Mathematics of Sound

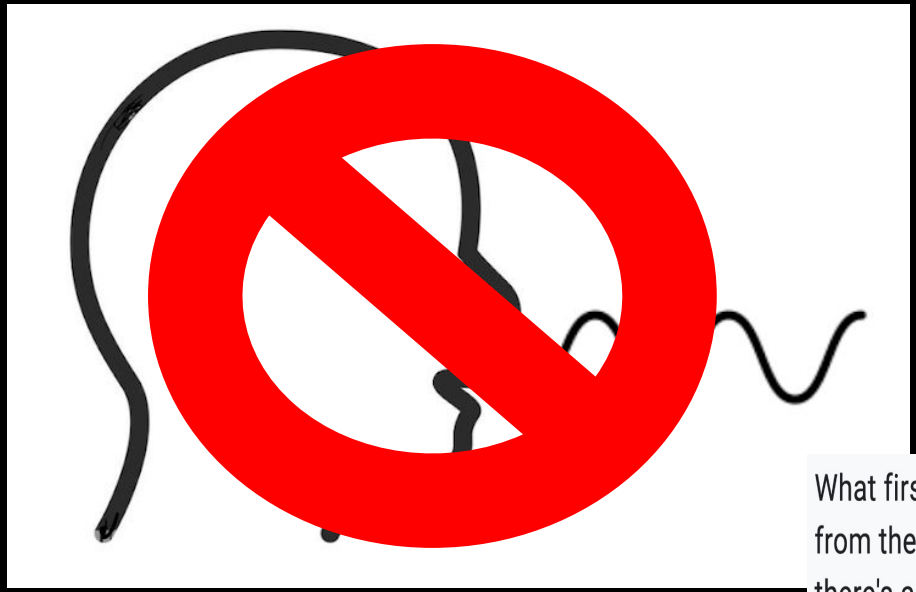
—

12/02/2022 (Rafael Collado)

What is sound?

Discuss.

Revisiting this Diagram



The person is speaking, making a constant tone.

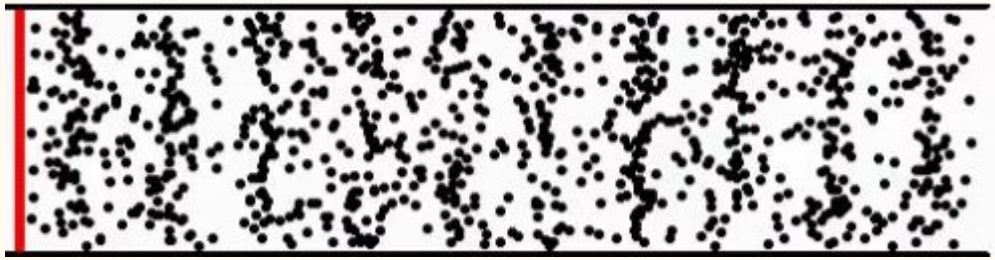
The figure is trying to convey sound travelling

“This conveys that whenever someone speaks, sound waves emit outwards in the direction they are speaking...”

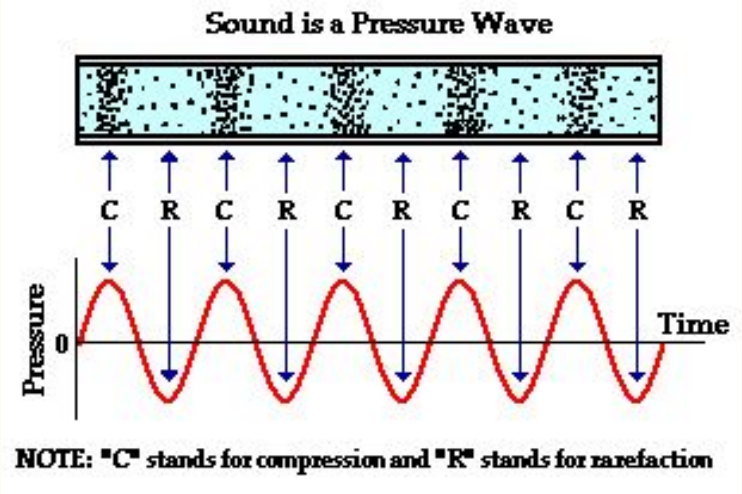
What first comes to mind is that this person is projecting some sort of sound from their mouth. Then, I think of alternative interpretations and I wonder if there's a flying worm traveling towards the human. Maybe it's not even a human at all, but rather, just a thick grey squiggly line and a thin grey squiggly line. Finally, I wonder if it's a giant staring at suspiciously symmetrical mountains in the distance.

What does it mean when we say sound is a “wave”?

- Sound IS a wave, but probably not how you would initially think. The air isn’t moving up and down at all as it would appear.



- The sine wave arises from periodic *compression* and *rarefactions* in air pressure.



- Sound is a longitudinal PRESSURE wave.

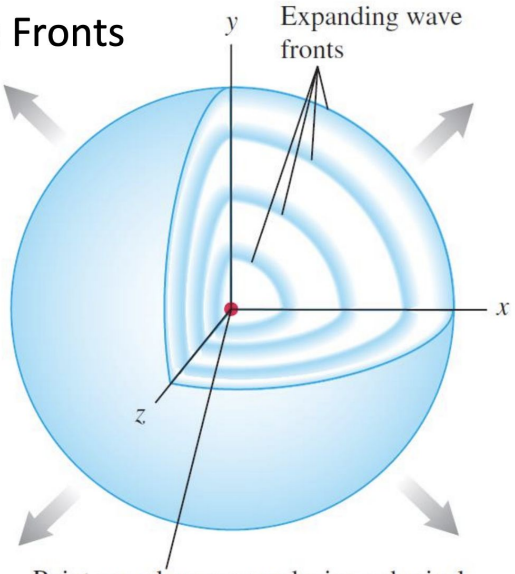
What does it mean when we say sound is a “wave”?

- Also important to note that sound doesn’t travel in one direction or within one plane.

- An idealized point source propagates sound spherically in 3D. Is my voice an ideal point source of sound?

Waves and Wave Fronts

- A **wave front** is the locus of all adjacent points at which the *phase* of a wave is the same.
- Spherical wave fronts of sound spread out uniformly in all directions from a point source.
- Electromagnetic waves in vacuum also spread out as shown here.



Point sound source producing spherical sound waves (alternating compressions and rarefactions of air)

Why do things sound different?

Discuss.

4 (well, 5) Properties of Sound

1. Volume
2. Pitch
3. Acoustics (Speed + Reflection)
4. Timbre*

Volume

- How “quiet” or “loud” a sound is.

- Volume = Amplitude of pressure wave! More concentrated compressions and more vacuous rarefactions. **IMPORTANT:** The sound doesn’t travel faster.

- Measured in dB, a base 10 logarithm of pressure

Pitch

- How “high” or “low” a sound is.

- The higher the frequency of the pressure wave, the higher we perceive the sound. **IMPORTANT:** The sound STILL doesn’t travel faster, the compressions/rarefactions are just closer together.

- 220 Hz vs 440 Hz

Acoustics

- The environment where the sound is produced affects how it propagates. This is called acoustics.

- There must be a medium through which the sound wave travels.
  - Air: 343 m/s (767 mph)
  - Water: 1,481 m/s (4.3x faster than air)
  - Iron (solid): 5,120 m/s (15x faster than air)
  - Diamond (solid): 12,000 m/s (35x faster than air)
  - Vacuum: Sound cannot propagate; no molecule collision!

$$T = \frac{V}{A} \cdot 0.161\,\mathrm{s\,m^{-1}}$$

- The room can have different qualities that promote or prevent the propagation of sound. (W.C. Sabine, father of architectural acoustics)

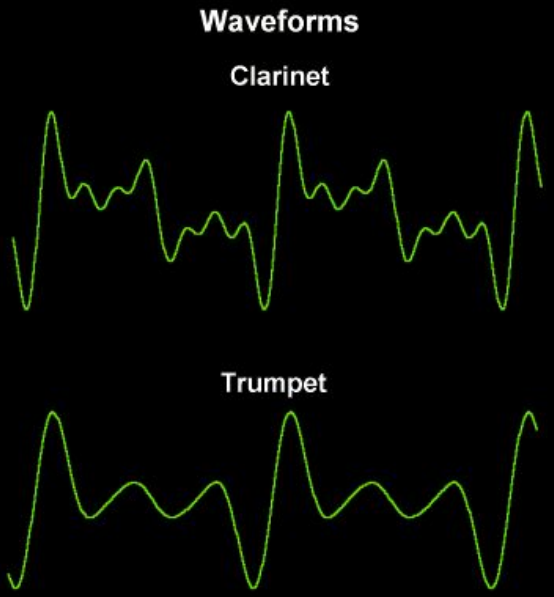
Timbre*

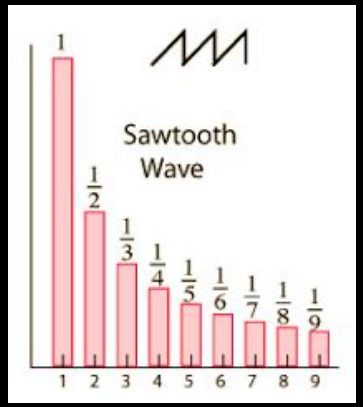
- The “quality” of a sound - described much more subjectively:
  - Bright
  - Dark
  - Buzzy
  - Pure
  - Brassy
  - Woody
  - Hollow
  - Shrill
  - etc...
- Why is there so much variety and where does it come from? We’ll come back to this...

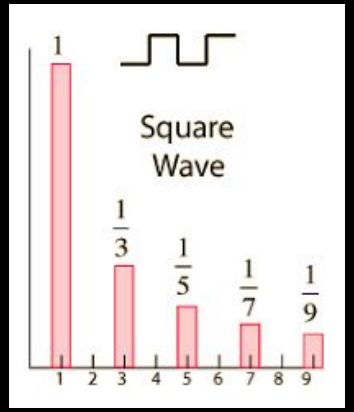
Digital Sound

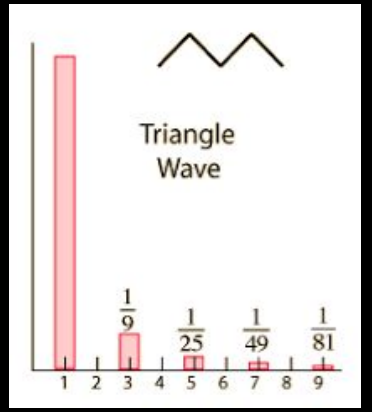
Tools: Audacity, Max, Spear

Non-sine periodic sound waves









All these waves are actually just compositions of sine waves - specifically, the *overtones* (also called the *harmonic series*) of the *fundamental frequency*

Fourier Transform

3Blue1Brown

$$\int_{-\infty}^{\infty} F(k)\, e^{2\pi i k x}\, dk$$

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