

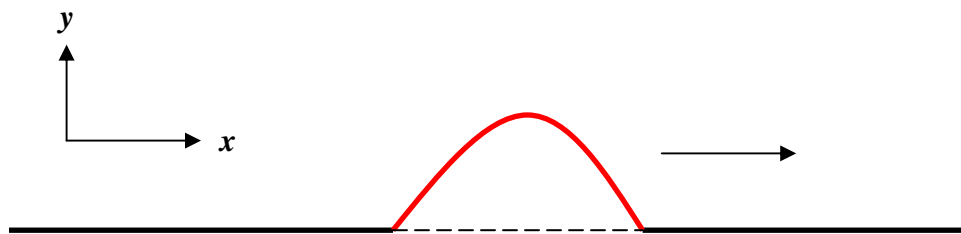
Lecture I:

This Week's Reading Assignment:

Please read Chapters 1 & 2 in John Backus' book, *The Acoustical Foundations of Music*.

What is Sound?

- The word **Sound** is used to describe two different physical phenomena:
 - Auditory sensation in one's ear(s) (one's brain?) – what is this exactly?
 - Disturbance (local energy over-density) in a physical medium (e.g. air, water – a gas, liquid, or solid) which *propagates* in that medium, and which causes an auditory sensation in one's ears.
 - Humans (and many other animal species) have developed ability to *hear* sounds, because sounds *exist* in the natural environment. Two ears are the *minimum* requirement for the ability to locate the *source* of a sound – evolutionarily an extremely beneficial capability!
- The scientific study of the phenomenon of sound is known as **Acoustics**.
 - Broad interdisciplinary field – physics, engineering, psychology, speech, music, physiology, neuroscience, architecture, etc.
 - Different branches of Acoustics:
 - Physical Acoustics
 - Musical Acoustics
 - Psycho-Acoustics
 - Physiological Acoustics
 - Architectural Acoustics
 - etc....
- Sound propagates in a physical medium (gas/liquid/solid) as a **wave**.
 - An acoustical disturbance propagates as a *collective* excitation (i.e. vibration) of a group of atoms and/or molecules that make up the physical medium.
 - Visualize a pulse traveling down a stretched rope, string or wire:



- This kind of wave is known as a **transverse** wave – because the *displacement*, $y(x)$ of the medium from its equilibrium position due to the disturbance is *transverse* (i.e. perpendicular) to the direction of propagation of the disturbance.

- Now visualize an acoustical pulse propagating in a gas, liquid or solid (e.g. air, water, or a metal – steel or aluminum).
 - This kind of wave is known as a **longitudinal** wave – at the microscopic scale, atoms/molecules in these media are displaced *longitudinally* (i.e. parallel) to the direction of propagation of the disturbance, as the disturbance passes through a given region of the medium.
- Thus, sound waves that we can hear with our own ears are the result of physical vibrations of matter – i.e. the collective vibrations of atoms/molecules!
- Food for Thought: Is it possible to “hear” the sound associated with *one* atom or one molecule vibrating?
- Sound waves propagating in a physical medium propagate with a characteristic speed in that medium – known as the **speed of sound**.
 - Speed of sound in (dry) air (at sea level) is $v_{\text{air}} \sim 344$ meters/second (m/s)
 - A more accurate relation is $v_{\text{air}} \sim 331.4 + 0.6 * T$ m/s where T is the temperature of the air, given in Celsius degrees.
 - HW problem: If lightning strikes the ground 1 mile away from you (= 5280 ft = 1609.3 m), how long after you see the lighting will you hear the thunder? Distance (m) = speed (m/s) * time (s), i.e. $d = v * t$ so therefore $t = d/v$.
The answer is $t \sim 4.7$ s. Please do the work and see for yourself!
- Sound waves propagating in a physical medium also carry **energy**, E (Joules, J) in the wave and also carry **momentum**, p (kg-m/s) in the wave.
- Sound waves propagating in a physical medium exert a **force**, F (Newtons, N) on the atoms/molecules in the medium in the vicinity of the wave disturbance.
 - In a gas, such as air, these forces create local high/low variations in the gas density and gas pressure (via/due to the ideal gas law: $PV = NRT$).
 - True also for fluids.
 - Solids are elastic – atoms/molecules are bound together making up the solid – spacing of arrangement of atoms/molecules in the solid deforms/stretches as the acoustic disturbance passes/propagates through the solid material.

What is Music?

- What is music??? Answer(s) to this question are profound...
 - An aesthetically pleasing sequence of tones? *Why* are they aesthetically pleasing?
 - Anthropocentric – because of the way our vocal chords vibrate, the human voice is rich in harmonic overtones, related by integer multiples to the frequency of the fundamental (lowest frequency): $f_n = nf_1, n = \text{integer} = 1, 2, 3, 4, 5, \dots$
 - It is not an accident/random coincidence that the musical instruments we humans have developed over the millennia mimic/emulate the human voice (some to greater extent than others) – thus our musical instruments also have overtone structures of $f_n = nf_1$ as opposed to e.g. completely arbitrary or no relation. (n.b. percussion instruments & the beat/tempo/rhythms of music emulate the internal rhythms of humans – e.g. our heart beat, & also play on our internal sense of the rate of passage of time...)
 - The musical scale(s), chords and chord progressions that we humans have developed for our music reflect our anthropocentric interest/enjoyment in hearing complex sounds having human voice-like $f_n = nf_1$ harmonic structure.
 - *Why* is music pleasurable to humans?
 - Can trace music in human society back to stone age/paeleolithic era/prehistoric times (i.e. ~ 30,000-40,000 years ago). Does it go back even earlier???
 - Music is an intimate part of human culture, apparently from way back...
 - Music is of fundamental importance to humans – *Why?*
 - Important in/for human evolution? To what degree? *Why? How?*
 - Have you ever met anyone who *hates* music? {Yes – problems with their brain...}
 - Music has been shown to *stimulate* the human brain, in many ways...
 - Music *facilitates* brain development of young children and in *learning*. *Why? How?*
 - Memory of music is different from that of normal “everyday” memory – very strong!!
 - Can recall/“play” entire songs/albums back in one’s head. *How/why?*
 - If music memory so strong, \Rightarrow music must be important to us! *Why/how?*
 - Music is important for other living creatures – birds, whales, frogs, etc. *Why? How?*
 - Other living creatures don’t *need/use* a formal musical scale, like we humans do!
 - Singing animals certainly don’t know anything about formal musical scales.
 - Yet, the songs of many animals are quite musical-sounding! *Why???*
 - Use of a formal musical scale enables humans to more easily learn/play each others music; also to impose structure/form & rules for music genres.
- Human Development of Musical Instruments
 - Emulate/mimic human voice (some instruments more so than others), with $f_n = nf_1$ harmonic structure.
 - Sounds from musical instruments can evoke powerful emotional response(s) in humans – happiness, joy, sadness, etc. because auditory signals are wired into various emotional centers of our brains!
 - Music is innate - runs very deep in human psyche. *Why? How?*

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