- **Vowel articulations**
- **Spectrograms and vowel formants**

Background reading:

- *V&C* Ch 4, "The sounds of vowels"
- *AAP* Ch 6, sec 6.4, "Vowel formants and the acoustic vowel space"
- See also *V&C* Ch 12, sec 12.1, “Movements of the tongue and lips for vowels”

Today's topics

- **Vowel articulations** in terms of **height**, **backness**, and **rounding**
- **Vowel articulations** in terms of vocal-tract **tubes** and **constrictions**
- **Spectrograms**
- **Vowel acoustics**: How **height** and **backness+rounding** relate to **vowel formants**

1. Vowel articulations

- What are the traditional articulatory descriptions of the commonly occurring vowels [i e a o u]?

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[i] high front unrounded		[u] high back round
[e] mid front unrounded		[o] mid back round
	[a] low central unrounded	

- *Note:* In the British tradition, the symbol [a] is used for a low **front** vowel, similar to [æ]; this is also official IPA usage. But we will follow typical US practice and use [a] for the low **central** vowel. See S. Wood's discussion.

1. Vowel articulations

Vowels are traditionally described in terms of:

- A **height** dimension, originally thought to refer directly to the height of the highest part of the tongue
- A **backness** dimension, originally thought to refer directly to the front/back position of the highest part of the tongue
- **Rounding** (lip rounding)

1. Vowel articulations

Watch how these vowels are produced:

- X-ray video of [i e a o u] (no audio), from *V&C* Figure 12.3, via YouTube
- MRI video of English speakers singing [a(ɑ) e i o u] (in that order), by Matthew Edwards, Shenandoah Conservatory
  - Their low vowel is back [ɑ] rather than central [a]

Can you see which vowels are higher/lower? More front/more back?

1. Vowel articulations

- There is certainly some articulatory basis to the traditional categories of **height** and **backness**
  - But not all “high” vowels have an equally “high” tongue, and likewise for backness
  - See sec 12.3 in *V&C* (optional reading) for a more detailed critique of the view that these terms *directly* refer to articulatory properties

1. Vowel articulations

- "Height" and "backness" actually more directly reflect **acoustic** properties of vowels, namely, their first few **formants**
  - Review question: What is a **formant**?

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    → A **resonance frequency** of the **vocal tract**

1. Vowel articulations

- The shape of the vocal tract for the vowels [i e a o u] diverges from the uniform tube we modeled for [ə]
  - Therefore, modeling their formants involves more than just calculating tube length
- Next class, we will look at two ways of using tubes to model vowel formants beyond [ə]
  - The **multiple-tube model**
  - The **perturbation model**
- In preparation, we will take a closer look at the vocal-tract shape for these vowels

2. Vocal-tract tubes and constrictions

- See X-ray diagrams and plastic models of the vocal tract for the American English vowels [ɑ i e o u], from the Exploratorium web site
  - As an aside, this is also a nice demo of the source-filter model of vowel acoustics if you listen to the sound files
- How can we describe each vowel's **vocal tract shape**, in terms of…? (focus on [ɑ i u])
  - **Tubes**: Where is the vocal tract **wide** vs. **narrow**?
  - **Constrictions**: Which anatomical **landmarks** are the narrow parts near?

2. Vocal-tract tubes and constrictions

[ɑ]
- Constriction in the **pharynx** (vertical part of vocal tract downstream of velum/uvula)
- **Wide tube** in front, **narrow tube** in back

[i]
- Constriction at the **palate**
- **Wide tube** in front, **small narrow tube** in middle, **wide tube** in back

[u]
- Constrictions at the **velum** and **lips**
- (**Longer) wide tube** in front, **small narrow tube** in middle, **wide tube** in back + **lip rounding**

- We can use our understanding of **resonance frequencies in tubes** to model **vowel formants**

3. From spectrum to spectrogram

- What are the axes on a **spectrum** display?

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- What are the axes on a **spectrum** display?
  - **Amplitude** as a function of **frequency**

- There is no time dimension shown on a spectrum — why not?

3. From spectrum to spectrogram

- Review: What does a **spectrum** show?

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- Review: What does a **spectrum** show?

  For **a given point in time**,
  - the **components** of a complex wave
  - in terms of their **amplitude** and **frequency**

- How to show **change** in the **spectrum** over **time**?
  - We need a **3D display** to add a time dimension
  - **Rotate** the spectrum: **frequency** on ***y* axis**, **amplitude** on ***z* axis** (sticking out at you=darkness)
  - Show these rotated spectra one after the other: now **time** is on the ***x* axis**
  - This is a **spectrogram** (see diagram on *ACP* web site)

4. Wide-band vs. narrow-band

- If we want to look at the shape of a complex wave, we need to track the waveform over a certain **duration** (length of time)
  - This is the **window length** we can set in Praat

4. Wide-band vs. narrow-band

- We can look at the waveform for a (relatively) **long** duration and get its components
  - This gives us good **frequency** resolution: **narrow-band spectrum**
  - But bad **time** resolution: if the wave shape changes during our time window, we're essentially getting all the components mixed together

4. Wide-band vs. narrow-band

- We can look at the waveform for a (relatively) **short** duration and get its components
  - This gives us poor **frequency** resolution: **wide-band spectrum**
    - *Why* poor frequency resolution? Essentially, because we are further away from the sharp spectrum lines of an infinitely long complex wave
  - But good **time** resolution: since we are looking at shorter sections of the waveform, we are more sensitive to changes in its shape

4. Wide-band vs. narrow-band

- Consider Lab #04: What is easier to see on a…
  - **narrow-band** spectrum?
  - **wide-band** spectrum?

4. Wide-band vs. narrow-band

- Consider Lab #04: What is easier to see on a…
  - **narrow-band** spectrum? | **components (f_0)**
  - **wide-band** spectrum? | **formants!**
    - "Poor" frequency resolution is actually **helpful** when you don't have components right at the resonance frequencies of the vocal tract!
- Sound files *schwa01, schwa02*: Did they have the same source, or the same filter?
  - What if we look at a wide-band spectrum?

4. Wide-band vs. narrow-band

- Since a spectrogram is a series of spectra over time, we can also have **wide-band** and **narrow-band spectrograms**

5. Vowel articulations and acoustics: Formants

- Back to our five reference vowels, [i e a o u]
  - Look at the vowels of Hawaiian (*V&C*) in Praat
    (wide-band spectrogram: window length 0.005 s)
- Which formants are most useful for distinguishing between them?
- Which formant corresponds to vowel height?
- Which formant corresponds to backness+rounding for this set of vowels?