- **Defining and measuring waves**
- **Classifying waves**
- **Properties of simple periodic (sine) waves**

Background reading:

- *AAP* Ch 1, through the end of sec 1.3.1

0. Today’s plan

- Finishing introductions and checking in
- Defining waves
- Measuring and graphing waves
- Classifying waves:
  - Simple periodic waves (sine waves)
  - Complex periodic waves
  - Aperiodic waves
- Periodic waves
  - Defining properties
  - Calculating frequency, given period

0. Today's plan

- If you have prior background in acoustics or even high-school physics, this may be review for you
  - But please note: The next few classes will build on one another quickly, so **be sure you are solid on these basic ideas**

1. Checking in

- Introductions from anyone who didn’t have a chance on Friday

1. Checking in

- Any questions about consonant or vowel IPA symbols?

1. Checking in

- *True* or *false*?

  One subfield of phonetics is concerned with how the vocal organs move to produce each letter in a word.

1. Checking in

- *True* or *false*?

  One subfield of phonetics is concerned with how the vocal organs move to produce each ~~letter~~ in a word.

Always remember:

SOUNDS, NOT LETTERS

2. What is a wave? What is a sound wave?

- A **wave** is a _______________ that _______________ through a __________

2. What is a wave? What is a sound wave?

- A **wave** is a **disturbance** that **propagates** through a **medium**

- What are some real-life **examples** of waves? Describe them in the above terms:
  - What is the **medium**?
  - What property of the medium is being **disturbed**?

2. What is a wave? What is a sound wave?

- A **wave** is a **disturbance** that **propagates** through a **medium**

- See these wave animations

  by Dan Russell, Graduate Program in Acoustics, Penn State

  - People doing “the wave”
  - Air molecules inside a tube
  - A pulse of displacement moving along a string

2. What is a wave? What is a sound wave?

- A **wave** is a **disturbance** that **propagates** through a **medium**

- Important: The **disturbance** propagates; the pieces of the **medium** do not
  - When **sports fans** do “the wave”, they stay in their own seats
  - When **air molecules** vibrate, they move slightly back and forth, but they don’t travel to the end of the tube

2. What is a wave? What is a sound wave?

- What is **sound**?
  In *AAP*, p 7, Johnson defines sound as a **sensation**

  Motion of object →

  pressure fluctuations in medium →

  pressure fluctuations reach eardrum →

  neural transmission →

  perception/sensation of sound

  - If a tree falls in the forest when no one is there, does it make a **sound** (according to this definition)?

2. What is a wave? What is a sound wave?

- Where is the **sound wave** in this chain of events?

  Motion of object →

  pressure fluctuations in medium →

  pressure fluctuations reach eardrum →

  neural transmission →

  perception/sensation of sound

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- Where is the **sound wave** in this chain of events?

  Motion of object →

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  - If a tree falls in the forest when no one is there, does it make a **sound wave**?

- Note: there can be no **sound** without **motion**

3. Measuring waves: Time vs. space

- Think about waves in water
  - What is the **medium**? — the water
  - What is the **disturbance**?

- How could we **describe** (**graph**) waves in a lake?

3. Measuring waves: Time vs. space

- Think about waves in water
  - What is the **medium**? — the water
  - What is the **disturbance**? — the *height* of the water above/below the *resting state*

- How could we **describe** (**graph**) waves in a lake?
  - Look at this animation
    by Dan Russell, Graduate Program in Acoustics, Penn State
  - What does each **graph** of the wave represent?

    Note: You are not responsible for knowing the formula at the top of the page

3. Measuring waves: Time vs. space

- How could we **describe** (**graph**) waves in a lake?
  - We could plot water **height** by **distance** from the disturbance at a **single point in time** (like a photograph of the water surface)
    - This is the graph on the right

3. Measuring waves: Time vs. space

- How could we **describe** (**graph**) waves in a lake?
    - We could plot water **height** over **time** for a **single point in space** (imagine watching a measuring stick on the end of a dock in the lake)
        - This is the graph on the left

- Always look at the **axes** on a graph when you are trying to interpret what it shows

3. Measuring waves: Time vs. space

- Sound waves are different from water waves: sound waves are **pressure** waves
  - Look again: Animation of air inside a tube
    by Dan Russell, Graduate Program in Acoustics, Penn State
- But, as with the water example, we can **measure** and **graph** sound waves in two different ways
  - **Air pressure** by **distance** from the source at a **single point in time**
  - **Air pressure** by **time** at a **single point in space**
- Which of these is what a **microphone** does?

3. Measuring waves: Time vs. space

- Look at *V&C* Figure 1.1 (p 7):

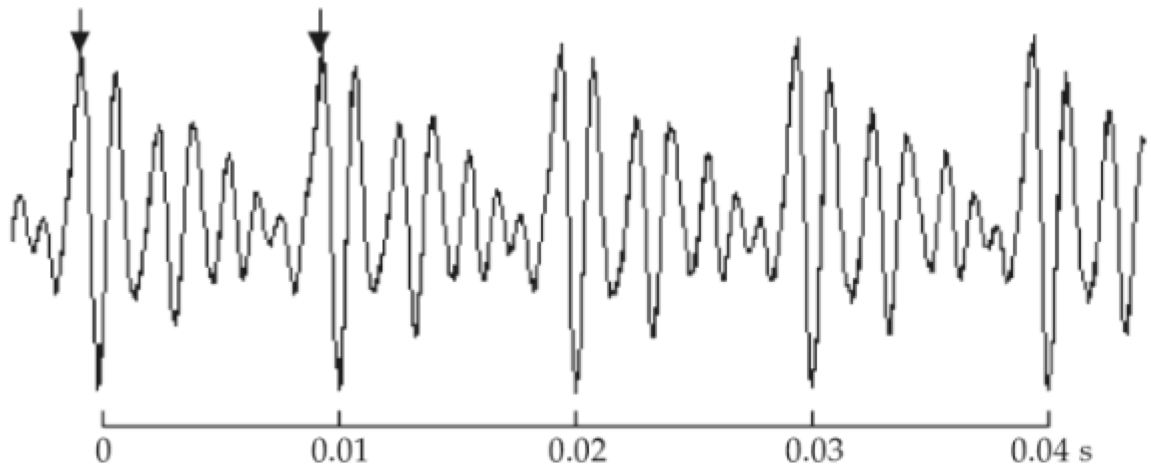
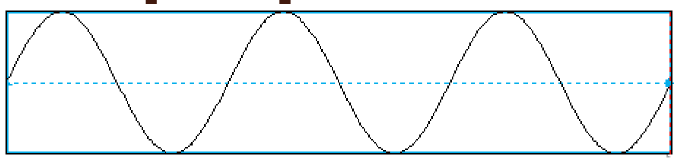


Figure 1.1 Part of the sound wave of the vowel ɑ as in *father*. The arrows indicate a section that is repeated every one-hundredth of a second.

- This is a sound wave (the axes aren’t explicitly labeled)
  - How does this display show that there is a **disturbance** in a **medium**?

4. Classifying waves

- **Periodic** — has a repeating pattern
  - **Simple periodic** — a sine wave |*details today*

    (← sine wave)

  - **Complex periodic** — any other repeating pattern | *details next class*

- **Aperiodic** — no repeating pattern | *details later*
  - **Noise** — aperiodic sound that persists in time
  - **Transient** — instantaneous aperiodic sound

4. Classifying waves

- Look at *V&C* Figure 1.1 (p 7):

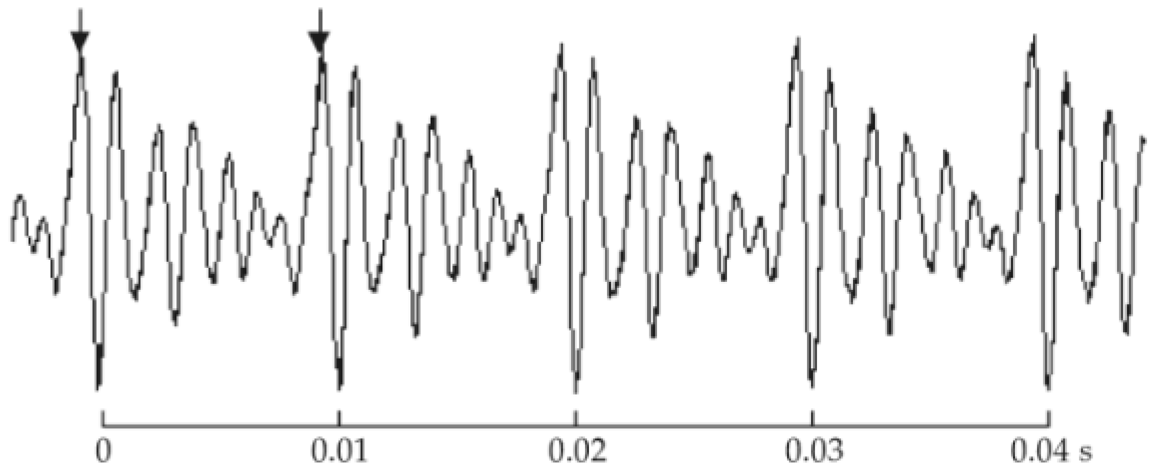


Figure 1.1 Part of the sound wave of the vowel ɑ as in *father*. The arrows indicate a section that is repeated every one-hundredth of a second.

  - Periodic or aperiodic?
  - Simple or complex?

4. Classifying waves

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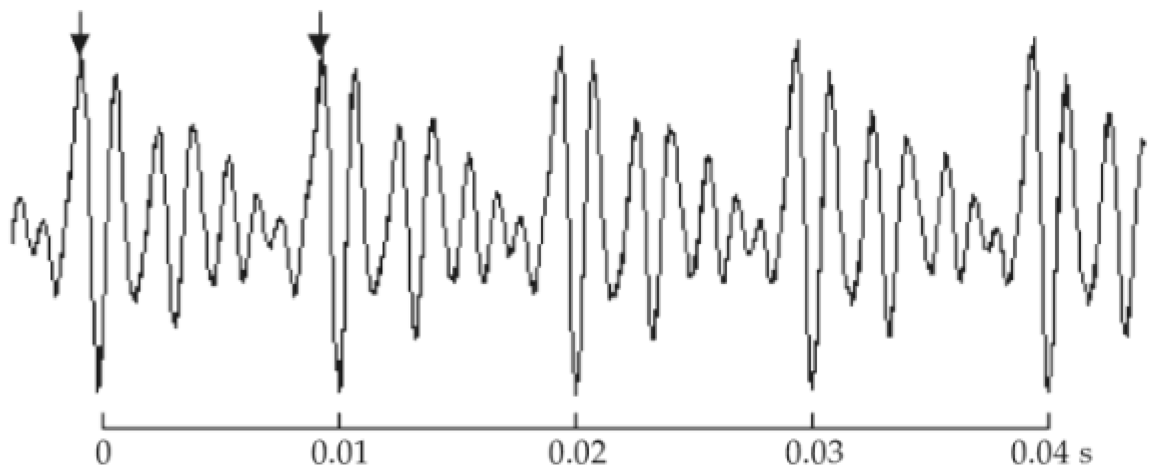


Figure 1.1 Part of the sound wave of the vowel ɑ as in *father*. The arrows indicate a section that is repeated every one-hundredth of a second.

  - Periodic or aperiodic? | repeating pattern?
  - Simple or complex? | sine wave, or other?

5. Properties of periodic waves

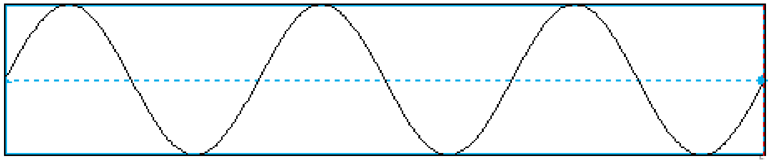
- To describe a periodic wave (for speech analysis), the most relevant properties are…

Physical property (acoustics)	*Human perception*
frequency	pitch
amplitude	loudness
wave shape	quality (timbre)

- These factors can vary independently

6. Simple periodic waves

- A **simple periodic wave** has the shape of a **sine wave**



(may be phase-shifted!)

- Not many real-world sound waves are sine waves
- But, as we will soon see, **complex periodic waves** can be described in terms of sine waves
  → We need to understand the **properties** of sine waves for doing acoustic analysis

6. Simple periodic waves

- Three properties are needed to define (describe) a simple periodic wave:

  Frequency

  Amplitude

  Phase

6. Simple periodic waves

- Three properties are needed to define (describe) a simple periodic wave:

  Frequency — how often the wave repeats per a given unit of time | *see more below*

  - For sound waves, frequency is *perceived* by a listener as **pitch**: high-frequency sound waves have a high pitch

  Amplitude

  Phase

6. Simple periodic waves

- Three properties are needed to define (describe) a simple periodic wave:

  Frequency

  Amplitude — the maximum (positive and negative) displacement of the medium by the wave

  - For sound waves, amplitude is *perceived* by a listener as **loudness**
  - We will be most concerned with *relative* amplitude, not specific amplitude values

  Phase

6. Simple periodic waves

- Three properties are needed to define (describe) a simple periodic wave:

  Frequency

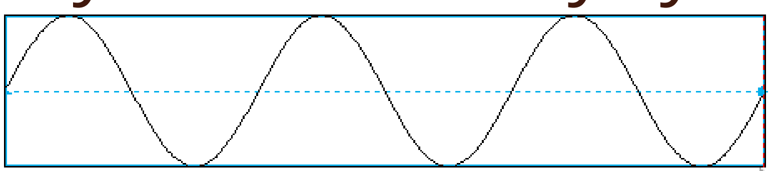
  Amplitude

  Phase — Relative timing; two waves with the same frequency are **in phase** if their max and min amplitudes occur at the same time

  - For sound waves, the phase (timing) of an individual wave doesn't really affect how it is *perceived*
  - Phase will become more important later, when we look at standing waves, reflection, and resonances

7. Frequency

- The **fundamental frequency** of *any* periodic wave (simple or complex) is the number of **cycles** in a given **time** interval
  - One **cycle** is one **repetition** of the wave pattern
  - For a simple periodic wave, the repeating pattern includes one “peak” and one “trough” — be careful to measure the whole cycle
  - Try it: How many cycles are pictured here?



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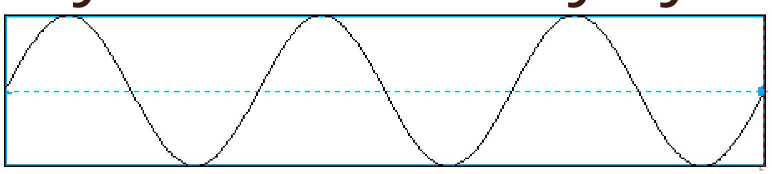


3 cycles (between |…|)

| 1 | 2 | 3 |

7. Frequency

- We will often need to measure or calculate the (fundamental) frequency of a speech sound
  - There are several ways to **measure frequency** using Praat tools (you will learn some in upccoming labs)
  - For today, we will learn to measure frequency from the **waveform** — an **amplitude × time** graph (remember the float in the lake)

7. Frequency

Calculating a wave's frequency from its period

- The **period** of a (periodic) wave, **T**, is the **time** it takes for one cycle to occur
- The **frequency**, ***f***, is the **reciprocal** of the period

$$f=1/T$$

- Measure **period** in seconds (**s**) or milliseconds (**ms**)
  - 1s = 1000ms
- Measure **frequency** in hertz (**Hz**)
  - Hertz equals "**cycles per second**"; **1Hz = 1/s**

7. Frequency

Calculating a wave's frequency from its period

- How this works, conceptually:
  - The #37 bus runs continuously all day
    It takes the bus 15 minutes to run its route once
    How many times per hour does the bus run?

7. Frequency

Calculating a wave's frequency from its period

- How this works, conceptually:
  - The #37 bus runs continuously all day

    It takes the bus 15 minutes to run its route once

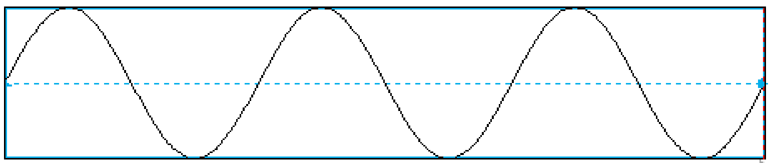
    How many times per hour does the bus run?

    → 4 times per hour
  - Figure it out by dividing 1/T: (15 min = 0.25 h)

    $f = 1/T = 1/(0.25\ h) = 4/h$ | 4 per hour
  - Note: having **"h" in the *denominator*** means ***per*** **hour**

Calculating a wave's frequency from its period

- Now try a sound wave — it works the same way
  - Suppose the time axis shows **0.075 s**

    Remember, there are 3 cycles of the wave here
  - First, what is the **period** of this wave? **T**=…?

7. Frequency

Calculating a wave's frequency from its period

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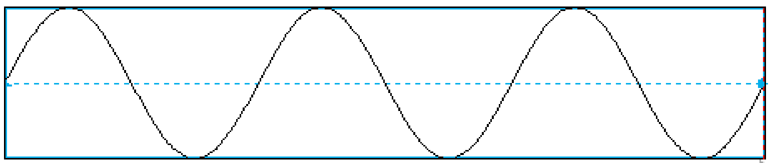
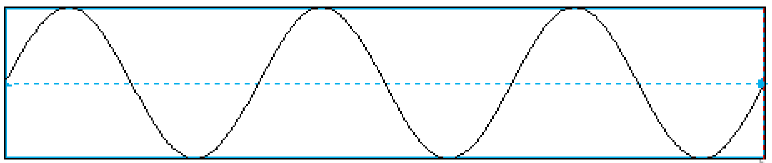
    

    Remember, there are 3 cycles of the wave here
  - **T** = (0.075 s)/(3 cycles) = 0.025 s/cycle
  - Next, what is the **frequency** of this wave? ***f*** =…?

Calculating a wave's frequency from its period

- Now try a sound wave — it works the same way
  - Suppose the time axis shows **0.075 s**



Remember, there are 3 cycles of the wave here

  - **T** = (0.075 s)/(3 cycles) = 0.025 s/cycle
  - ***f*** = 1/T = 1/(0.025 s/cycle) = 40 cycles/s
  - "Cycles per second" = Hertz, so, ***f*** = **40 Hz**

*** Remember to report units when doing a calculation ***

8. For next class

- Try comparing frequency, amplitude, shape for two sound waves (prep questions)
- We will discuss complex periodic waves and how they can be analyzed in terms of simple waves