- **Resonance frequencies**
- **The glottal source**

Background reading:

- *AAP Ch 2, sec 2.1, first half*
- *AAP Ch 3, sec 3.3.3, "Auto-correlation pitch tracking"*

0. Today’s objectives

After today’s class, you should be able to:

- Calculate tube length, resonance wavelength, or resonance frequency (for a tube), given one of the other values
- Recognize a glottal-source spectrum and understand the relationship between its component frequencies and its f_0
- Understand some common pitch-tracker errors and what they mean

1. Review: Standing waves, resonances

- We can model the **multiple modes of vibration** of a **string**, or of **air in a tube**
  - To do this, we determine the _______________ of each of the **resonances** of the system, based on the physical size of the system
  - Then (for air in a tube) we can calculate the _______________ of each of the resonances

1. Review: Standing waves, resonances

- We can model the **multiple modes of vibration** of a **string**, or of **air in a tube**
  - To do this, we determine the **wavelength** of each of the **resonances** of the system, based on the physical size of the system
  - Then (for air in a tube) we can calculate the **frequency** of each of the resonances

1. Review: Standing waves, resonances

- The resonances ("waves that fit") for a string or a tube are determined by
  -
  -

1. Review: Standing waves, resonances

- The resonances ("waves that fit") for a string or a tube are determined by
    - its **length**
    - its **boundary conditions**

1. Review: Standing waves, resonances

- What are the boundary conditions for...
  - The fixed end of a string
  - The free end of a string
  - The open end of a tube of vibrating air
  - The closed end of a tube of vibrating air
- **Why?**

1. Review: Standing waves, resonances

- What are the boundary conditions for…
  - The fixed end of a string | **node**
  - The free end of a string | **antinode**
  - The open end of a tube of vibrating air | **(pressure) node** / (displacement) antinode
  - The closed end of a tube of vibrating air | **(pressure) antinode** / (displacement) node
- **Why?** | **physical conditions** determine this!

1. Review: Standing waves, resonances

- If we know
  - the **length** of the string or tube (***L***)
  - **"how much wave" fits** for the ***n*th resonance** (based on boundary conditions)
- We can calculate the ***n*th** resonance **wavelength** λ_n
- **Wavelength (λ)** and **frequency (*f*)** are related:

$$c = \lambda f$$

where c is the speed of the wave
(about 350 m/s for sound in air, according to AAP)

- We can calculate the ***n*th** resonance **frequency *fn***

1. Review: Standing waves, resonances

- For a **node/node** system with tube of length L

$\lambda_n = 2L/n$	relates wavelength to tube length
$f_n = c/\lambda_n$	relates frequency to wavelength
$f_n = c\,/\,(2L/n)$	relates frequency to tube length
$\boldsymbol{f_n = n \cdot c/2L}$	

- **Shortcut!** Once you know the **1st resonance** $\boldsymbol{f_1}$:

$\boldsymbol{f_n =}$ ________

1. Review: Standing waves, resonances

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- **Shortcut!** Once you know the **1st resonance** $\boldsymbol{f_1}$:

$\boldsymbol{f_n = n \cdot f_1}$ | because $\boldsymbol{f_1} = 1 \cdot c \,/\, 2L = c \,/\, 2L$

→ The resonance frequencies in a **node/node** system are **whole-number multiples** of f_1

1. Review: Standing waves, resonances

- For a **node/antinode** system with tube of length *L*

$\lambda_n = 4L / (2n-1)$	relates wavelength to tube length
$f_n = c/\lambda_n$	relates frequency to wavelength
$f_n = c / (4L / (2n-1))$	relates frequency to tube length

$\boldsymbol{f_n = (2n-1) \cdot c / 4L}$

- **Shortcut!** Once you know the **1st resonance f_1** :

$f_n =$ ________________

1. Review: Standing waves, resonances

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- **Shortcut!** Once you know the **1st resonance f_1** :

$\boldsymbol{f_n = (2n-1) \cdot f_1}$ | because $f_1 = 1 \cdot c / 4L = c / 4L$

→ The resonance frequencies in a **node/antinode** system are **odd-numbered multiples** of f_1

1. Review: Standing waves, resonances

- What is the **relationship** between $\boldsymbol{f_1}$ (the **first resonance** frequency) and $\boldsymbol{f_0}$ (the **fundamental frequency** of the complex wave itself) for...
  - a **node/node** system?
  - a **node/antinode** system?

1. Review: Standing waves, resonances

- What is the **relationship** between $\boldsymbol{f_1}$ (the **first resonance** frequency) and $\boldsymbol{f_0}$ (the **fundamental frequency** of the complex wave itself) for...
  - a **node/node** system?
    - Resonance *f*s = whole-number multiples of f_1
      What does this tell us?
  - a **node/antinode** system?
    - Resonance *f*s = odd-numbered multiples of f_1
      What does this tell us?

2. The glottal source wave

- What is the **glottal source wave**?
  - Also called the **voicing wave**(form) in *AAP* Ch 2
  - → The sound wave produced by ______

2. The glottal source wave

- What is the **glottal source wave**?
    - Also called the **voicing wave**(form) in *AAP* Ch 2
    - → The sound wave produced by the vibration of the vocal folds

- To actually hear this sound wave, you would have to put a microphone right above the glottis
    - The sound waves of any speech we normally hear are **further modified** by passing through the vocal tract
        - This is the content of the rest of the course!

2. The glottal source wave

- The glottal source wave is a complex wave with the following property:
  - All of the components of this complex wave have frequencies that are **whole-number multiples** of the lowest-component frequency

- How does the fundamental frequency of the glottal source wave **relate** to the frequency of its lowest component?

3. Pitch tracker — Overview

- Autocorrelation methods (see AAP, sec 3.3.3)
  - Overlay the waveform on itself
  - What time interval between the original waveform and the copy is needed for the best correlation between the two?
- Pitch tracker errors:
  - Pitch halving
  - Pitch doubling
- Bad settings?
  Or, irregular pitch periods in the voice?