Introduction to Linguistic Phonetics

Sounds and Waves

Mykel Loren Brinkerhoff

University of Washington

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Recap and Reflection

Reflection

- Spend ∼3 minutes reviewing your notes from last lecture, homeworks, exit tickets, etc.
- Look for questions you have or clarifications you would like.

What is sound?

- The basic definition = a pressure wave that moves through some medium (like air, water, etc.)
- It is a vibration of the particles in that medium, and it propagates, or moves, through the medium

Acoustic waves

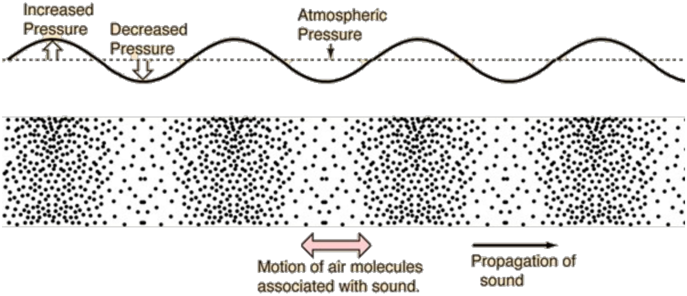
- Acoustic waves are typically generated by compression of particles, which then expand back to their original position
- This **compression** and expansion (more technically called **rarefaction**) expands and affects nearby particles, spreading in a wave-like pattern
  - Important: the particles themselves move in a relatively restricted area, the waves travel much further!
  - It can be analogized to be spring-like or slinky-like (see images)
- Sound waves in gasses and liquids travel as **longitudinal** waves
  - Examples of wave types from Daniel Russell
  - The Magic Schoolbus - Inside the Haunted House (14:25–17:50)

Wave propagation

- Sound waves "propagate" or move away from the source in all directions, unless obstructed or modified by changes in the medium
- The speed of propagation of sound in air depends on the temperature and humidity
  - In our atmosphere, near sea level it is $\approx$ 34,300cm/s (343m/s, 767mph[1])
  - In water, it's 148,000cm/s (1480m/s, 3310mph)
  - The vocal tract is fairly warm and humid, and the speed of sound is $\approx$35,000cm/s (350m/s, or 783mph)
    - This is what we will be using for the speed of sound.
  - If sound is traveling through a different medium, that differs in density, it might be faster or slower

[1] For us non-SI crazies.

Wave propagation



- Top part is the **waveform** (fancier term: **oscillogram**) and graphically represents sound waves
  - It shows changes from **atmospheric equilibrium**
  - We typically assign zero to atmospheric equilibrium and refer to relative changes from it
  - Thus it is commonly called the **zero**, or **zero line**
- Bottom shows the compression and rarefaction of the particles

Two types of waves

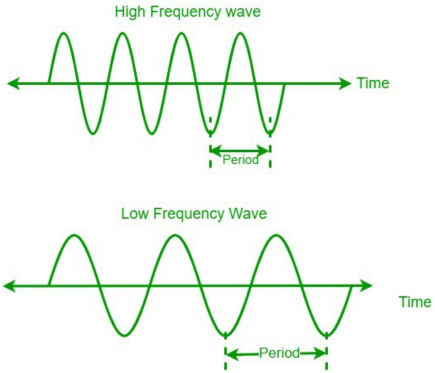
- **Periodic**
  - Wave with a regularly repeating pattern
  - Examples: Bowed string instrument, voiced sounds
- **Aperiodic**
  - No discernible repeating pattern in the wave
  - Can be continuously produced, still without a repeating pattern (e.g. white noise, pink noise, fricatives)
  - A single burst of aperiodic sound is called a transient (e.g. a clap, drum hit, stop burst)

Periodic Waves

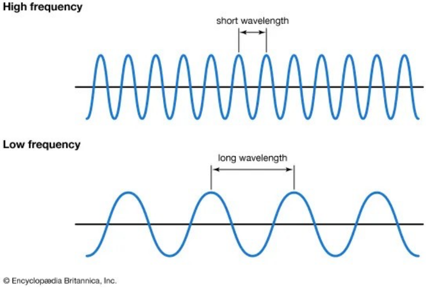
- **Frequency**
  - The rate at which a portion of a wave (a period) repeats in a given time unit
  - Unit of measure: periods (cycles) per second, called **Hertz** (**Hz**)
- **Wavelength** (λ)
  - Distance (in meters) from one period to the next
- **Amplitude**
  - Magnitude of the oscillation, measured in Pascals (absolute), or Decibels (relative)

Frequency

- The rate at which a cycle/period repeats
- More frequent repetitions are perceived as having higher pitch than less frequent ones
- Western (equal temperament) musical tuning and frequency



Wavelength (λ)



wavelength

$$\lambda = \frac{c}{f}$$

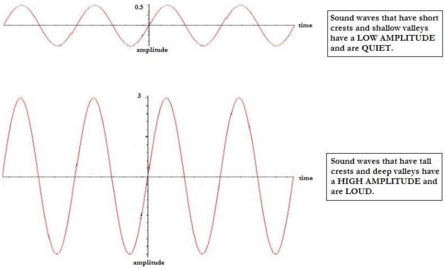
speed of sound (m/s)

frequency (Hz)

- The distance from one period to another, using the same part of the wave
  - e.g., peak–to–peak, trough–to–trough, positive zero crossing to positive zero crossing
- Represented as the Greek letter lambda (λ)
- Inversely related to frequency (longer wavelength $\rightarrow$ lower frequency)

Amplitude

- Amplitude is how far the particles move away from equilibrium, show on a waveform by how high the peaks and low the troughs are from the zero line
- In simple terms, we hear this as loudness: the greater the amplitude, the louder the sound
- We'll go more in-depth later when we talk about audition



Aperiodic waves

- No repeating pattern
- No consistent wavelength
- Overall amplitude might be consistently within a range, but not on small scale
- Related to turbulent airflow
- white noise and pink noise are two mathematically defined types

10 minute break
(stretch, grab a drink, etc.)

Complex waves and spectra

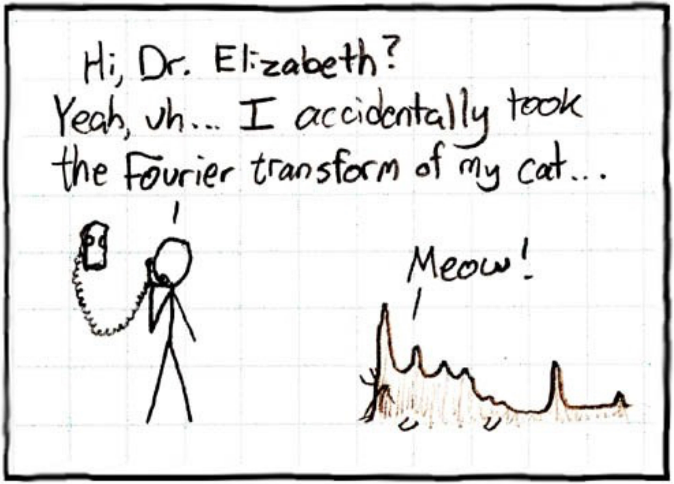


Image copyright Randall Munroe, XKCD comics

Simple period waves

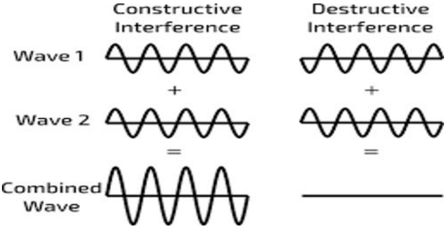
- A very specific type of wave defined by the **sine** trigonometric function
- Important because it forms the building block for more complex sounds
- It is geometrically related to a circle

Sine and Cosine waves

- Sine and Cosine waves are closely related
- The difference between the two can be described as a **phase** difference

Superposition of waves

- When waves interact, the result is constructive or destructive interference
    - Constructive = additive
    - Destructive = subtractive
- Adding simple waves together results in a **complex wave**



"Adding" waves

- The phasing of waves matters to how they will combine
- At left, the waves are in phase (top), 90° out of phase, and 180° out of phase (bottom)
- If we add these waves, we get constructive and destructive interference

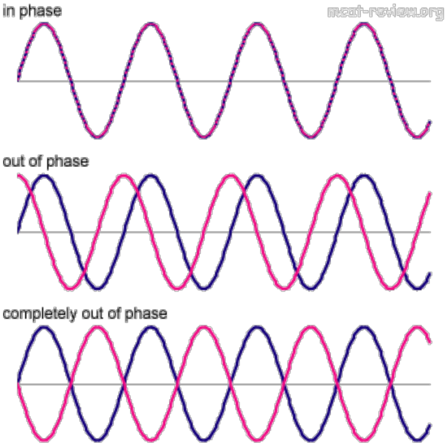


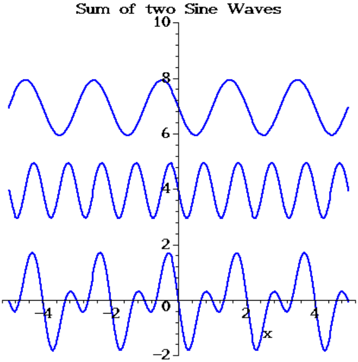
Illustration of Constructive and Desctructive Interference

Interference Illustration

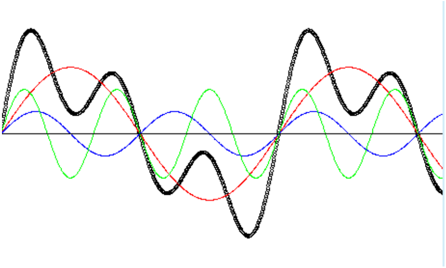
Superposition of waves

- So far all the waves we've discussed in this section are the same frequency and amplitude

- Things get slightly more complicated for waves of different frequencies and amplitudes



Complex waves



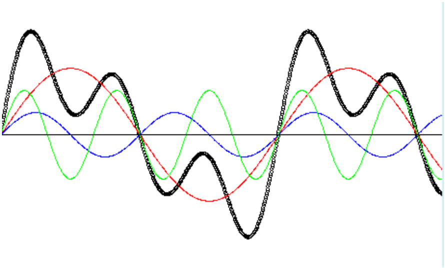
- The simple waves we've been discussing don't exist in nature on their own
- The sound waves all around us are **complex waves** made up of many simple waves
- You can generate some using this applet

Components of complex waves

- Since waves combine into more complex ones predictably, we can take complex ones and break them down into their simple **components**
- This is actually a bit complicated, but modern computing makes it easy
    - Praat has this built in.
- It's called **Fourier Analysis**

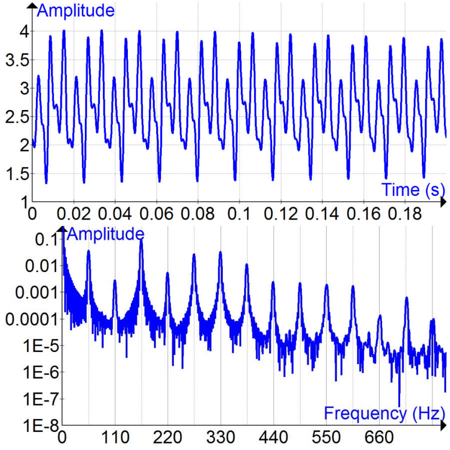
Fourier Analysis

- This process takes a complex wave and breaks it down into its component waves
- In terms of periodic waves, we get the frequency and amplitude of those waves

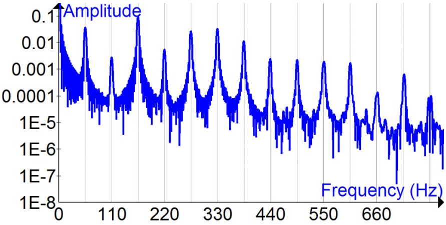


Visualizing component waves

- Fourier analysis Waveform produces a spectrum
- A spectrum shows a snapshot of a sound
- This snapshot shows the amplitude and frequency of component waves



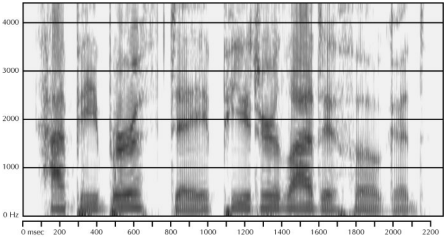
Spectrum (pl. spectra)



- X-axis shows frequency
- Y-axis shows amplitude
- This is a mathematical estimation, so there's some "fuzziness", especially in the lower amplitude

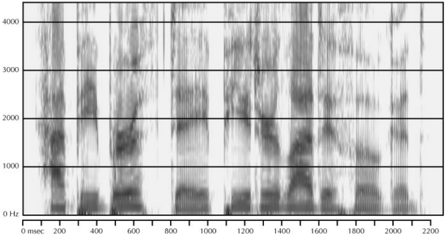
Spectrograms

- The spectrum just shows a snapshot in time and can't show *changes* over time
- We use the spectrum information and show how it changes over time by adding another dimension
- We call this a **spectrogram**



Spectrograms

- Time is on the x-axis
- Component frequencies on the y-axis
- Shading shows amplitude, darker = higher amplitude



Spectrogram

- There's a tradeoff between time and frequency in terms of resolution
- Two types of spectrograms
    - Narrowband: shows frequency in more detail at the expense of changes over time
    - Wideband: shows changes in time in more detail at the expense of frequency

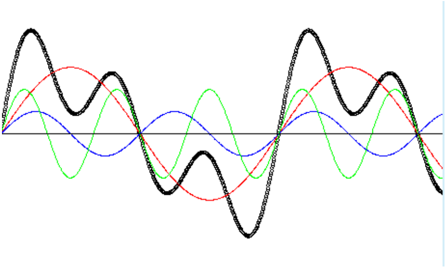
Frequency confusion

- We need to be very specific about *which* frequency we're talking about because there are two references
    1. The frequency of the complex wave we are analyzing
    2. The frequencies of the component parts

Fundamental frequency

- The frequency of the complex wave we are decomposing is called the **fundamental** frequency, or $f0$
- In speech sounds, the rate of vocal fold vibration equals the fundamental

Harmonics



- The component parts of a complex wave each have their own frequencies
- These frequencies are called harmonics, because they are in a harmonic relationship with the fundamental
- Represented as Hn where $n =$ a specific harmonic

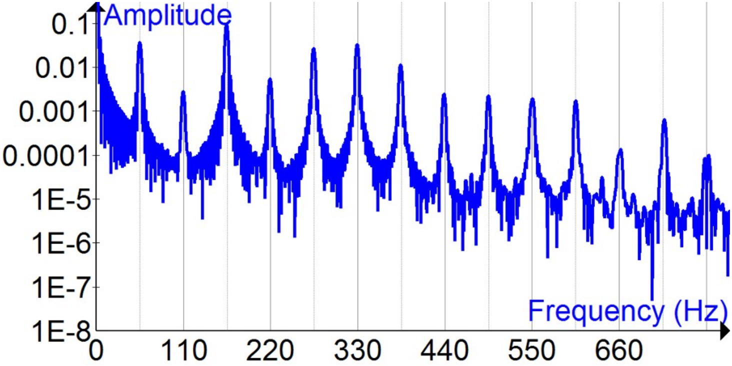
$f0$ and Harmonics

- The harmonics are each an integer value of the fundamental
  - $f0 = H1$
- Meaning: a given harmonic, say the fourth one, is 4x the fundamental
- So, if the fundamental is 200Hz:
  - the first harmonic, H1 = 200Hz x 1 = ?Hz
  - the second harmonic, H2 = 200Hz x 2 = ?Hz
  - the third harmonic, H3 = 200Hz x 3 = ?Hz
  - the fourth harmonic, H4 = 200Hz x 4 = ?Hz
  - etc.

$f0$ and Harmonics

- The harmonics are each an integer value of the fundamental
  - $f0 = H1$
- Meaning: a given harmonic, say the fourth one, is 4x the fundamental
- So, if the fundamental is 200Hz:
  - the first harmonic, H1 = 200Hz x 1 = 200Hz
  - the second harmonic, H2 = 200Hz x 2 = 400Hz
  - the third harmonic, H3 = 200Hz x 3 = 600Hz
  - the fourth harmonic, H4 = 200Hz x 4 = 800Hz
  - etc.

Where are the harmonics?



Playing around with Praat!

(if there is time)

To Do:

- Complete the exit ticket for today on Canvas by 12:30pm.
- Submit your discussion posts on the readings
- Bring your computers for next time, we'll be playing with Praat and sound waves!!!