

CMPT 468: Lecture 1  
Fundamentals of Acoustics and Sound

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## Musical Acoustics

### Mechanical Waves

- A disturbance travelling through a medium
- Transports energy from one location to another

### Travelling waves

- Waves propagating in one direction with negligible change in shape
- Two types: *longitudinal* and *transverse*

## What is Sound?

If a tree falls in a forest and no one is there to hear it, does it make sound?

- Nearly all objects will vibrate when disturbed.
- Sound is the result of a **wave** created by vibrating objects, propagated through a medium from one location to another.
- **Acoustics** is the science that deals with the quantifiable measure of the *production, control, transmission* and *reception* of sound.
- **Psychoacoustics** is the study of the way humans perceive sounds.

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## Musical Acoustics cont.

### Longitudinal Wave

Particle displacement is parallel to the direction of wave propagation.

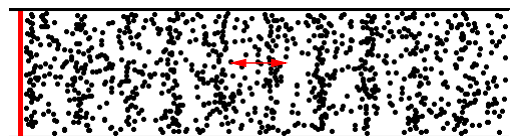


Figure 1: Longitudinal wave. Animation, courtesy of Dr. Dan Russell, Kettering University, available on class website.

### Transverse Wave

Particle displacement is perpendicular to the direction of wave propagation.

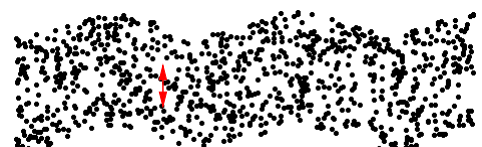


Figure 2: Transverse Wave, animation courtesy of Dr. Dan Russell, Kettering University.

## Sound

- Sound waves are longitudinal waves.
- A disturbance of a source (such as vibrating objects) creates an initial region of compression or high pressure.
- When the source vibrates, alternating regions of low and high pressure are produced in the surrounding air, called *rarefactions* and *compressions* respectively.
- The alternating pressure propagates through a medium, away from the source, before reaching our ears.

## Properties of a Wave

The *waveform* of the sound shows the time evolution of the pressure variations.

- **Amplitude:** maximum particle displacement from rest position (Pa or N/m<sup>2</sup>).
- **Wavelength:** length of one complete cycle (m).
- **Period:** time to complete one cycle (s).
- **Frequency:** number of cycles per second (Hz).

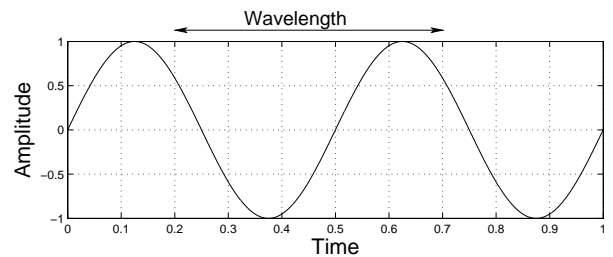


Figure 3: Sinewave.

## Properties of Sound Waves

- Speed of sound<sup>1</sup>:
  - in air: 340 m/s
  - in water: 1480 m/s
- Amplitude range of hearing (humans)
  - Threshold of audibility: 0.00002 N/m<sup>2</sup>
  - Threshold of feeling (or pain!): 200 N/m<sup>2</sup>
- Frequency range of hearing
  - humans: 20 - 20 000 Hz
  - dogs: 20 - 45 000 Hz
  - beluga whale: 1000 - 123 000 Hz
- Period of lowest and highest audible frequencies
  - 1/20 Hz = 0.05 s    1/20 000 Hz = 0.05 ms
- Shortest audible wave
  - 340/20000=1.7cm
- Longest audible wave
  - 340/20=17m

<sup>1</sup>Quantity depends on temperature: For air, the speed of sound is  $c = 20.1\sqrt{T}$ , where  $T$  is the absolute temperature found by adding 273 to the temperature on the Celsius scale.

## Power and Intensity

- The two physical quantities for a sound wave described so far are the frequency and amplitude of pressure variations.
- Related to the sound pressure are
  1. the sound **power** emitted by the source
  2. the sound **intensity** measured some distance from the source.

## Intensity

- Intensity is given by

$$I = p^2 / (\rho c)$$

where  $p$  is the pressure,  $\rho$  is the density of air, and  $c$  is the speed of sound.

- The intensity is the power per unit area carried by the wave, measured in watts per square meter ( $\text{W}/\text{m}^2$ )
- Intensity therefore, is a measure of the power in a sound that actually contacts an area, such as the eardrum.
- The range of human hearing is
  - $I_0 = 10^{-12} \text{ W}/\text{m}^2$  (threshold of audibility)
  - $1 \text{ W}/\text{m}^2$  (threshold of feeling)

## Linear vs logarithmic scales.

- Human hearing is better measured on a logarithmic scale than a linear scale.
- On a linear scale, a change between two values is perceived on the basis of the **difference** between the values. Thus, for example, a change from 1 to 2 would be perceived as the same amount of increase as from 4 to 5.
- On a logarithmic scale, a change between two values is perceived on the basis of the **ratio** of the two values. That is, a change from 1 to 2 (ratio of 1:2) would be perceived as the same amount of increase as a change from 4 to 8 (also a ratio of 1:2).

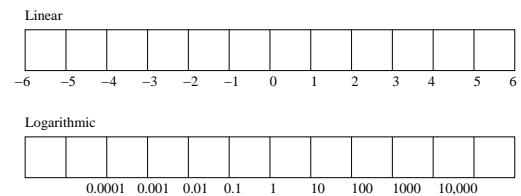


Figure 4: Moving one unit to the right increment by 1 on the linear scale and multiplies by a factor of 10 on the logarithmic scale.

## Decibels

- The decibel is defined as one tenth of a bel, a unit named after Alexander Graham Bell, the inventor of the telephone.
- The decibel is a logarithmic scale, used to compare two quantities such as the power gain of an amplifier or the relative power of two sound sources.
- The decibel difference between two power levels  $\Delta L$  for example, is defined in terms of their power ratio  $W_2/W_1$  and is given in decibels by:

$$\Delta L = 10 \log W_2/W_1 \quad \text{dB.}$$

- Since power is proportional to intensity, the ratio of two signals with intensities  $I_1$  and  $I_2$  is similarly given in decibels by

$$\Delta L = 10 \log I_2/I_1 \quad \text{dB.}$$

## Sound Power and Intensity Level

- Decibels are sometimes used as absolute measurements.
- Though this may seem contradictory (since the decibel is always used to compare two quantities), one of the quantities is really a fixed reference.
- The *sound power level* of a source, for instance, is expressed using the threshold of audibility  $W_0 = 10^{-12}$  as a reference and is given in decibels by

$$L_W = 10 \log W/W_0.$$

- Similarly, the *sound intensity level* at some distance from the source can therefore be expressed in decibels by comparing it to a reference—usually  $I_0 = 10^{-12} \text{ W}/\text{m}^2$ :

$$L_I = 10 \log I/I_0.$$

## Sound pressure Level

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- Recall that intensity is proportional to sound pressure amplitude squared

$$I = p^2/(\rho c)$$

- Though  $\rho$  and  $c$  are dependent on temperature, their product is often approximated by 400 to simplify calculation.
- The *sound pressure level*  $L_p$  (SPL) is equivalent to sound intensity level and is expressed in dB by:

$$\begin{aligned}L_p &= 10 \log I/I_0 \\ &= 10 \log p^2/(\rho c I_0) \\ &= 10 \log p^2/(4 \times 10^{-10}) \\ &= 10 \log (p/(2 \times 10^{-5}))^2 \\ &= 20 \log p/(2 \times 10^{-5}) \\ &= 20 \log p/p_0.\end{aligned}$$

where  $p_0 = 2 \times 10^{-5}$  is the threshold of hearing for amplitude of pressure variations.