• Oral stops (plosives):
  Formant transitions, bursts

Background reading:
• V&C Ch 6, sec 6.2, "Stop consonants" (review)
• AAP Ch 8, chapter introduction
• AAP Ch 8, sec 8.2, "Vocal tract filter functions in stops"
0. Overview: Consonant acoustics

• Material for the midterm built up to applying the **source-filter model** of speech acoustics to **vowels**

• In the next part of the course, we will apply the source-filter model to **consonants**

• Still relevant:
  - Resonance frequencies of tubes
  - The glottal-source spectrum
  - Perturbation theory

• Today we will apply these **concepts** to **oral stops**
1. Oral stops: Overview and articulation

• **Oral stops** are often called simply *stops*
  - The term *plosive* may also be used — this refers specifically to oral stops produced with the **pulmonic egressive airstream mechanism** (more about this later)

• Which oral stops are found in **English**?
1. Oral stops: Overview and articulation

- Which oral stops are found in **English**?
  - Contrastive (phoneme) categories:
    
    **bilabial**  **alveolar**  **velar**
    
    voiceless:
    
    \( [p] \)  \( [t] \)  \( [k] \)
    
    voiced:
    
    \( [b] \)  \( [d] \)  \( [ɡ] \)
  
    - Positional variants of other phonemes:
      
      voiceless aspirated
      
      \( [p^h] \)  \( [t^h] \)  \( [k^h] \)
      
      glottal stop
      
      \( [ʔ] \)
1. Oral stops: Overview and articulation

• What *articulatory properties* distinguish oral stops from other consonant classes?
  - How are they different from *fricatives* and *approximants* (=liquids and glides)?
  - How are they different from *nasal stops*?
1. Oral stops: Overview and articulation

• What **articulatory properties** distinguish oral stops from other consonant classes?
  - Complete **obstruction** in the oral tract
  - **No** nasal airflow

• Oral stops can **differ** in
  - **Voicing** (voiced/voiceless)
  - **Phonation type** (breathy voice/creaky voice)
  - **Aspiration** (voice onset time, VOT)

→ We’ll look at these factors in more detail in later classes
1. Oral stops: Overview and articulation

• How does AAP divide the articulation of stops into sub-stages?
• How does AAP divide the articulation of stops into sub-stages? | **shutting, closure, release**

**Figure 8.1** Three stages in the time course of stop or affricate production. The lines indicate articulators moving toward each other during the shutting stage and separating during the release stage.

- Be sure you understand how to read this articulator timing diagram — we will use these later also
2. Formant transitions and place of articulation

• Consider a stop between two schwa vowels

• Articulation:
  - What is the state of the oral tract during schwa?
  
  - What is the state of the oral tract during the closure stage of a stop (oral or nasal)?
2. Formant transitions and place of articulation

• Consider a stop between two schwa vowels
• Articulation:
  - What is the state of the oral tract during schwa?
    → Uniform tube
  - What is the state of the oral tract during the closure stage of a stop (oral or nasal)?
    → Completely closed

• What are the acoustic consequences?
2. Formant transitions and place of articulation

- Consider a stop between two schwa vowels
- Articulation → acoustics:
  - What is the state of the **oral** tract during **schwa**?
    → Uniform tube
    → Evenly spaced formants
2. Formant transitions and place of articulation

• Consider a stop between two schwa vowels

• Articulation → acoustics:
  - What is the state of the oral tract during the closure stage of a stop (oral or nasal)?
    → Completely closed
  - If the stop is voiceless, no sound energy at all
  - If the stop is voiced, the glottal source is filtered by the closed skull (see gray box, AAP p 175)
• Only a few low-frequency components are audible (“voice bar” on spectrogram)
2. Formant transitions and place of articulation

• Consider a stop between two schwa vowels

• Articulation → acoustics:
  - What is the state of the oral tract during the shutting or release stage of a stop?

• What are the acoustic consequences?
2. Formant transitions and place of articulation

• Consider a stop between two schwa vowels

• Articulation → acoustics:
  - What is the state of the oral tract during the shutting or release stage of a stop?
    → A transition between uniform tube and complete closure

• What are the acoustic consequences?
2. Formant transitions and place of articulation

- Consider a stop between two schwa vowels

- Articulation → acoustics:
  - What is the state of the oral tract during the shutting or release stage of a stop?
    → Transition from uniform tube → closure

- What are the acoustic consequences?
  - Tube is gradually more and more (or less and less) constricted at C’s place of articulation

→ Formant transitions
2. Formant transitions and place of articulation

- **Formant transitions** are visible at the edge of a vowel when it is adjacent to a consonant.
  - They reflect the effect of the consonant's *constriction* on the *formants* (vocal-tract resonances).
  - Formant transitions *happen* during the vowel, but they *provide information* about the *place of articulation* of the consonant.
2. Formant transitions and place of articulation

• We know how to model the effects of a constriction at different locations in a tube | *how?*
2. Formant transitions and place of articulation

• We know how to model the effects of a constriction at different locations in a tube | pertubation theory!

• Consider the vocal-tract landmarks:

• What effect on schwa formants do we predict for labial, alveolar, velar closures?
2. Formant transitions and place of articulation

• Consider the vocal-tract landmarks:

• Predicted formant transitions (*into* the consonant):

<table>
<thead>
<tr>
<th></th>
<th>labial</th>
<th>alveolar</th>
<th>velar</th>
</tr>
</thead>
<tbody>
<tr>
<td>F3</td>
<td>↓</td>
<td>↑</td>
<td>↓</td>
</tr>
<tr>
<td>F2</td>
<td>↓</td>
<td>~</td>
<td>↑</td>
</tr>
<tr>
<td>F1</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
</tr>
</tbody>
</table>
2. Formant transitions and place of articulation

• Look at these in Praat (get sound files from V&C web site IPA chart):

[əbə] [ədə] [əɡə]
2. Formant transitions and place of articulation

- The picture gets more complicated for perturbation theory if the vowel is not schwa
  - The vocal tract is already being perturbed by the **vowel** articulation
  - On top of that, we now add effects of the **consonant** articulation

- Multiple tube model is useful in principle, but also more complex to implement — lots of tubes!
2. Formant transitions and place of articulation

• What do we actually get for formant transitions on a non-schwa vowel?
  - **Labial** Cs usually do what we predict for schwa
  - **Velar** Cs usually do what we predict for schwa
  - **Alveolar** Cs usually do what we predict for schwa for F1, F3

• What about F2 transitions for alveolar Cs?
• Look at these in Praat: Sound files from [di da du] spectrograms (synthesized) from Louis Goldstein, U Southern California
2. Formant transitions and place of articulation

• What do we actually get for formant transitions on a non-schwa vowel?

  - **Alveolar** Cs usually do what we predict for schwa for F1, F3

• Whether F2 shows a rising or falling formant transition with an alveolar consonant **depends** on the *vowel F2*

• There is a **locus** for the F2 transition with an alveolar consonant
  (a frequency value it’s “heading for”)

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2. Formant transitions and place of articulation

• Review: Any questions about place of articulation or vocal-tract anatomy?
  - Work on learning oral stop (plosive) IPA symbols
  - English examples: V&C, Table 6.1
  - The Interactive Sagittal Section (by Daniel Currie Hall) is a good way to review consonant articulators and IPA symbols
3. Stop bursts

• During an oral stop’s closure stage, high air pressure has built up behind the oral constriction
  - This is because air continues to flow up from the lungs even during stop closure

• At the instant that the constriction is released, this air rushes out

• This is a **stop burst**
  - High volume velocity, narrow constriction
  - What does this resemble?
3. Stop bursts

• During an oral stop’s closure stage, high air pressure has built up behind the oral constriction
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• At the instant that the constriction is released, this air rushes out

• This is a **stop burst**
  - High volume velocity, narrow constriction
  - Acoustically, it resembles a very short **fricative** for the appropriate place of articulation
3. Stop bursts

- **Warning:** V&C (pp 51–52) refers to a “burst of noise” that accompanies voiceless stops in English
  - The first part of this is the actual **stop burst**
  - The remainder is actually **aspiration**, which we will discuss next week
4. Affricates

• What is an **affricate**?

• Which affricates do we have in English?
4. Affricates

• What is an **affricate**?
  
  - Similar to an **oral stop followed by a fricative** at the same (or very similar) place of articulation

• Which affricates do we have in English?
  
  - Post-alveolar (palatoalveolar, “alveopalatal”)
    
    - [ʧ] voiceless
    - [ʤ] voiced
4. Affricates

- How can we distinguish an affricate from an actual oral stop + fricative sequence?
  - Sometimes an affricate has a faster ‘rise time’ — the amplitude increases more quickly once the stop closure has been released.