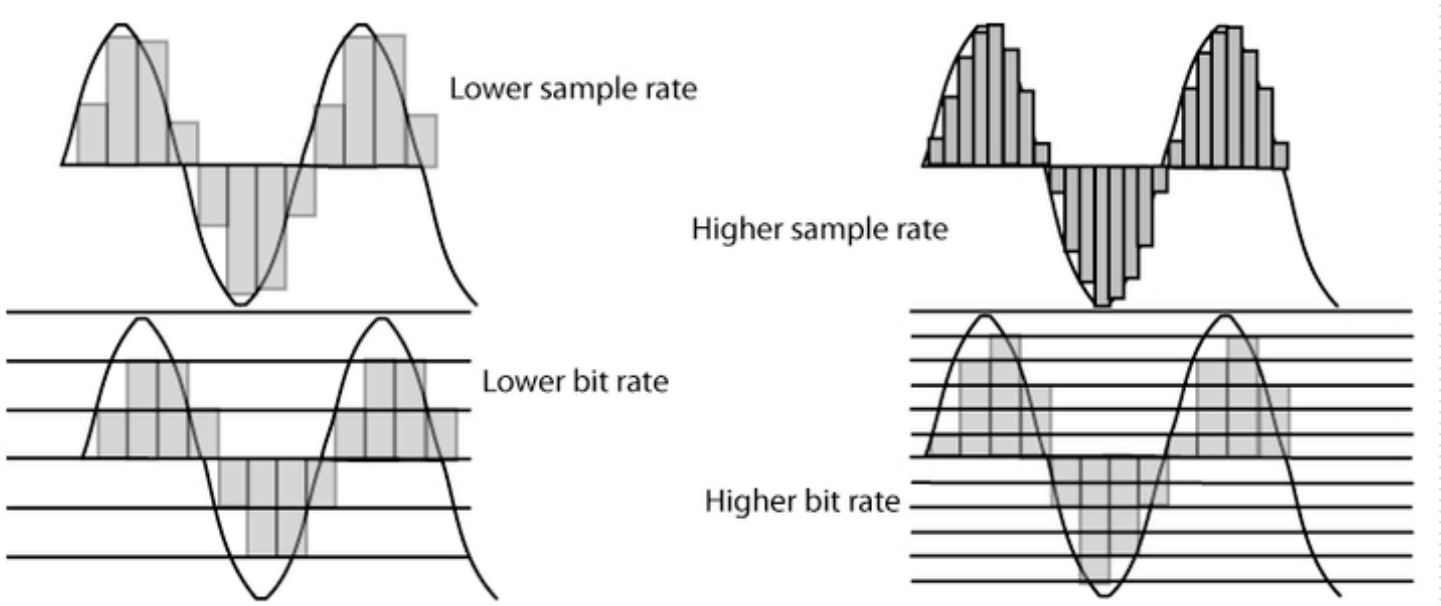
Combining Wave Forms

- Adding up waves creates new waves



Sampling Rates and Bit Rates

- Analog signals need to be translated into digital ones
  - Actually, analog is better in terms of quality!
  - Digital is easier to handle (manipulate)



Spatialized Audio Effects

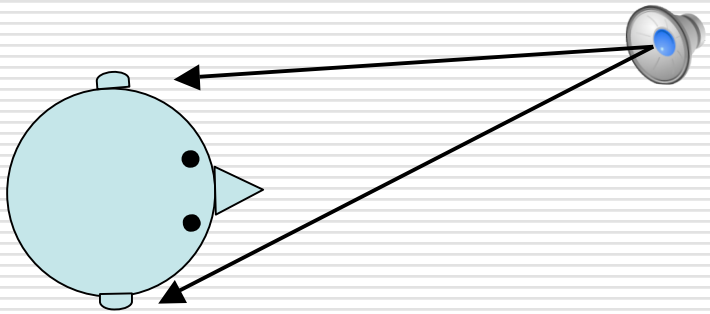
- Naïve approach
  - Simple left/right shift for lateral position
  - Amplitude adjustment for distance
- Easy to produce using commodity hardware/software
- Does not give us "true" realism in sound
  - No up/down or front/back cues
- We can use multiple speakers for this
  - Surround the user with speakers
  - Send different sound signals to each one

Spatialized Audio Effects (cont.)

- What is Dolby 5.1 surround sound?
- We hear with two ears
  - So, why is 5.1 (or 7.1) sound needed?!?!
- If we can correctly model how sound reaches our ears, we should be able to reproduce sounds from arbitrary locations in space
- Much work was done in 1990s on this

Head-Related Transfer Functions

- A.k.a. HRTFs
- A set of functions that model how sound from a source at a known location reaches the eardrum



Constructing HRTFs

- Small microphones placed into ear canals
- Subject sits in an anechoic chamber
  - Can use a mannequin's head instead
- Sounds played from a large number of known locations around the chamber
- Functions are constructed for this data
- Sound signal is filtered through inverse functions to place the sound at the desired source

More About HRTFs

- Functions take into account, for example,
  - Individual ear shape
  - Slope of shoulders
  - Head shape
- So, each person has his/her own HRTF!
  - Need to have a parameterizable HRTFs
- Some sound cards/APIs allow you to specify an HRTF to use
- Check Wikipedia or Google for more info!

Environmental Effects

- Sound is also influenced by objects in the environment
  - Can reverberate off of reflective objects
  - Can be absorbed by objects
  - Can be occluded by objects
- Doppler shift

The Tough Part

- All of this takes a lot of processing
- Need to keep track of
  - Multiple (possibly moving) sound sources
  - Path of sounds through a dynamic environment
  - Position and orientation of listener(s)
- Most sound cards only support a limited number of spatialized sound channels
- Increasingly complex geometry increases load on audio system as well as visuals
  - That's why we fake it ;-)
- GPUs might change this too!