CS 414 – Multimedia Systems Design

Lecture 2 –Auditory Perception and Digital Audio

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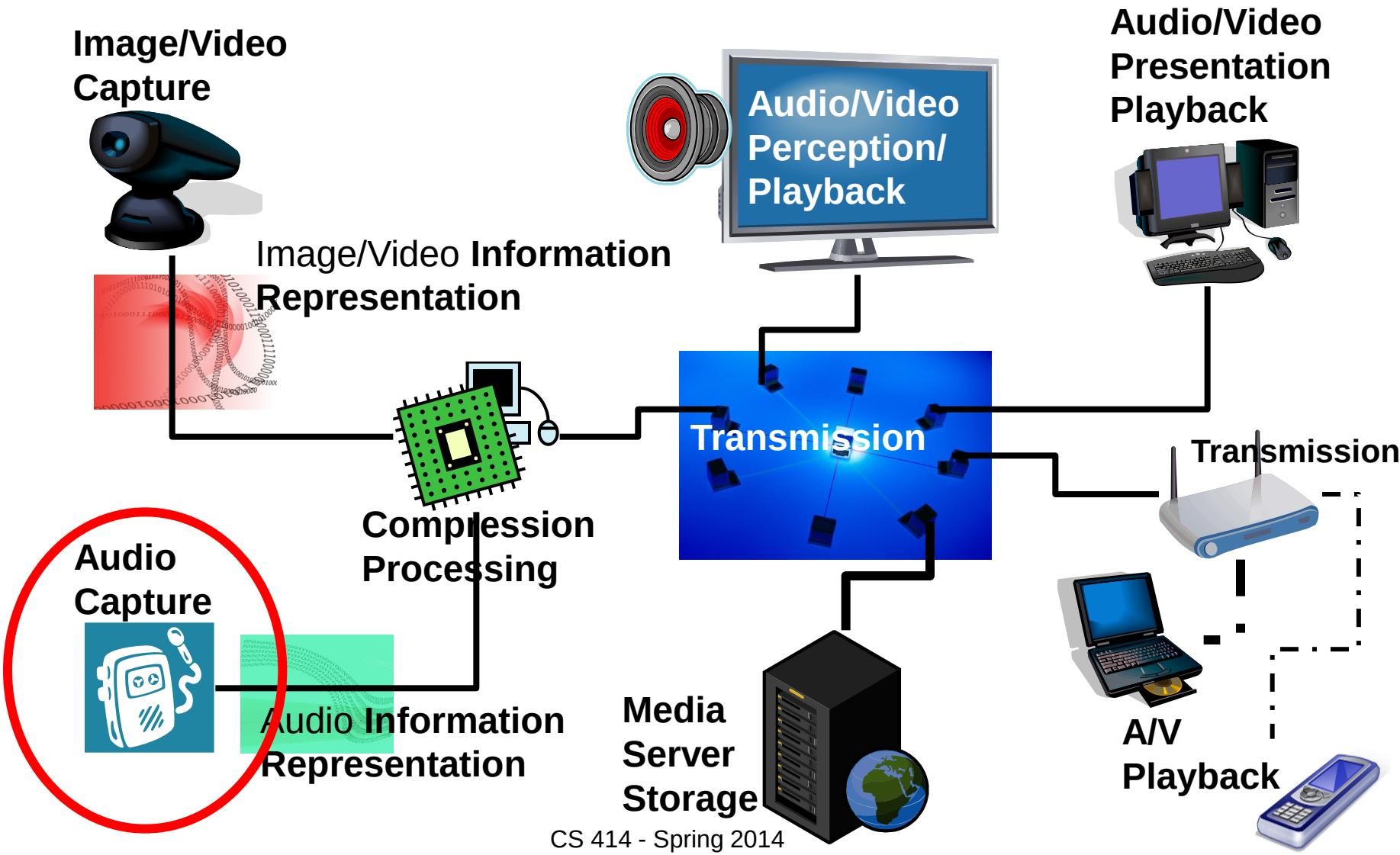
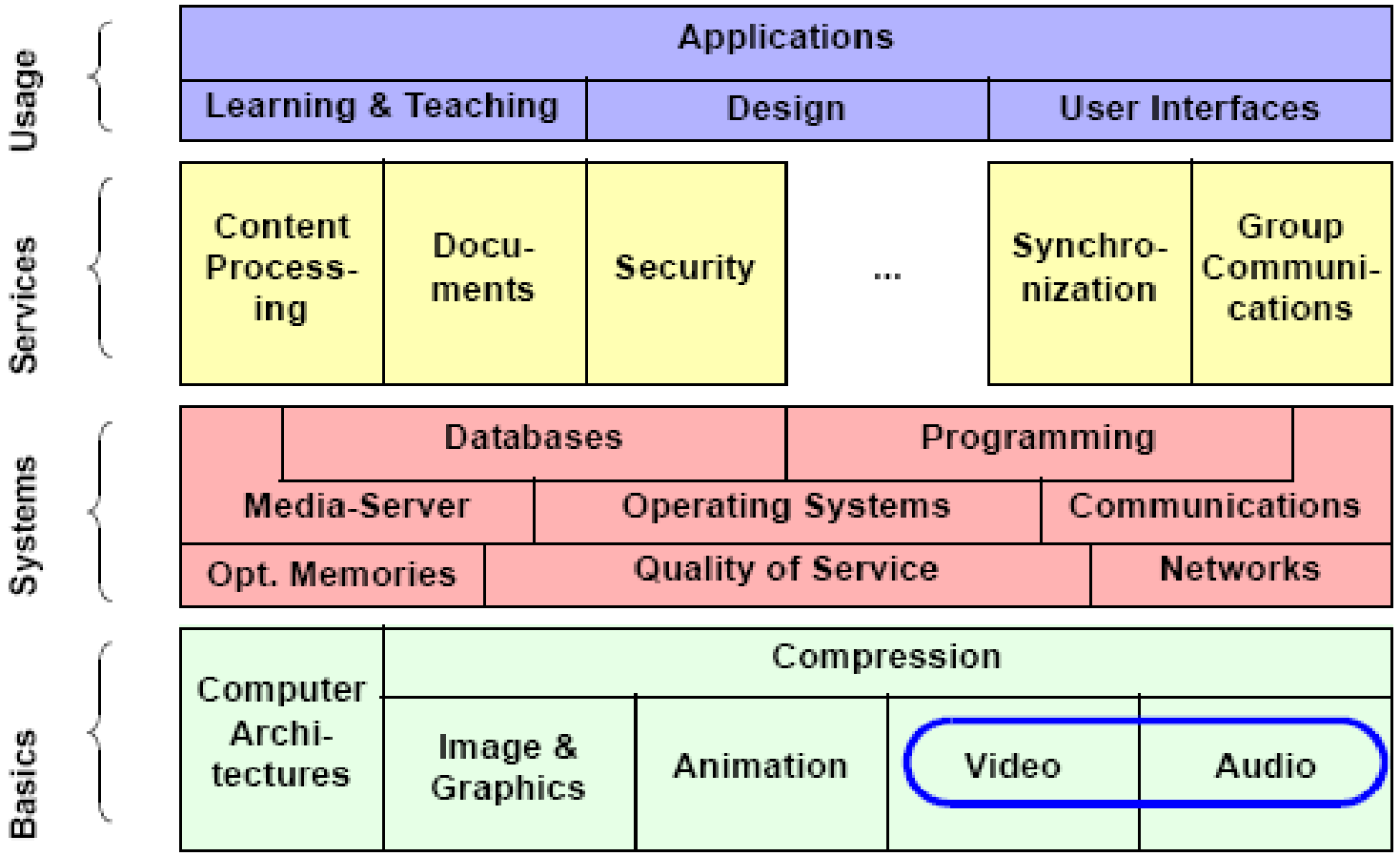
Spring 2012

Administrative

- Form Groups for MPs
  - Deadline: Latest January 27 (Monday) to email TA cchen116@illinois.edu

Integrating Aspects of Multimedia

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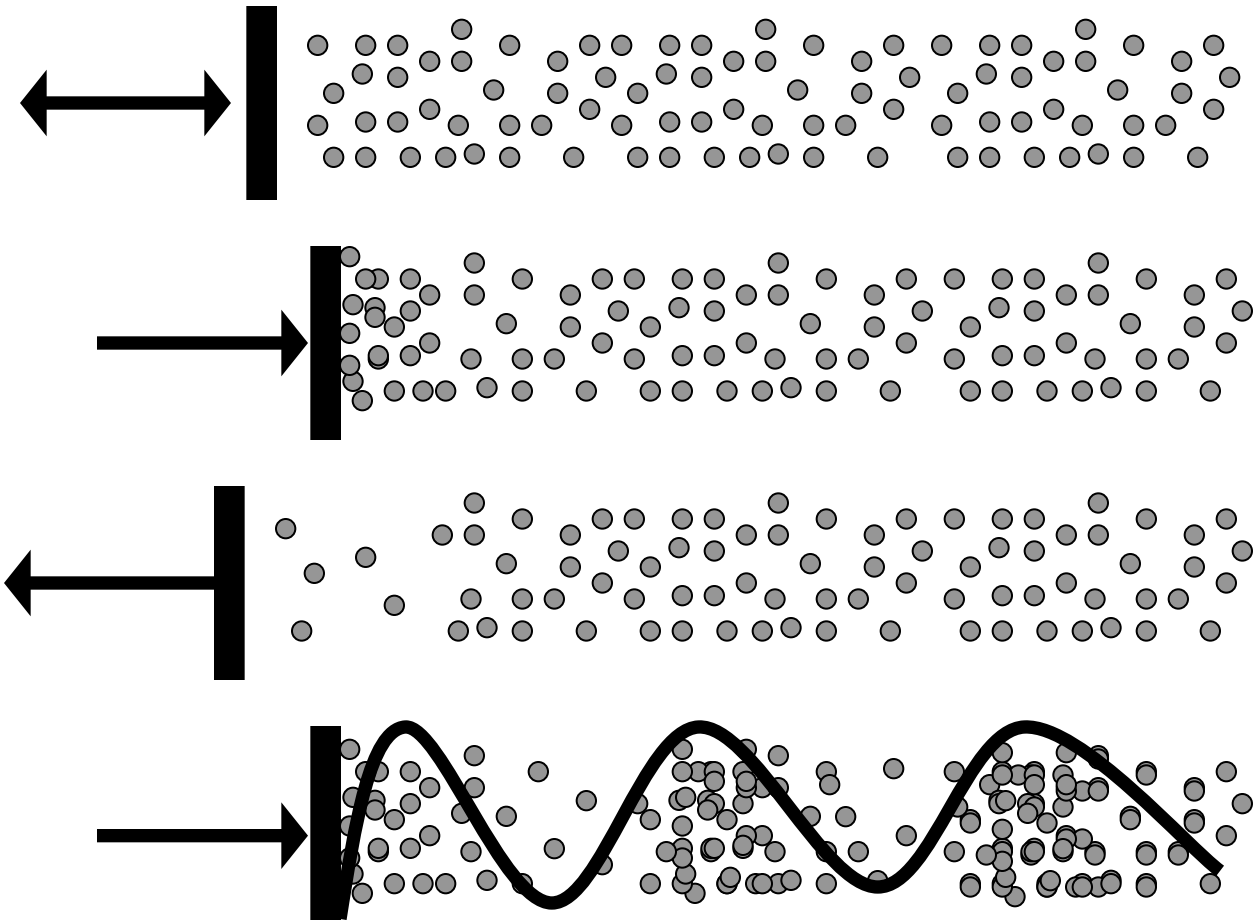
Today Introduced Concepts

- Human Auditory System
- Physical Dimensions
  - Amplitude, Wavelength, Frequency
- Psychological Dimensions
  - Concept of Psychoacoustic
  - Loudness, Pitch, Decibel, Sound Intensity
- Sound Masking
  - Fletcher-Munson Curves
  - Frequency and Temporal Masking

Auditory Perception

- Sound – physical phenomenon caused by vibration of material
- These vibrations trigger pressure wave fluctuations in the air
- Wave forms

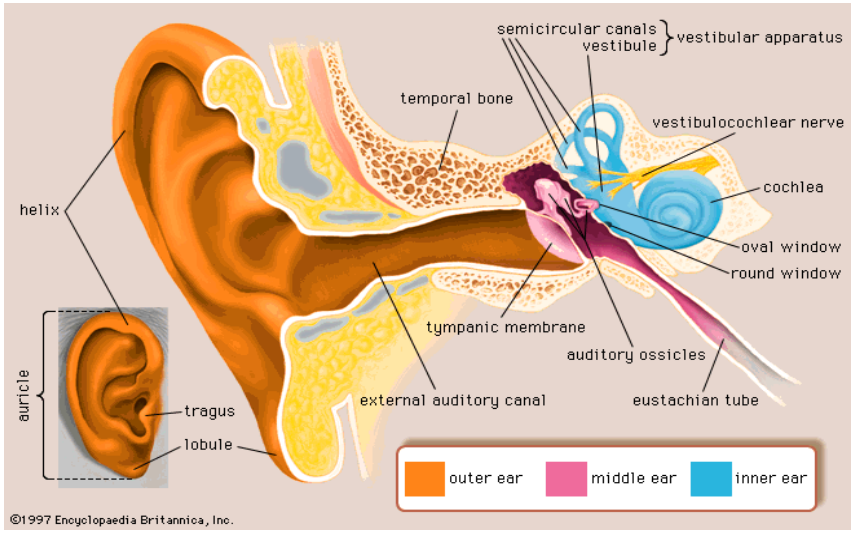
Changes in Air Pressure



Different Waves
Different Sounds

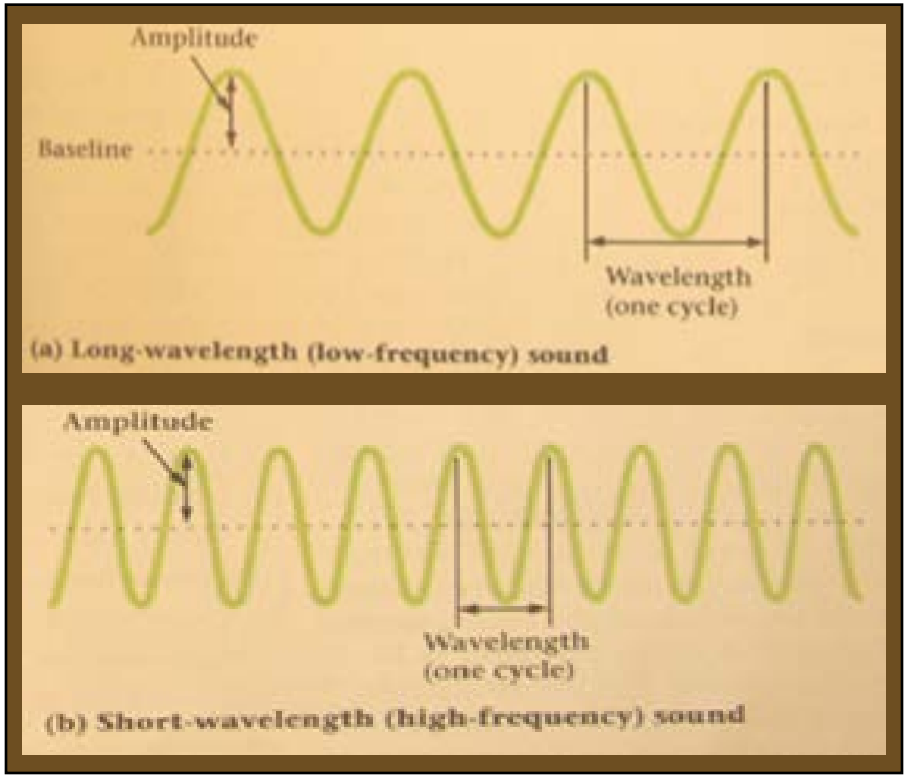
Auditory System

- Ears, parts of brain, and neural pathways
- Changes in pressure move hair-like fibers within the inner ear
- Movements result in electrical impulses sent to the brain



Physical Dimensions

- **Amplitude**
  - height of a cycle
  - relates to loudness
- **Wavelength** (*w*)
  - distance between peaks
- **Frequency** (λ)
  - cycles per second
  - relates to pitch
  - λw = velocity
- Most sounds mix many frequencies & amplitudes



Sound is repetitive changes in air pressure over time

Sound Perception and Psychoacoustics

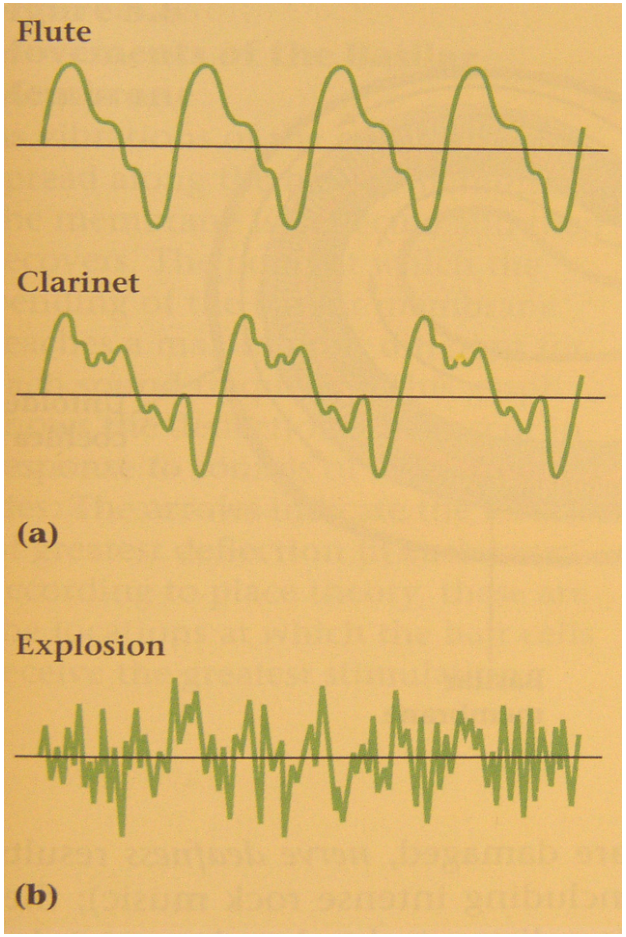
- **Psychoacoustics**
  - Study correlation between physics of acoustical stimuli and hearing sensations
  - Experimental data and models are useful for **audio codec**
- Modeling human hearing mechanisms
  - Allows to reduce the data rate while keeping distortion from being audible

Psychological Dimensions

- **Loudness**
  - higher amplitude results in louder sounds
  - measured in decibels (db), 0 db represents hearing threshold
- **Pitch**
  - higher frequencies perceived as higher pitch
  - Humans hear sounds in 20 Hz to 20,000 Hz range

Psychological Dimensions (cont.)

- **Timbre** (tam-bre)
  - complex patterns added to the lowest, or *fundamental*, frequency of a sound, referred to as *spectra*
  - spectra enable us to distinguish musical instruments
- Multiples of fundamental frequency give music
- Multiples of unrelated frequencies give noise



https://www.youtube.com/watch?v=gZrH00YfiXU

Sound Intensity

- ***Intensity*** (I) of a wave is the rate at which sound energy flows through a unit area (A) perpendicular to the direction of travel

$$I = \frac{1}{A}\frac{\Delta E}{\Delta t} = \frac{P}{A}$$

P measured in watts (W), ***A*** measured in m^2

- *Threshold of hearing* is at 10^{-12} W/m^2
- *Threshold of pain* is at 1 W/m^2

Decibel Scale

- Describes intensity relative to threshold of hearing based on multiples of 10

$$dB = 10 \log \frac{I}{I_0}$$

I_0 is reference level = 10^{-12} W/m^2

Decibels of Everyday Sounds

Sound	Decibels
Rustling leaves	**10**
Whisper	**30**
Ambient office noise	**45**
Conversation	**60**
Auto traffic	**80**
Concert	**120**
Jet motor	***140***
Spacecraft launch	***180***

Interpretation of Decibel Scale

- 0 dB = threshold of hearing (TOH)
- 10 dB = 10 times more intense than TOH
- 20 dB = 100 times more intense than TOH
- 30 dB = 1000 times more intense than TOH

- An increase in 10 dB means that the intensity of the sound increases by a factor of 10

- If a sound is 10^x times more intense than another, then it has a sound level that is 10*x more decibels than the less intense sound

Loudness from Multiple Sources

- Use energy combination equation

$$L = 10\log(10^{\frac{L1}{10}} + 10^{\frac{L2}{10}} + \ldots + 10^{\frac{LN}{10}})$$

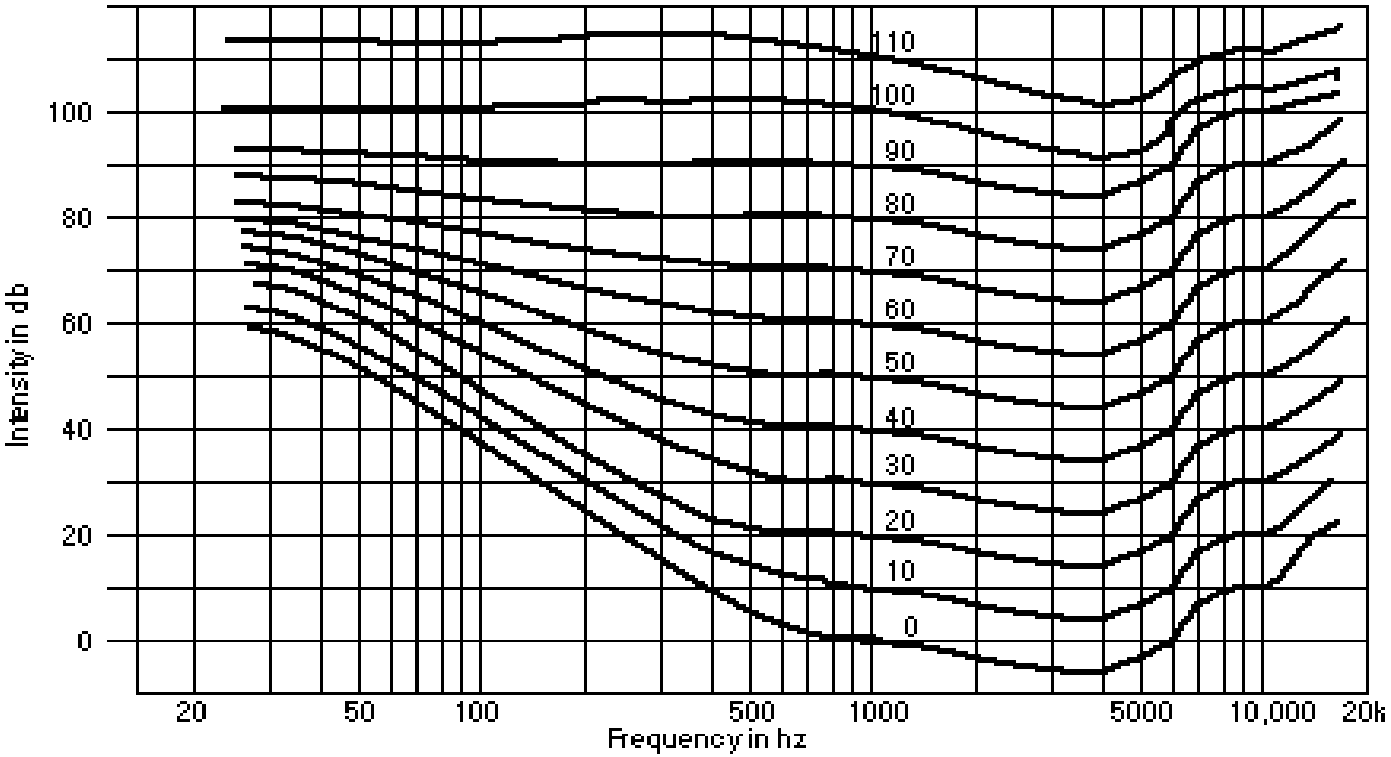
where L_1, L_2, …, L_n are in dB

Loudness and Pitch

- More sensitive to loudness at **mid frequencies** than at other frequencies
  - intermediate frequencies at [500hz, 5000hz]
  - Human hearing frequencies at [20hz,20000hz]
- Perceived **loudness** of a sound changes based on **frequency** of that sound
  - basilar membrane reacts more to intermediate frequencies than other frequencies

https://www.youtube.com/watch?v=H-iCZElJ8m0

Fletcher-Munson Contours



Each contour represents an equal perceived sound

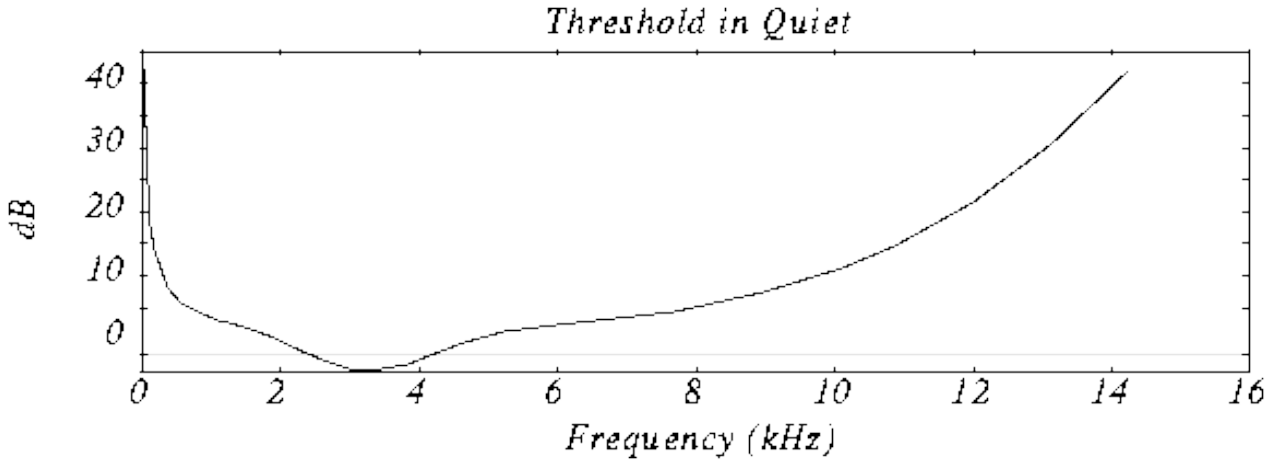
Perception sensitivity (loudness) is not linear across all frequencies and intensities

Masking

- Perception of one sound interferes with another
- Frequency masking
- Temporal masking

Frequency Masking

- Louder, lower frequency sounds tend to mask weaker, higher frequency sounds



From http://www.cs.sfu.ca/CourseCentral/365/

Frequency Masking

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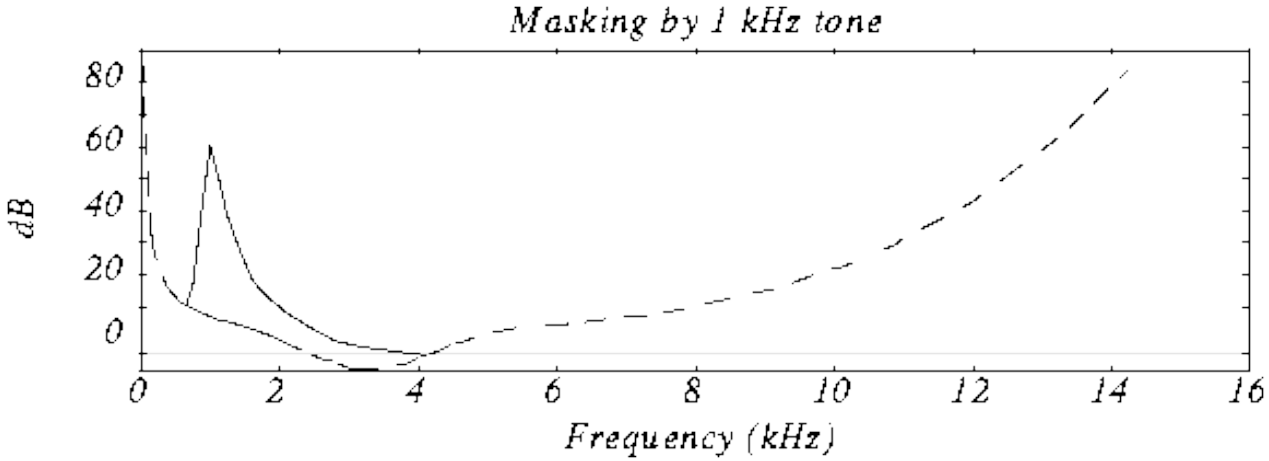

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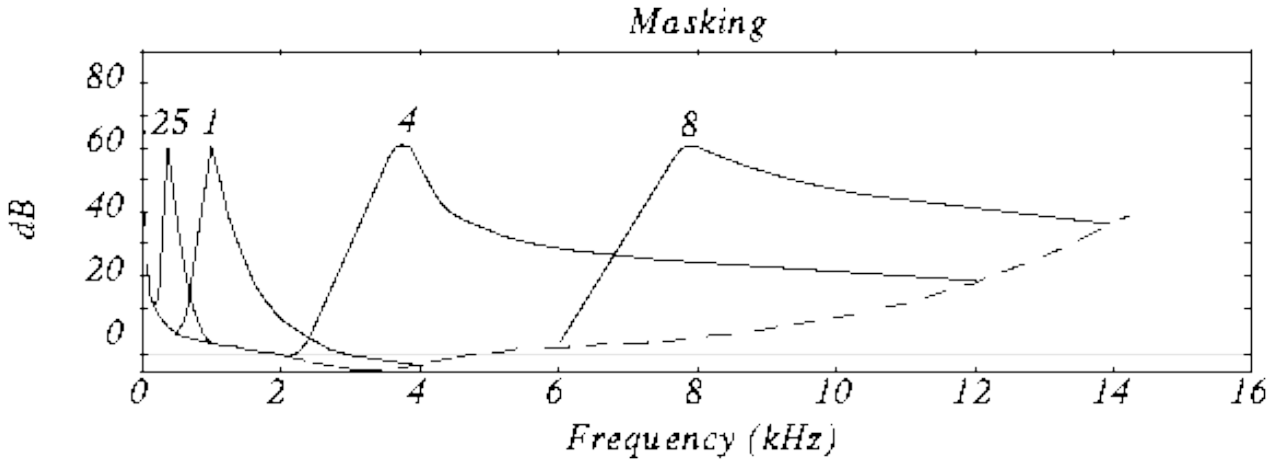
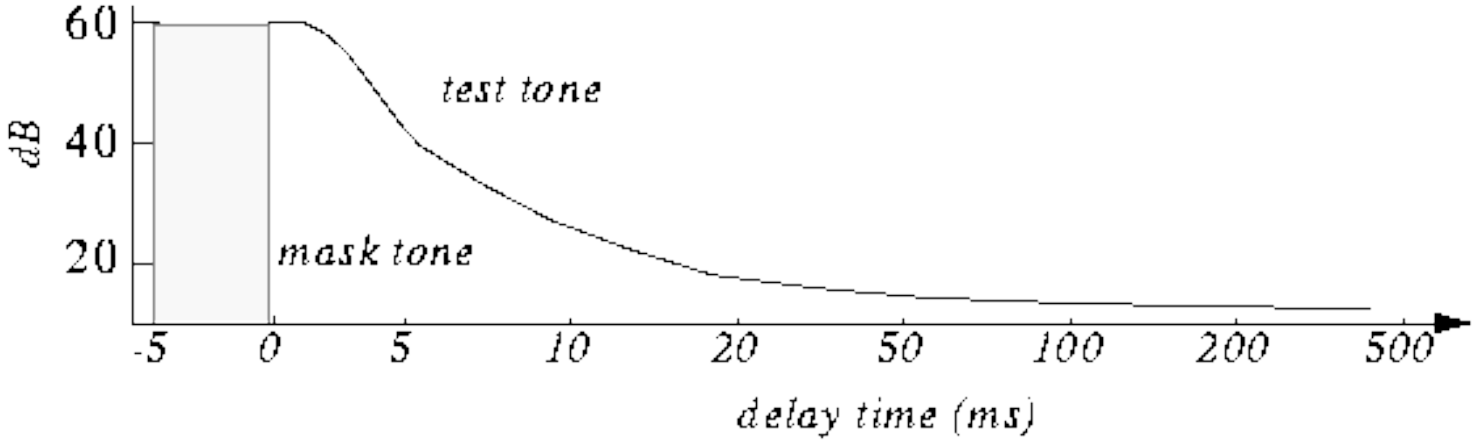


Temporal Masking

- When exposed to a loud sound, the human ear contracts slightly to protect delicate structures
- Causes louder sounds to overpower weaker sounds just *before* and just *after* it



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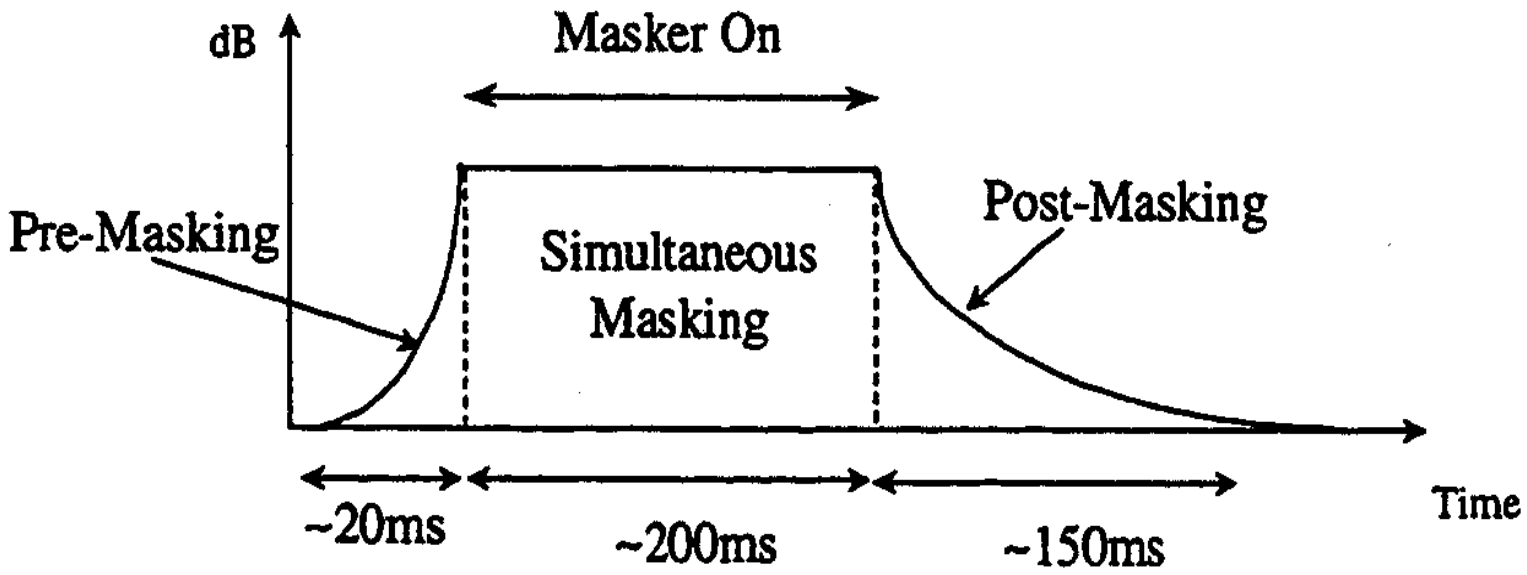

Summary

- Auditory Perception is very important for understanding digital audio representation
- Psychoacoustic is used in MP3 audio compression
- Listen to “The Coolest Things Sound Waves Do”
  https://www.youtube.com/watch?v=Ude8pPjawKI

Exercises

- Show that the threshold of hearing is at 0 dB
- Show that the threshold of pain is at 120 dB

- Suppose an electric fan produces an intensity of 40 dB. How many times more intense is the sound of a conversation if it produces an intensity of 60 dB?

- One guitar produces 45 dB while another produces 50 dB. What is the dB reading when both are played?

- If you double the physical intensity of a sound, how many more decibels is the resulting sound?