# The Physics of Sound

EECS 4462 - Digital Audio



September 9, 2020

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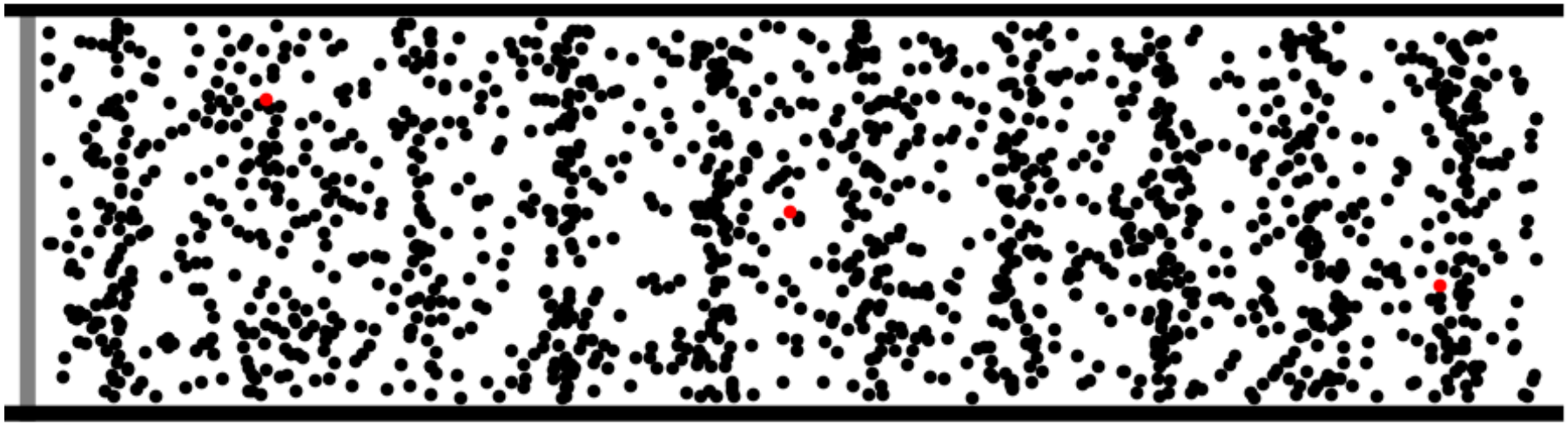
# What is sound?

1. Physical disturbance in a medium such as air
2. Psychophysical perception

- Dual Nature of Sound

# Sound as a wave

- A vibrating source pushes adjacent air molecules that in turn push neighbouring molecules, and so on.
- This creates a **longitudinal** wave
  - The particle displacement is parallel to the direction of wave propagation

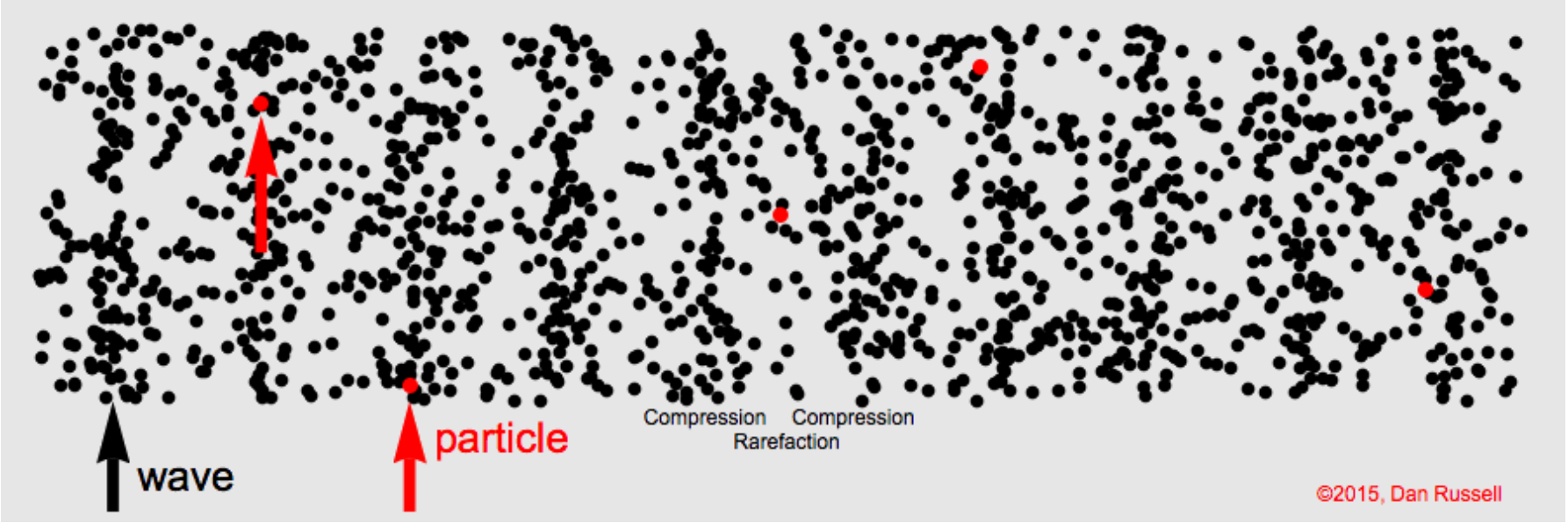




http://www.acs.psu.edu/drussell/DEmos/waves/wavemotion.html

# Sound as a wave

- The wave moves using a series of **compressions** and **rarefactions**
- Rarefactions are due to the air's elasticity



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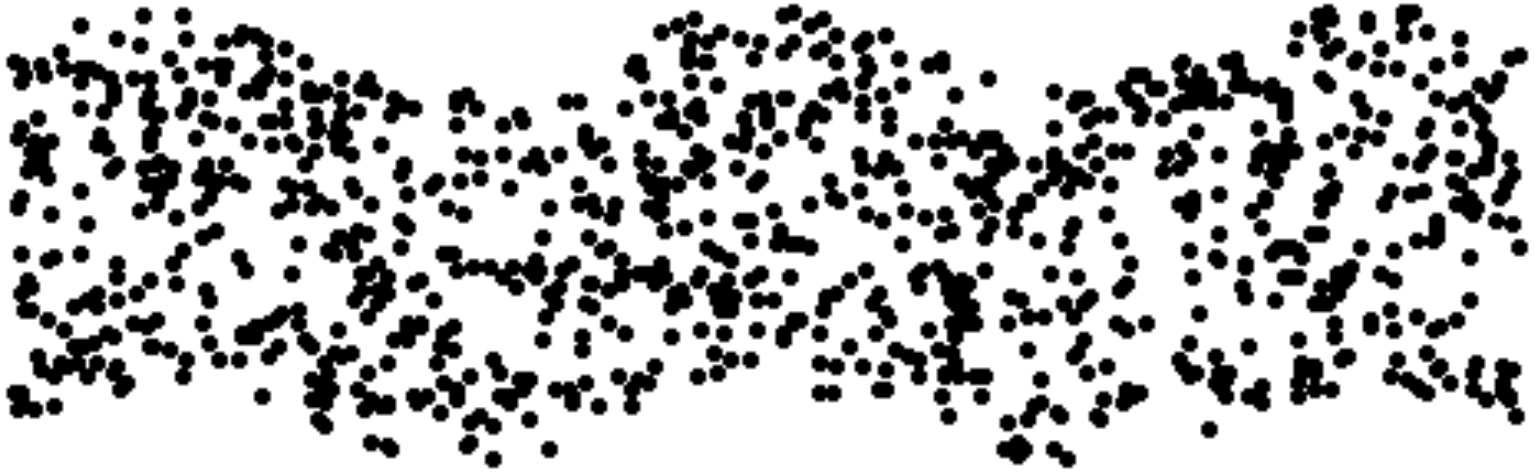
# Aside: Transverse waves

- The particle displacement is perpendicular to the direction of wave propagation



- Only longitudinal waves travel through the air

# Periodic motion

- Two factors are necessary for periodic motions

1. **Elasticity**
   - The capacity to return precisely to the original configuration after being distorted.
   - Air is elastic
2. **A source of energy**
   - Vibrators such as speakers or musical instruments

# Simple harmonic motion

- The simplest periodic motion is the simple harmonic motion, as it contains **only one frequency**
- The displacement **d** of an air molecule from a single frequency is given by

$$d = A \sin(2\pi f t)$$

- Let's hear it!
- http://onlinetonegenerator.com/

# 5 characteristics of a sound wave

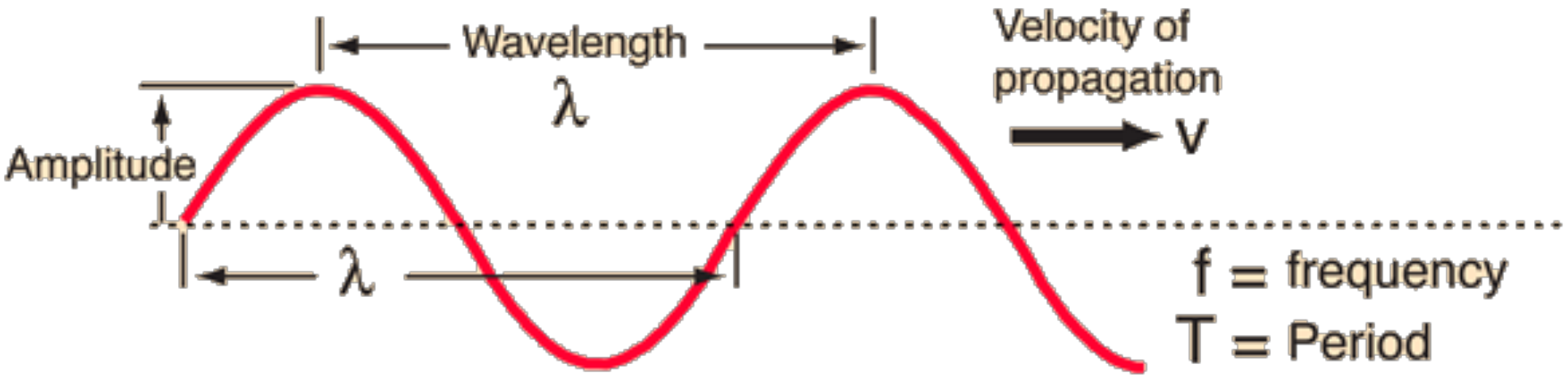
1. Amplitude **A**: How far the air molecule moves / is displaced.
   - This determines the loudness of the sound. The unit of measurement is the deciBel or dB.
2. Frequency **f**: How many cycles there are in a second. Measured in Hz.
3. Period **T**: The time it takes for one cycle to complete.

$$T = 1 / f$$

# 5 characteristics of a sound wave

- Speed of sound (velocity) **V**: 344 m/s
- Wavelength **λ**: Distance from compression to the next compression

$$\lambda = V / f$$




http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html



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# Some cool videos

- https://www.youtube.com/watch?v=GkNJvZINSEY
- https://www.youtube.com/watch?v=XpNbyfxxkWE
- https://www.youtube.com/watch?v=INqfM1kdfUc
- https://www.youtube.com/watch?v=1yaqUI4b974
- https://www.youtube.com/watch?v=Q3oItpVa9fs

# Inverse square law

- The intensity of sound at any given point is given by

$$I = S / 4\pi r^2$$

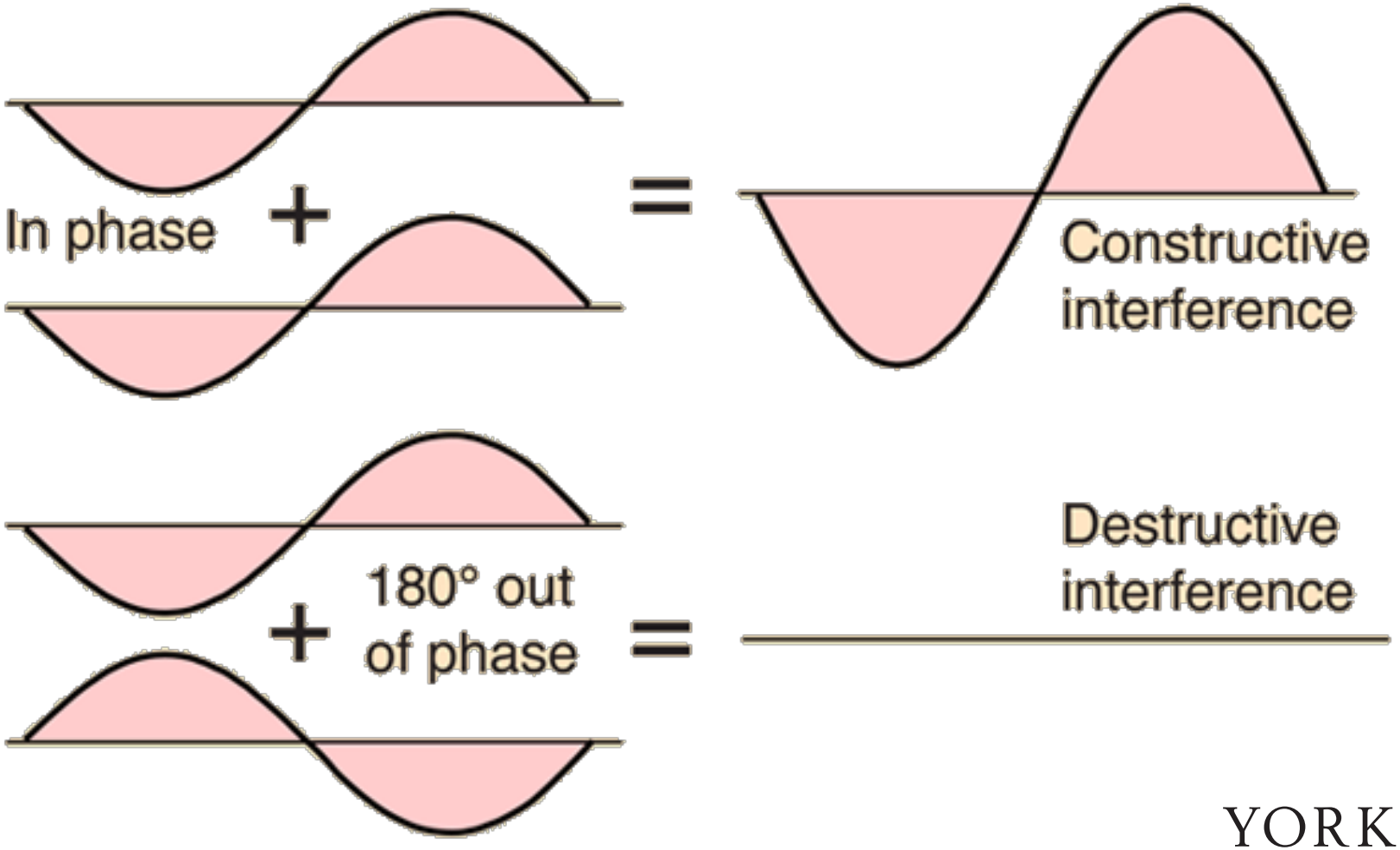
- S is the strength of the sound source
- r is the distance from the sound source

# Sound in a room

- In a room, sound reflects off every surface
- Inverse square law does not really apply
- Each listener receives multiple versions of a signal
  - Our brain reconstructs into one signal usually
- Sound can be distorted due to **phase interference**

# Phase Interference

- When two signals of same frequency combine






http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html

# Natural Sounds

- Most sounds in nature are the combination of several sine waves at different frequencies
- Our brain perceives sounds as pleasing, when they are composed of several frequencies that are multiples of each other
- Many natural sounds or sounds from musical instruments have this property
- This leads us to the harmonic nature of sound

# Harmonic nature of sound

- Why does playing the same note with a guitar sound different than the same note on a piano?

- https://www.youtube.com/watch?v=yYiKcsrL0mg&t=44s
- https://www.youtube.com/watch?v=DlMrl3EQ1bs&t=21s

# Fundamental frequency

- The fundamental frequency in both examples in the previous slide is the same (110 Hz)
- This is what determines a sound's **pitch**
- The fundamental frequency is usually the loudest component of a given sound

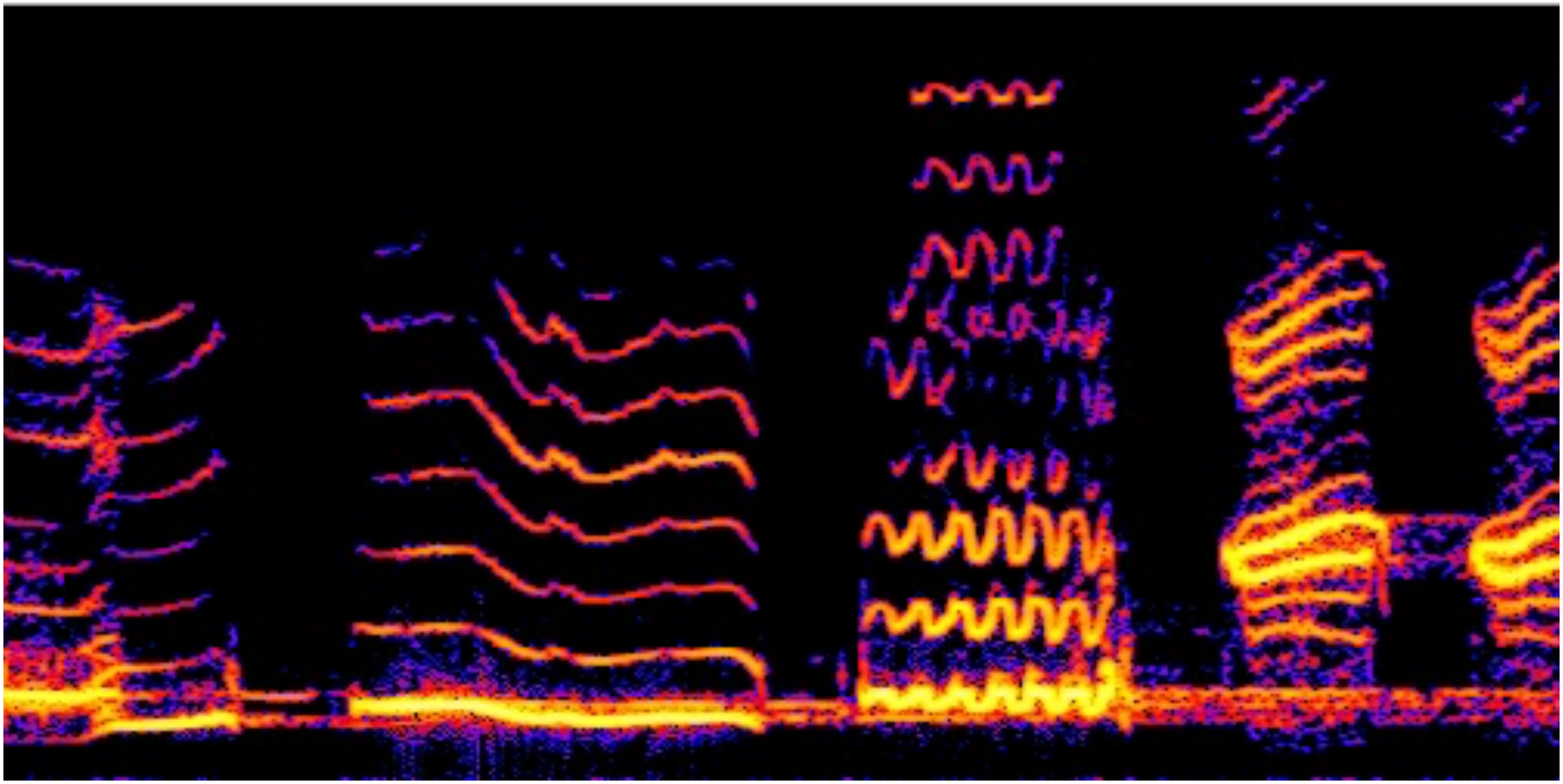
# Harmonics

- Each note also has a set of other frequencies at different amplitudes
- In a pitched sound, these frequencies are multiples of the fundamental frequency and are called **harmonics**
- Harmonics are typically quieter than the fundamental
- The set of harmonics in a given sound give it its distinct characteristic, its **timbre**

# Fourier analysis

- Any signal can be decomposed into the sum of several sine waves with different amplitudes and phase
- Natural sounds contain a large number of frequencies
- Fourier analysis determines what the constituent frequencies are
- This information can be presented in the form of a **spectrogram**

# Spectrogram example (bird call)



https://www.youtube.com/watch?v=eAtsRFZ_2VE