Chapter 2. Meeting 2, Measures and Visualizations of Sounds and Signals

2.1. Announcements

- Be sure to completely read the syllabus
- Recording opportunities for small ensembles
- Due Wednesday, 15 February: Mix Graph 1

- Quiz next Tuesday (we meet Tuesday, not Monday next week) on material from this and the next class
- Audio examples today will make use of Pd-extended and Martingale

2.2. Reading: Eargle: A Short History of the Microphone

- How did the early microphones of Bell, Berliner, and Blake operate?
- In basic terms, how do the electrostatic and electrodynamic microphones developed in the 1920s operate?
- What was the “breakthrough” of the electret microphone?

2.3. Basic Measures: Time

- Measured in seconds
- 1 millisecond (ms) is equal to .001 (10^{-3}) second
- Example: earLimits.pd
- 1 second is equal to 1000 milliseconds
- 1 microsecond (μsec) is equal to .000001 (10^{-6}) second, or .001 ms
- 1 second is equal to 1000000 microseconds

2.4. Basic Measures: Distance

- Microphone positioning diagrams may use feet or meters
- 1 foot is .305 meter; 1 meter is 3.28 feet

2.5. Sound

- Variations in pressure through a medium
  - Through air, water, solids
  - As a voltage, as a magnetic flux
- A disturbance in equilibrium
- Vibration: an oscillating disturbance in an elastic medium
- Oscillation offers a special class of sounds: periodic waves

2.6. Waves

- A disturbance transmitted over time
  - Tides
  - Ripples
  - Some waves are periodic (and oscillate) others are non-periodic (random or noise) or a picture of both
- Transverse waves: a ripple in water or a string

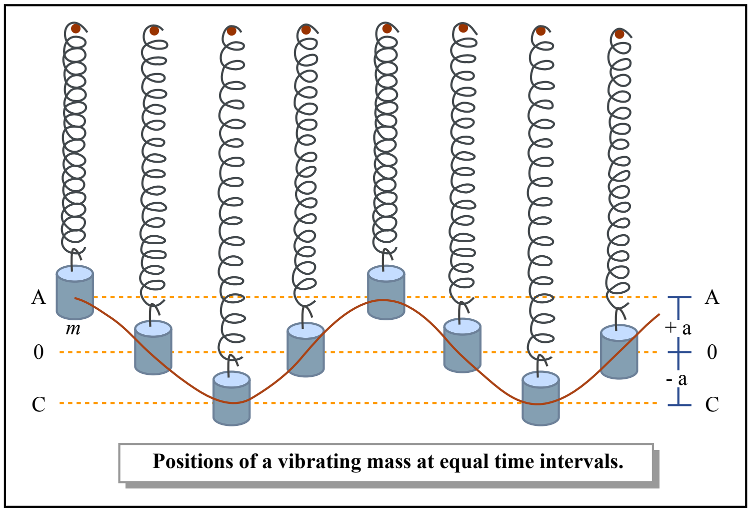

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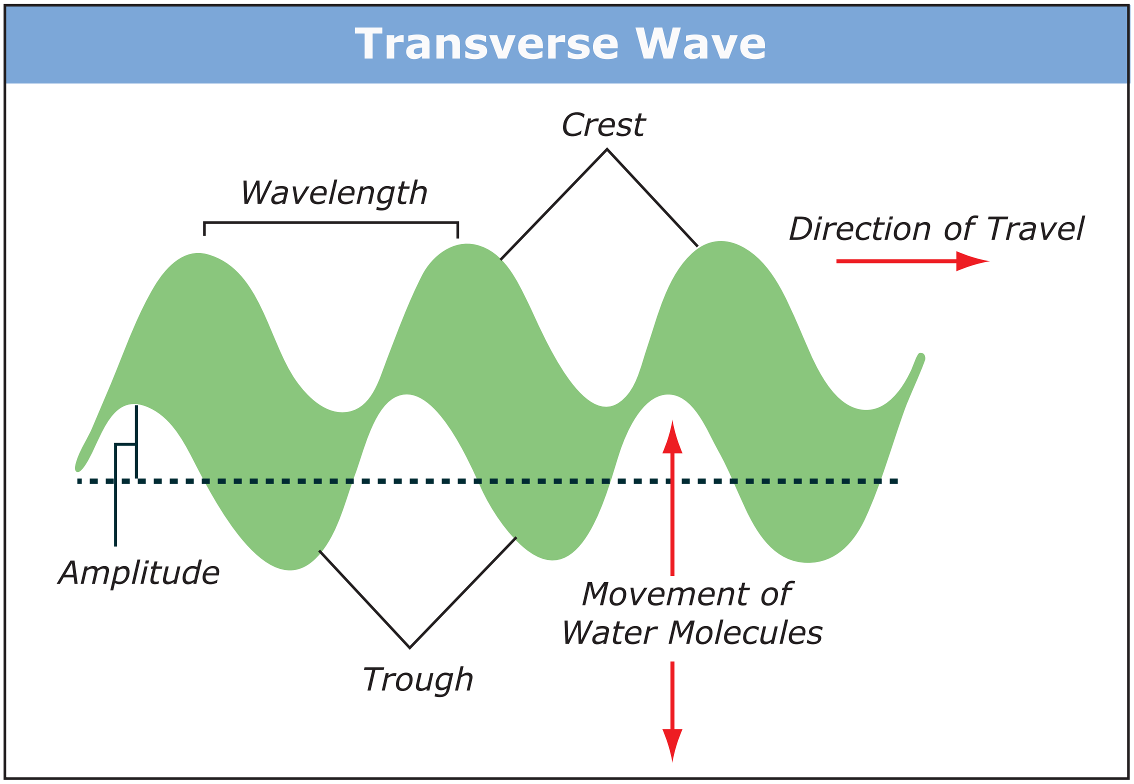
Image: "Sinusoidal Pressure Waves." From *Sound for Music Technology: An Introduction* http://openlearn.open.ac.uk/mod/resource/view.php?id=285732. (c) The Open University.



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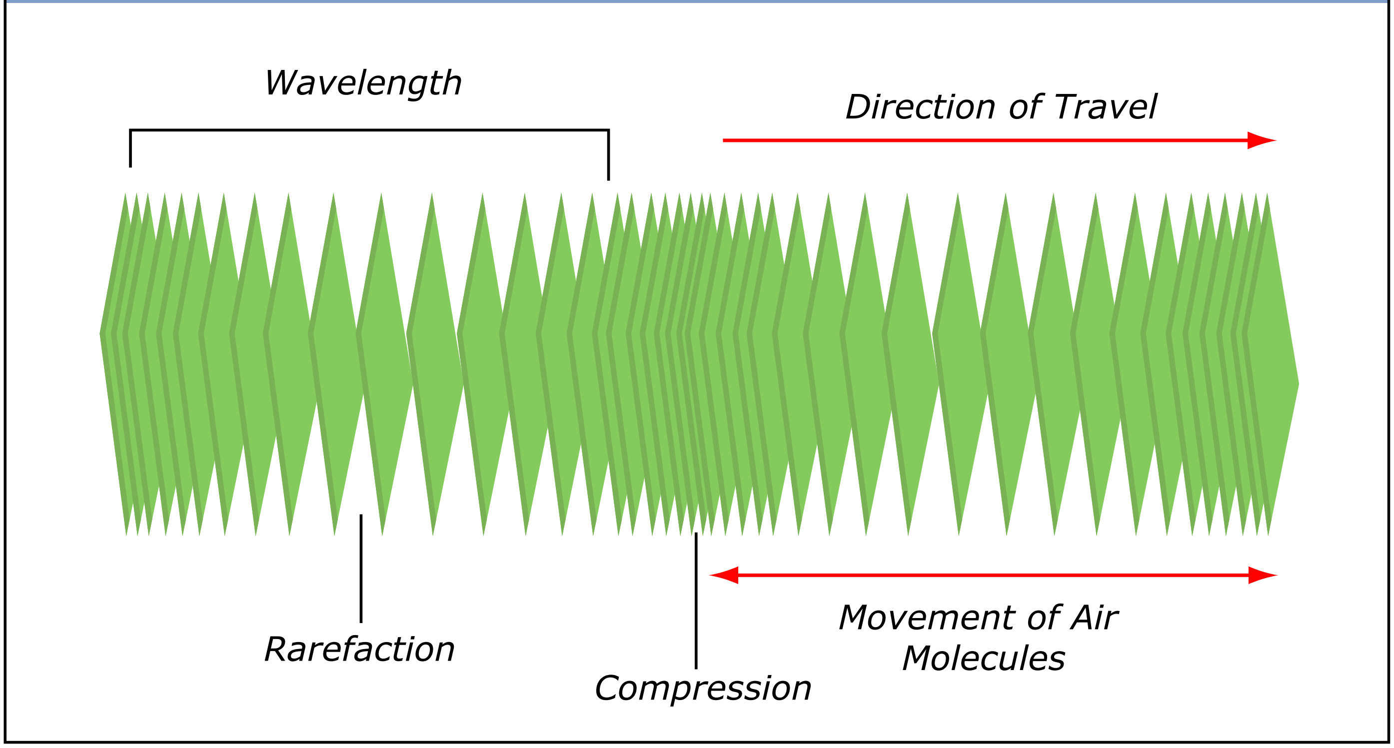
- Longitudinal sound waves: disturbances in air pressure

Longitudinal Wave



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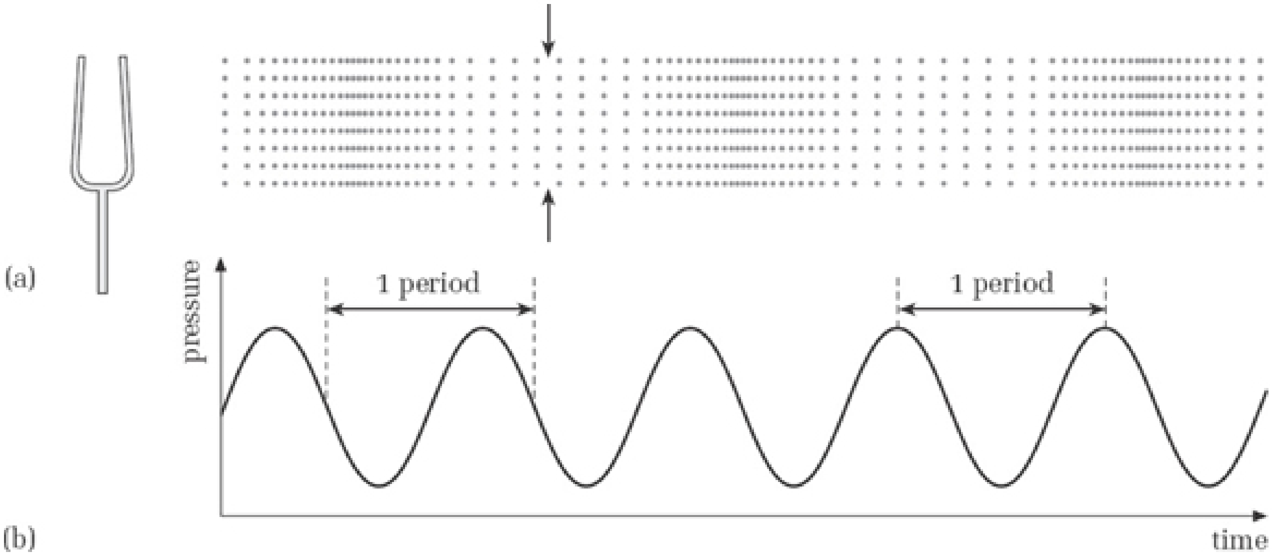

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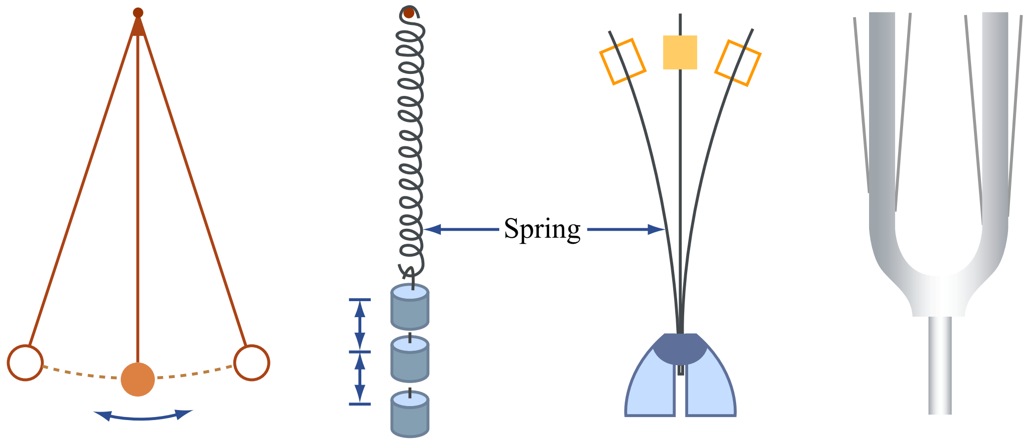
2.7. The Speed of Sound

- The speed of the sound wave depends on the medium and its temperature
  - Air: 1130 feet per second or 331 meters per second
  - Air: 1.13 feet per millisecond, or .885 ms per foot
  - Sea water: 1533 meters per second
  - Aluminum: 5100 meters per second
  - Diamond: 12000 meters per second
- Always remember how many ms per foot: .885 ms per foot

2.8. Natural Oscillation

- Oscillation is the natural motion of many physical objects disturbed from equilibrium



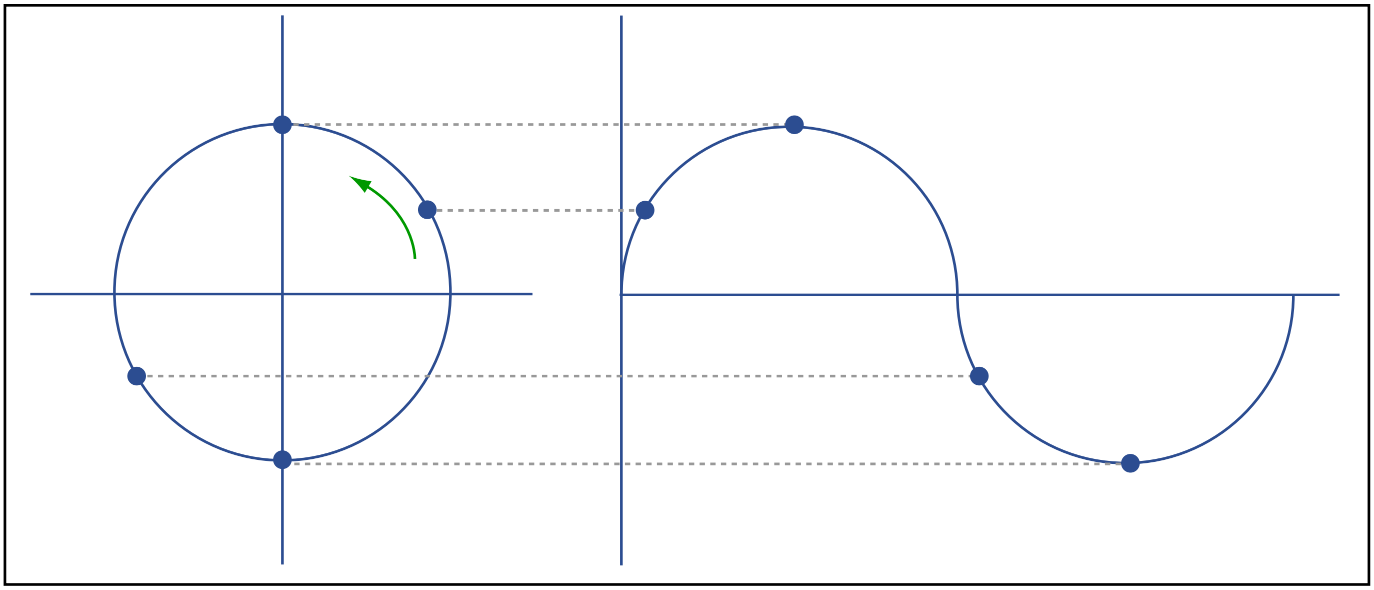
Four types of vibrating objects: simple pendulum, spring pendulum, vibrating strip, and tuning fork.

Image by MIT OpenCourseWare.

- Oscillation is a back and forth motion (up and down) over time
    - Pendulums (Swings)
    - Strings
- A natural point of oscillation in an object is a resonance
- Perfect oscillations are impossible in nature
- Noise is everywhere
    - Damping, friction, resistance
    - Mechanical and thermal noise

2.9. Perfect Oscillation

- A sine wave is a perfect oscillation
    - Named a sine to describe its shape: a circular motion extended in time



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- No damping or resistance
- No noise
- Machine-made: there are no sine waves in nature
- Example: signalWaveforms.pd

- There are other commonly used perfect oscillations with different shapes
  - Square (Rectangle) wave
  - Triangle wave
  - Sawtooth wave
  - Example: signalWaveforms.pd
  - Complex harmonic waveforms found in nature
- The sine provides a basic building block of sound
  - It is easy to generate mechanically and mathematically
  - It resembles simple harmonic motion: natural resonances in physical objects
  - It sounds as a single isolated tone
  - It provides frequency reference

2.10. Measuring a Sine Wave: Frequency

- How often it oscillates: its frequency

  - Measured in Cycles Per Second (CPS) or Hertz
  - Each cycle is one period, or the distance from crest to crest
- An audible sine wave produces the perception of a single frequency
- Frequency is very similar to pitch, but not the same
- Example: 20 Hz sine wave: 1 period lasts 50 msec (1 cycle / 20 cycle/s)
- Example: 200 Hz sine wave: 1 period lasts 5 ms
- Example: 2000 Hz sine wave: 1 period lasts .5 ms, or 500 µsec
- Example: 20000 Hz sine wave: 1 period lasts .05 ms, or 50 µsec
- Example: signalWaveforms.pd

2.11. Measuring a Sine Wave: Pitch

- Pitch relates to how the ear interprets frequency
- Pitches are commonly given names: A#, B-, etc
- 12 divisions per octave, each repeating at the octave, is most common
- Register is given with octave specifications as integers following the pitch name: A6, C2
- Middle C on the piano is C4; the range of the piano is from A0 to C8
- MIDI pitch numbers can be used to describe pitch: C4 is 60; C5 is 72; C3 is 48, etc.

2.12. Measuring a Sine Wave: Wavelength

- Distance between crests: wavelength
  - Measured in meters or feet
  - the speed of sound (m/s) divided by the frequency (cycle/s)
- Wavelength considerations are useful in considering how different frequencies interact with spaces and microphones
- Example: Kick drum @ 60 Hz: 18 feet in air (331 / 60 hz == 5.5 m)
- Example: Cymbal sizzle @ 16 kHz: .81 inches (331 / 16000 hz == .02 m)

2.13. Measuring a Sine Wave: Amplitude

- How large are the oscillations: its amplitude
- Intensity: an averaged measure over time
- Acoustic sound: a measure of pressure
- Numerous types of measurements
    - Acoustical power (intensity) as force over area: watts, dynes/cm2, pascals
    - In relation to a minimum and a maximum: 0% to 100%, or 0.0 to 1.0
    - In relation to some defined measure: Bels, decibels (dB)
- Decibels: condense a wide range of linear amplitude values into a smaller range
    - A logarithmic measure in relation to amplitude
    - A reference value defines 0 dB
    - dB == 20 * log $_{10}$ * amplitude
    - -3 dB change is a factor of .707 amplitude

      3 dB change is a good general unit of change
    - -6 dB change is a factor of .5 amplitude
    - Doubling a signal generally results in a 6 dB change

      Example: ampDbDemo
    - -20 dB is .1 amplitude

2.14. Measuring a Sine Wave: Decibels

- Numerous types of dB based on different reference values
- Sound Pressure Levels (dB SPL)
    - Pressure of air measured in reference to human ears
    - 0 dB SPL is equal to .0002 dynes/cm2
    - 0 dB SPL is threshold of hearing; 120-130 dB SPL is threshold of pain

- average conversation: 60 dB SPL
- pin-drop: 10 dB SPL
- jet engine: 150 dB SPL
- Visual scale

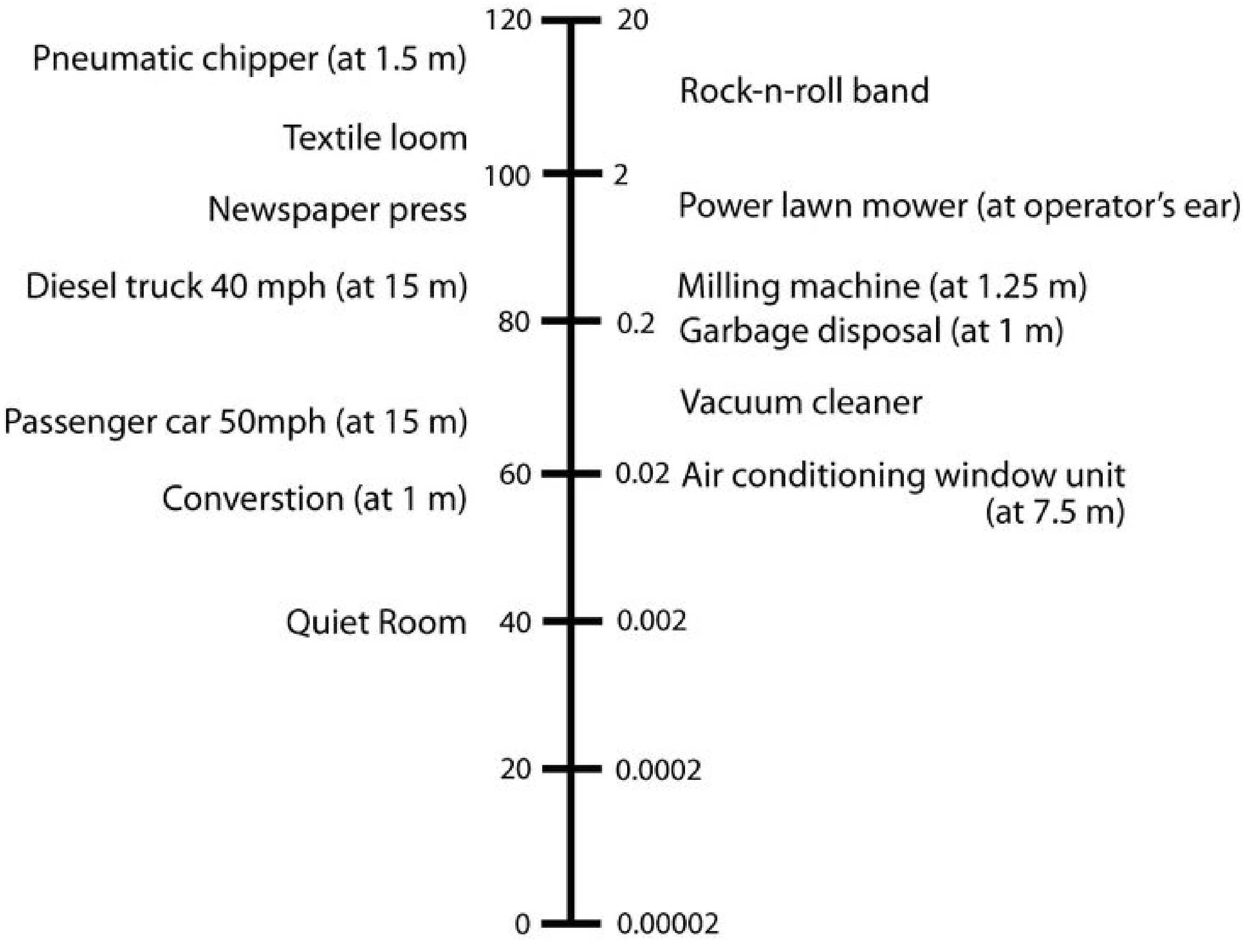


Image: "Sound Pressure Level (SPL) and Sound Pressure (Pa)." From *Principles of Industrial Hygiene* Available at: http://ocw.jhsph.edu. Copyright © Johns Hopkins Bloomberg School of Public Health.

- Voltages: dBV, dBu
    - 0 dBV is equal to 1 Volt
    - 0 dBu (or dBv) is equal to .775 Volt
    - Range is generally from -infinity to +20 dBu
- Digital Bits: dBFS (6.0206 dB per bit)
- Amplitude is similar to loudness, but not the same
- A range of amplitudes is called a Dynamic Range

2.15. Measuring a Sine Wave: Position

- Phase: relative position of the waveform in its period
- Measured in degrees (360 degrees as a complete cycle) or measured within the unit interval (0 to 1)
- Requires reference to a fixed point or another wave
- 180 degrees is one half-cycle out of phase
- Flipping the phase is the same as multiplying a signal times -1
- Combinations of in-phase signals results in amplitude boosts
- Combinations of out-of-phase signals results in interference or cancellation

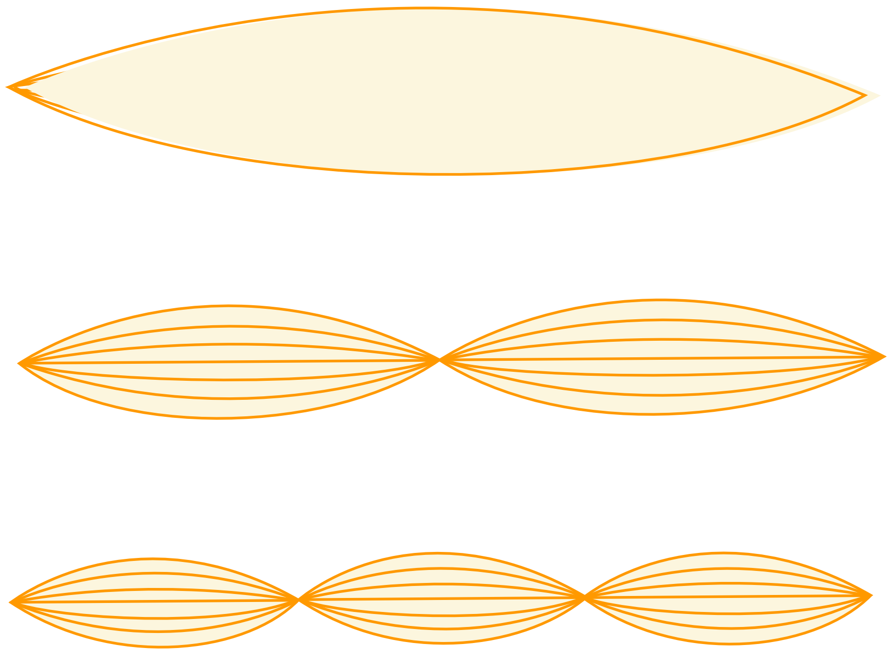
  Example: phase.pd

2.16. Signals Store Simultaneous Information

- Waves can store multiple signals at multiple frequencies in one channel
- Waves can be added (mixed together) to result in more complex waves
- Sometimes these combined waves can be later decomposed into simple waves
- A single wave can store a tremendous amount of complexity

2.17. Timbre

- All sounds in nature are more complex than a sine wave (pure frequency)
- Many physical objects (strings, air-columns) have multiple points of resonance



Characteristic vibrations of a stretched string. Vibrating in one, two or three equal parts emits the fundamental tone, octave and twelfth respectively.

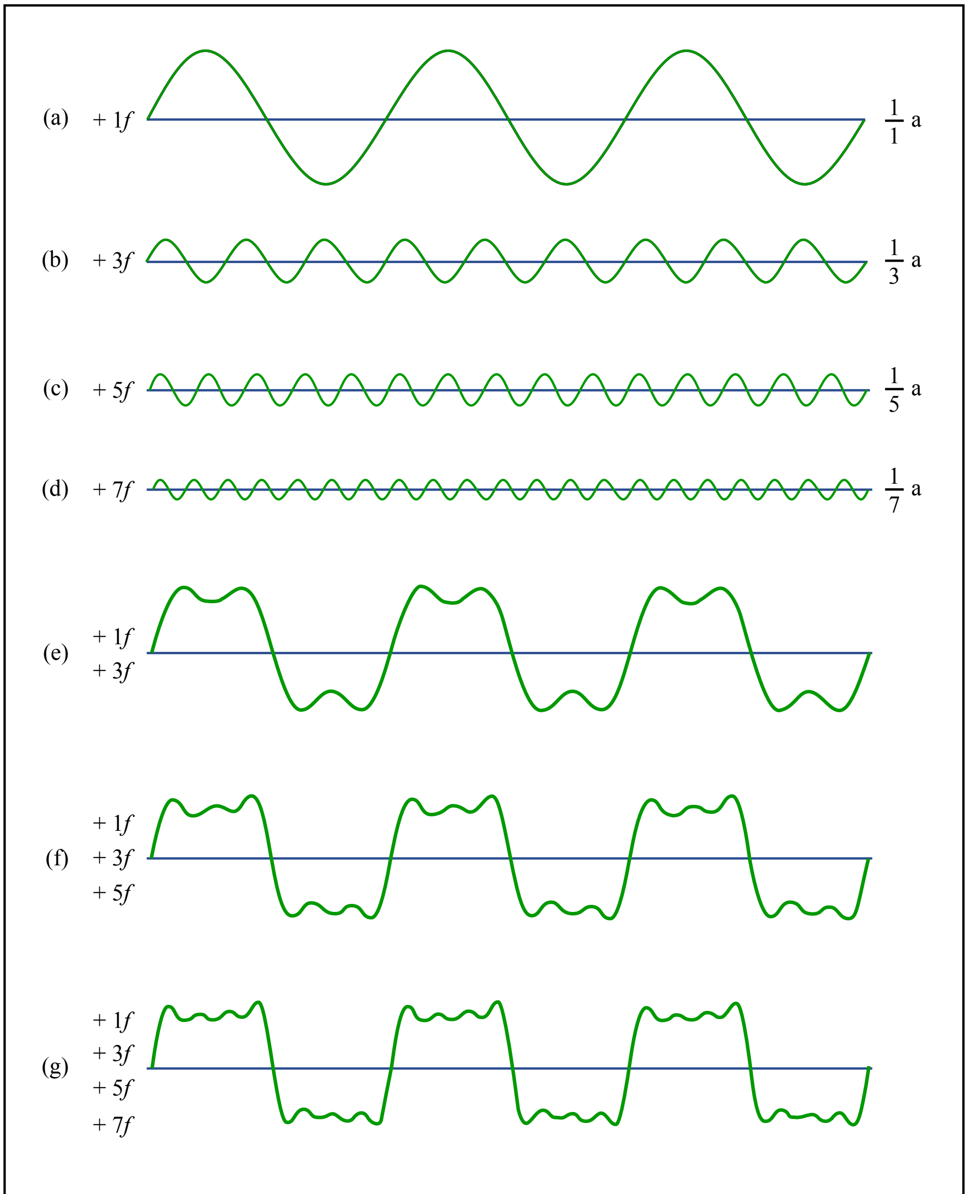
Image by MIT OpenCourseWare.

- The difference in the sound between two instruments has to do with which resonances are prominent
- The lowest resonance is called the fundamental, or the first harmonic (f0)
- Higher resonances are called harmonics, partials, or overtones
- Timbre (tone color) refers to the distinctions in sound due to these resonances

2.18. Harmonic Spectra

- Some objects resonate in whole-number multiples of the fundamental frequency
- These ratio-specific values are called harmonics

- Example: signalAddition.pd
- Arrangements of common harmonics produce common non-sinusoidal perodic waveforms



Square waves, analyzed as an additive series of harmonics.

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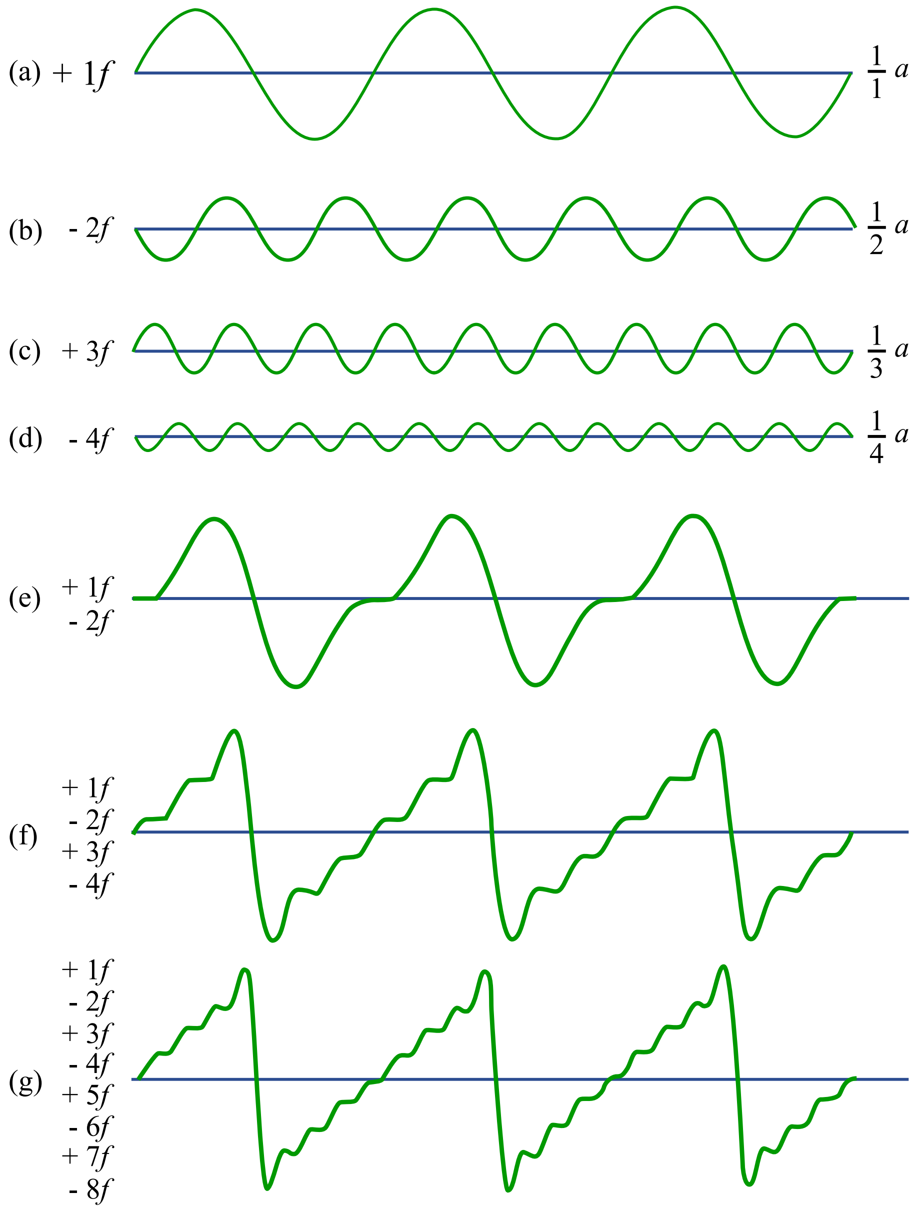

Sawtooth waves, analyzed as an additive series of harmonics.

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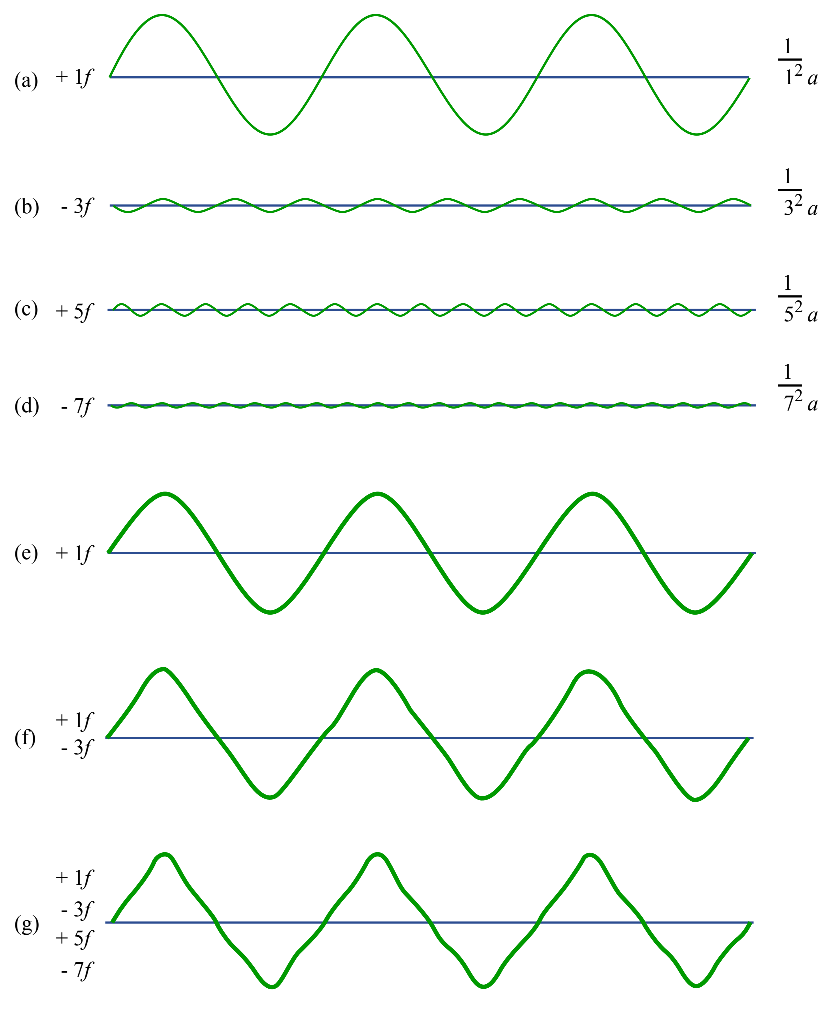

Triangle waves, analyzed as an additive series of harmonics.

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- Saw: all harmonics w amplitude decreasing by inverse of harmonic number
- Square: odd harmonics with amplitude decreasing by inverse of harmonic number
- Triangle: odd harmonics with amplitude decreasing by inverse of square of harmonic
- Example: sumOfSines.pd

2.19. Inharmonic Spectra

- Some objects resonate without a harmonic relation to the fundamental
- Called overtones or partials
- Example: signalAddition.pd

2.20. The Duality of Waveforms

- We can look at a waveform to see changes in amplitude over time
- We can look at a spectral analysis and see the amplitude of frequency components (timbre) during a window of time

2.21. The Time Domain

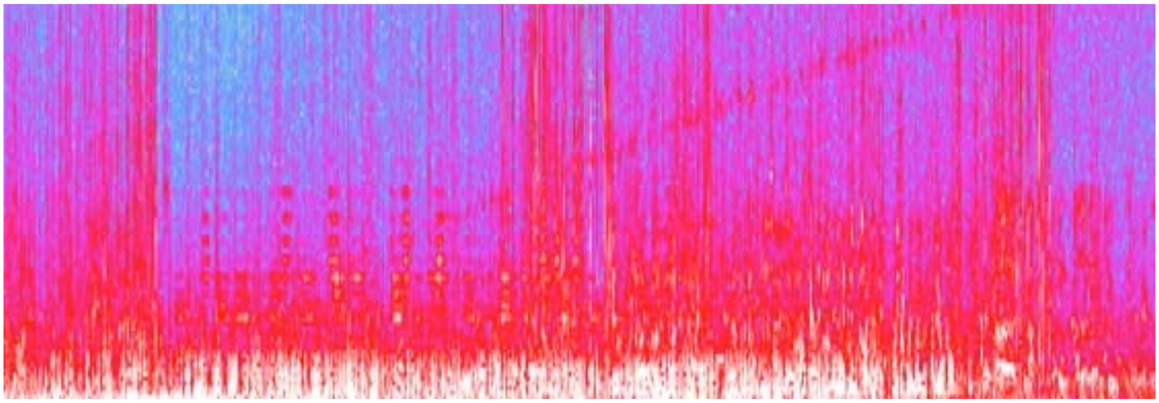
- Graph of displacement over time
- Draw amplitude change (y-axis) over time (x-axis)
- Illustrates the movement of a speaker, microphone, or air pressure
- Digital sound files, DAW waveforms
- Example: adding a track to Ableton Live (drumKitKickMic.aiff)
- Example: opening a file in Audacity (drumKitKickMic.aiff)

2.22. The Frequency Domain

- Graph of frequency amplitudes within a single time window
- Draw amplitude (y-axis) over frequency (x-axis)
- Illustrates what the ear hears at a given moment
- Requires mathematical decoding: Fourier Transform
- Reveals the spectrum (timbre) of a sound
- Example: viewing spectrum in Audacity (drumKitKickMic.aiff)
- Example: use of “Spectrum” Live Device (plugin) in Ableton Live (drumKitKickMic.aiff)

2.23. Combining Amplitude and Frequency Domains in Three Dimensions

- Two ways
  - Graph of frequency (x-axis), amplitude (color), and time (y-axis)



- Graph of frequency (x-axis), amplitude (y-axis), and time (z-axis)

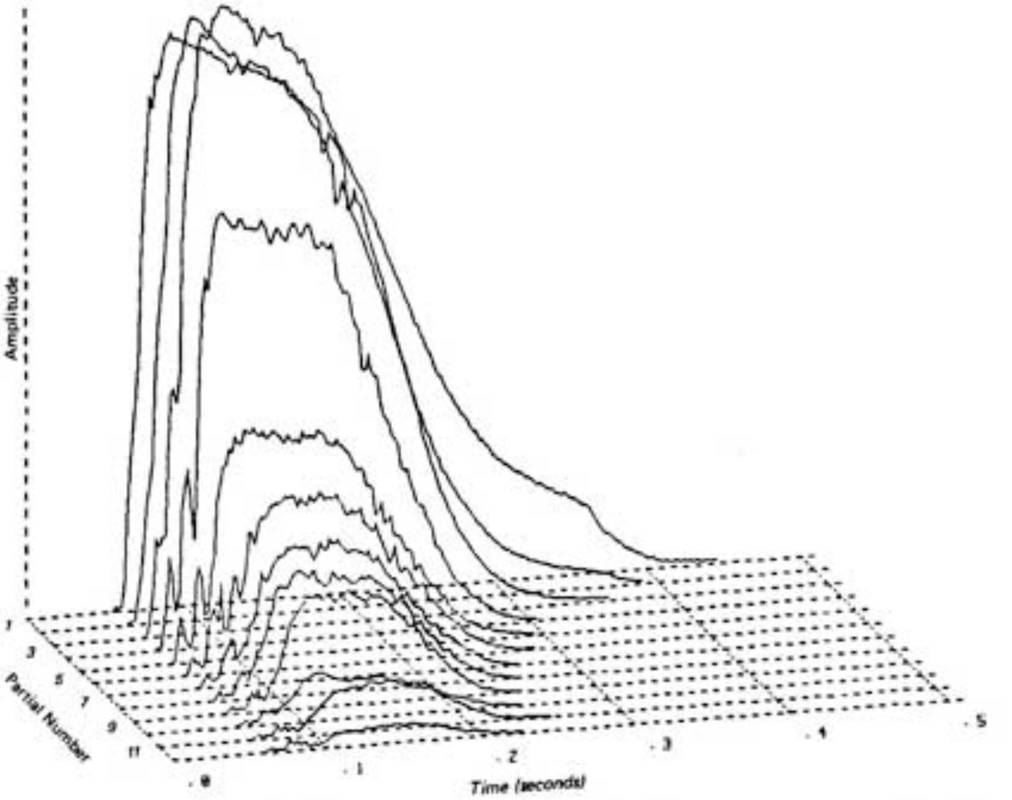


FIGURE 2.30 The amplitude progression of the partials of a trumpet tone as analyzed by Grey and Moorer. (*Reprinted with permission of* Computer Music Journal.)

Source: Moorer, J., J. Grey, and J. Strawn. "Lexicon of Analyzed Tones (Part 3: The Trumpet)."*Computer Music Journal* 2, no. 2 (1978): 23-31. © ownership uncertain (but not MIT Press). All rights reserved. This content is excluded from our Creative Commons license. For moreinformation, see http://ocw.mit.edu/fairuse.

- Sometimes called a spectrogram (or sonogram)
- Closest representation to our experience of sound

- Not perfect for technical and psychoacoustic reasons

21M.380 Music and Technology: Recording Techniques and Audio Production
Spring 2012