CS 414 – Multimedia Systems Design

# Lecture 2 –Auditory Perception and Digital Audio

Klara Nahrstedt

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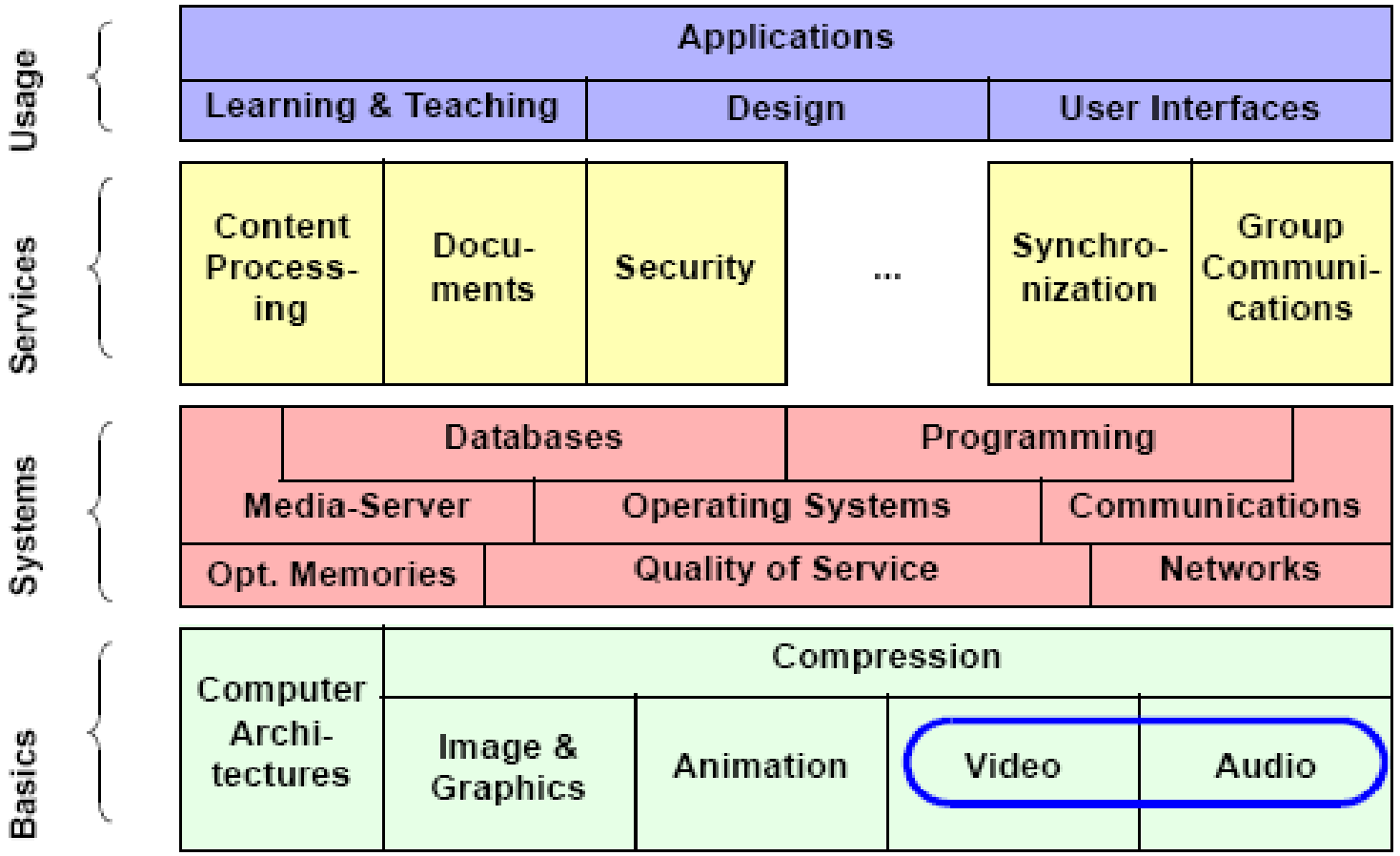
# Administrative

- Form Groups for MPs
  - Deadline: Latest January 26 to email TA hnguyen5@illinois.edu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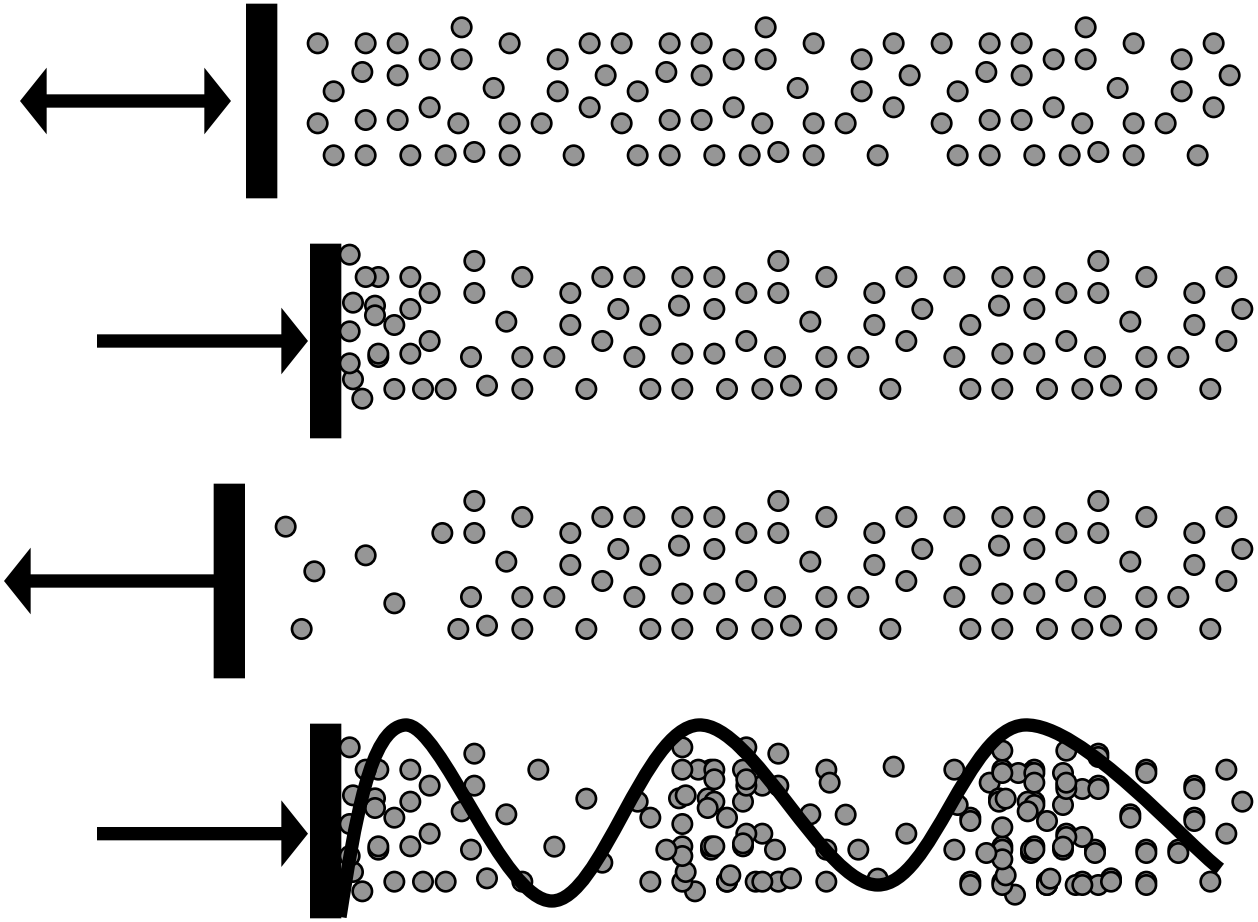
# Auditory Perception

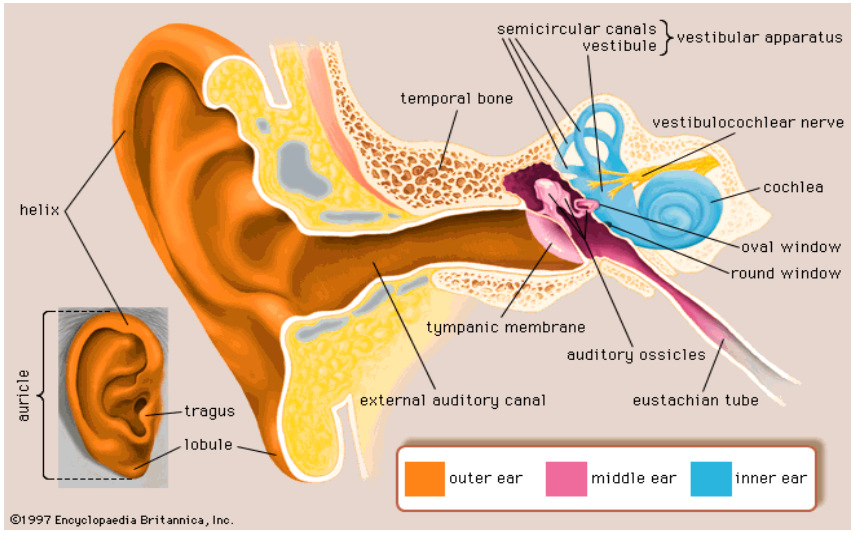
- Sound – physical phenomenon caused by vibration of material
- These vibrations trigger pressure wave fluctuations in the air
- Wave forms

# Changes in Air Pressure



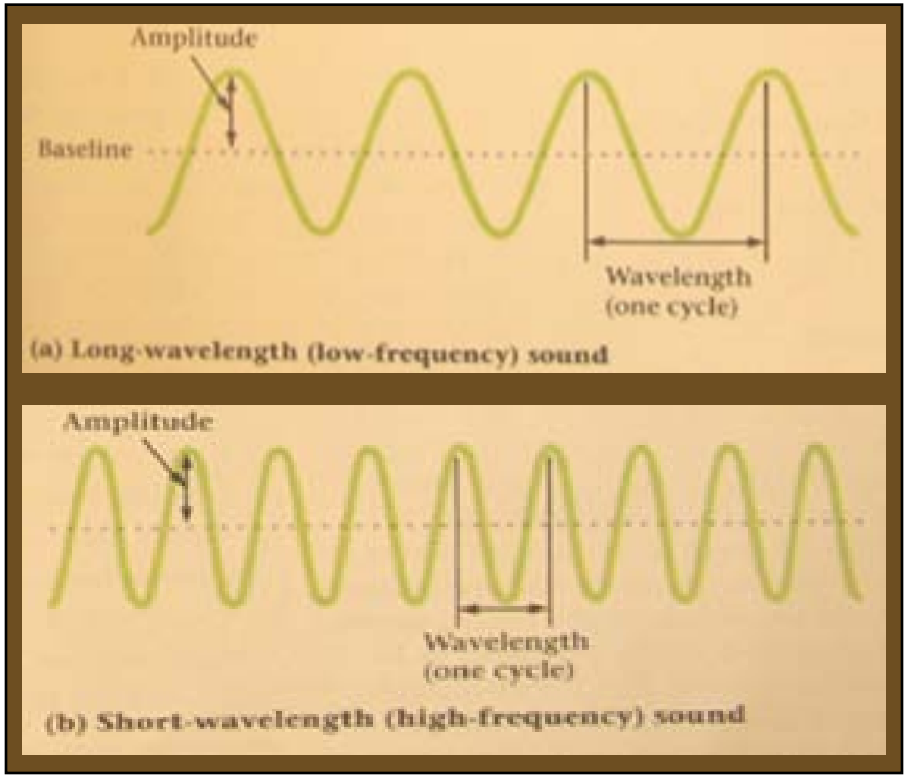
# Auditory System

- 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 ( $\lambda$ )
  - cycles per second
  - relates to pitch
  - $\lambda w$ = velocity
- Most sounds mix many frequencies & amplitudes




Sound is repetitive changes in air pressure over time

# Sound Perception and Psychoacoustics

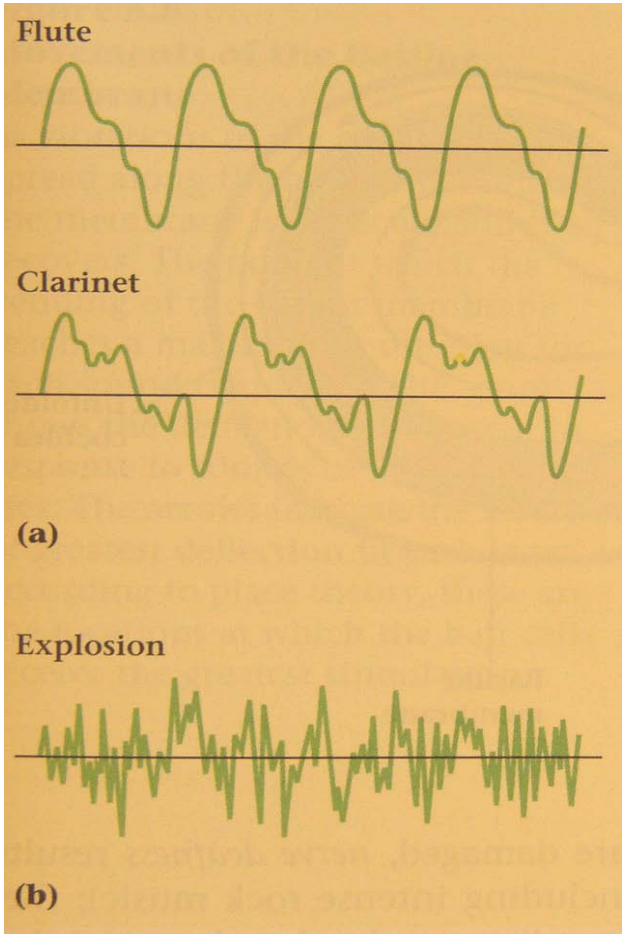
- Psychoacoustics
  - Study the correlation between the physics of acoustical stimuli and hearing sensations
  - Experiments data and models are useful for audio codec
- Modeling human hearing mechanisms
  - Allows to reduce the data rate while keeping distortion from being audible

# 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
  - 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



# 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

# 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?

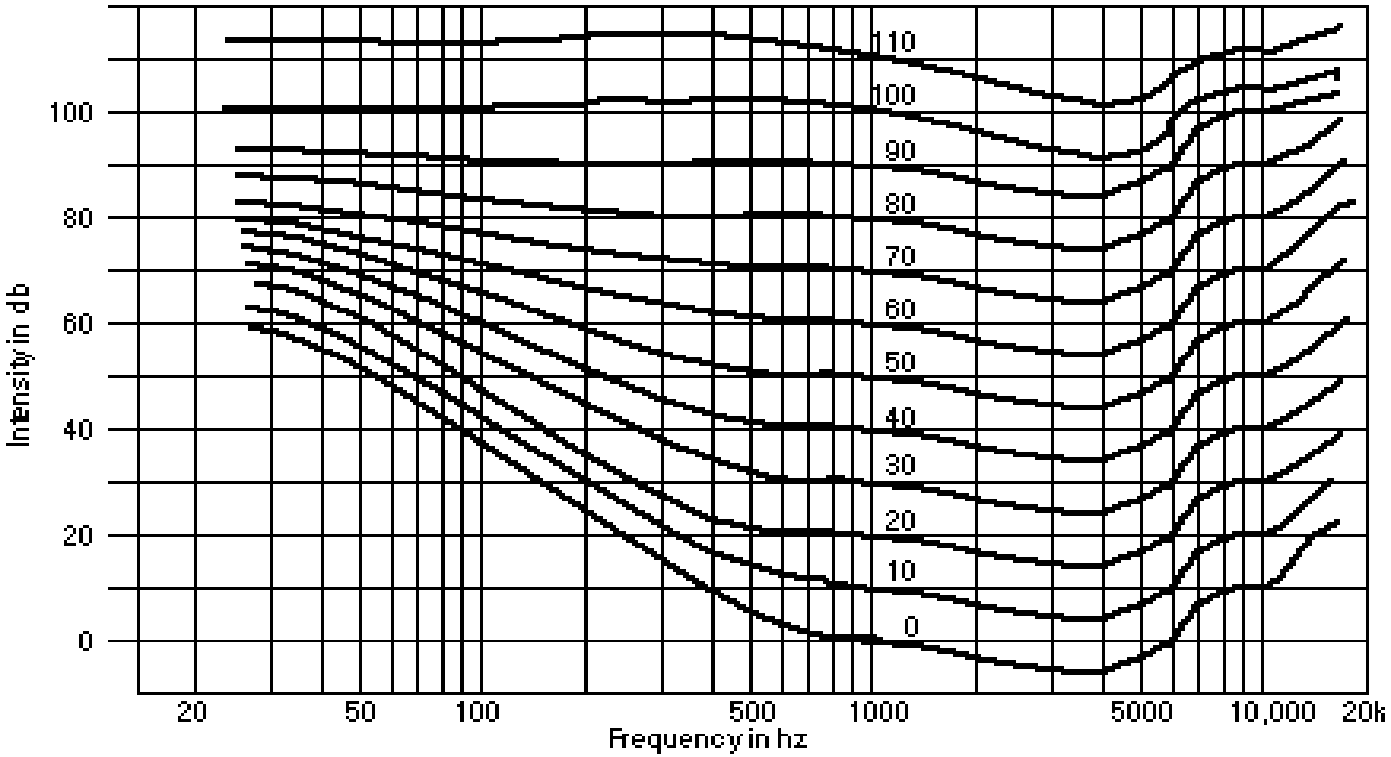
- One guitar produces 45 dB while another produces 50 dB. What is the dB reading when both are played?

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

# Loudness and Pitch

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

# Fletcher-Munson Contours



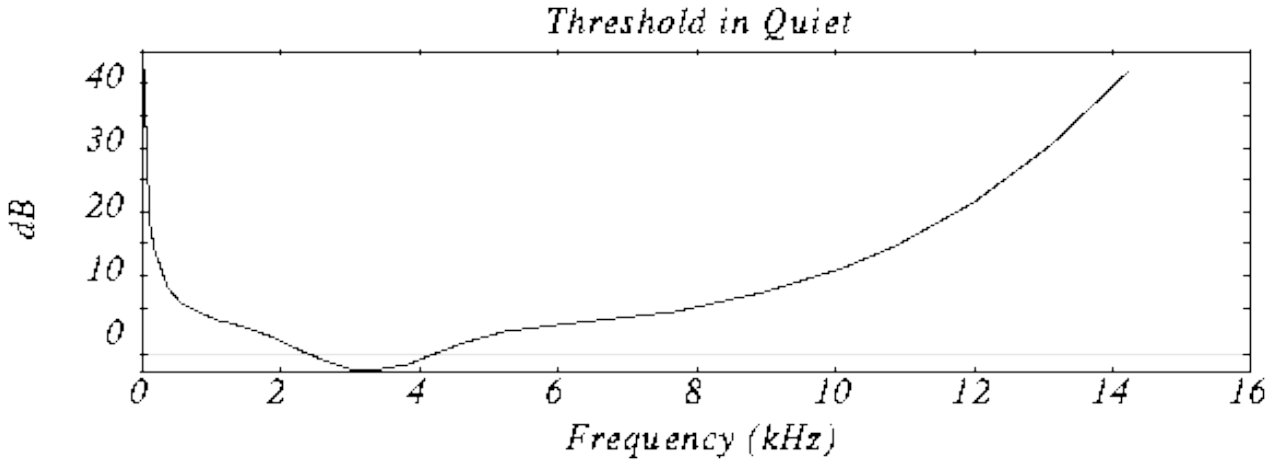

Each contour represents an equal perceived sound

# Masking

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

# Frequency Masking

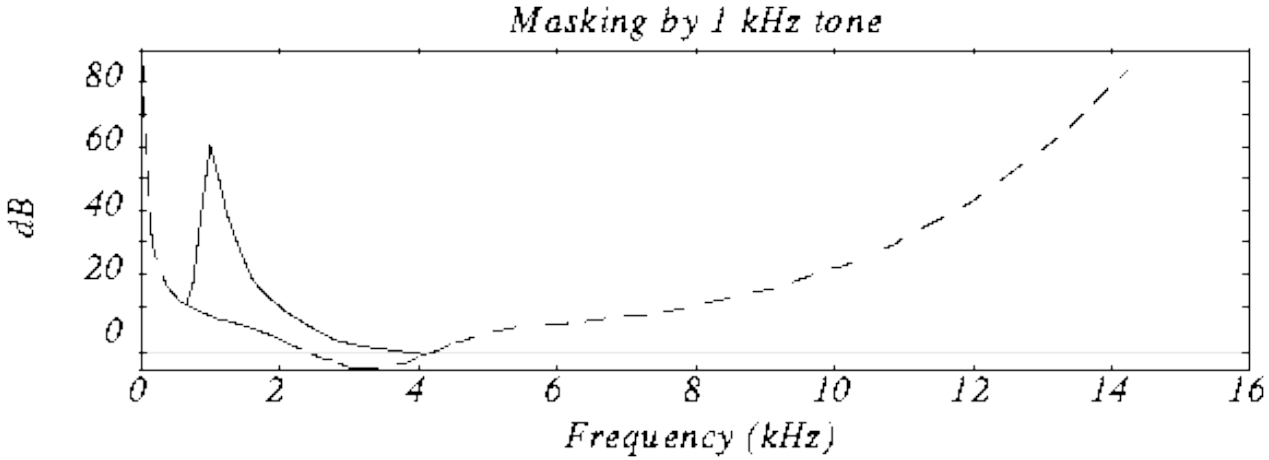
- Louder, lower frequency sounds tend to mask weaker, higher frequency sounds




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

# Frequency Masking

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



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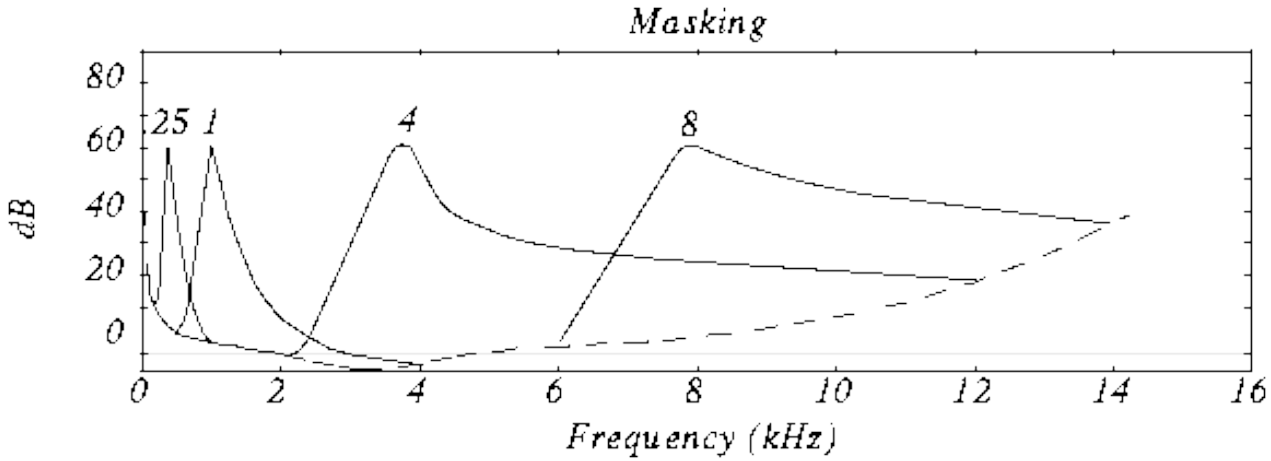
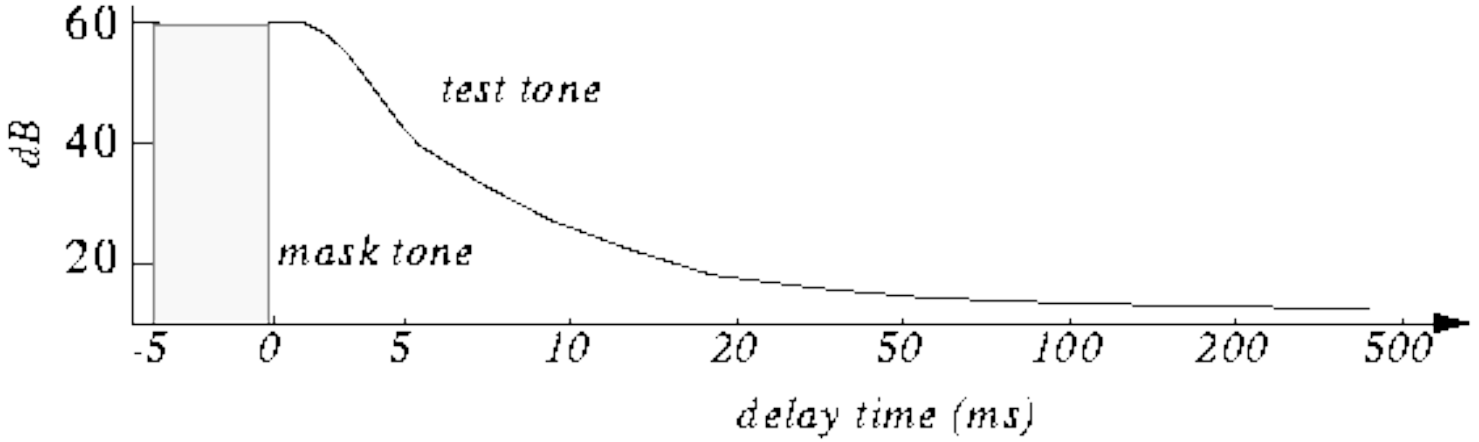


# Temporal Masking

- 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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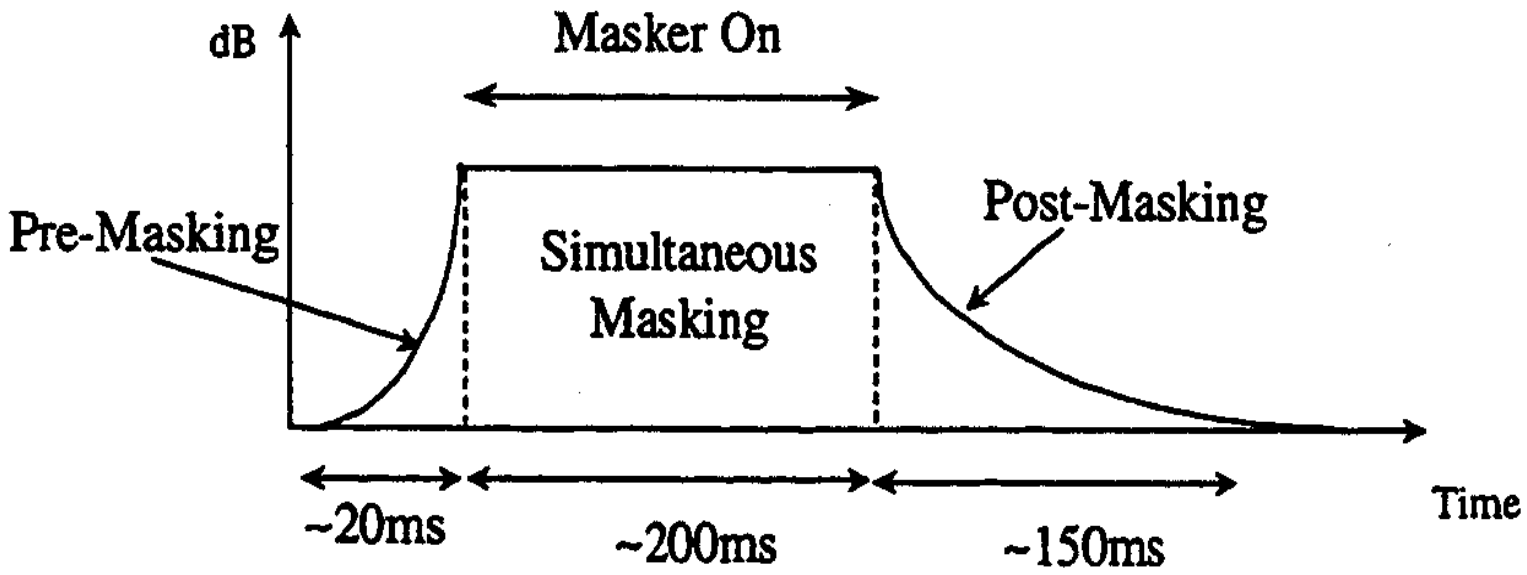

# Summary

- Auditory Perception is very important for understanding digital audio representation
- Psychoacoustic is used in MP3 audio compression