- **Perturbation theory check-in**
- **Source/filter model check-in**
- **Lab #05**

Background reading:

- *AAP Ch 6, sec 6.1, "Tube models of vowel prod’n"*
- *AAP Ch 6, sec 6.2, "Perturbation theory" (beware pressure vs. velocity standing-wave diagrams!)*

0. Today's objectives

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

- Work more confidently with
  - Vowels in the source/filter model
  - The mulitiple-tube model and [ɑ], [i]
  - Perturbation theory
- Use perturbation theory to predict relative formant frequencies for [ɑ], [i], and partly [u]

1. Review and Padlet questions

- Padlet question on terms for frequencies
  - component, harmonic, resonance, formant

1. Review and Padlet questions

Lab #04 schwa spectra

- How do we understand these graphics?
  - Which graphic represents the **glottal source**, and which represents the **vocal-tract filter**?
  - What does the **remaining graphic** represent?
  - What would a vowel look like if it had a different **source**? A different **filter**?
- Which spectrum (NB, WB) corresponds to which graphic?
  - One goal of Lab #04: Relate Praat information to source/filter diagrams from web, readings

1. Review and Padlet questions

- Reminder to **review outline slides** when working on prep questions (or labs)
  - Multiple-tube model for [ɑ], [i]: Which tube ends are open or closed?

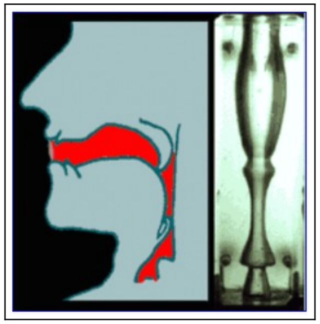
1. Review and Padlet questions

KNOW YOUR TUBE RESONANCES

- **Neutral vocal-tract [ə]:** Resonance frequencies depend on vocal-tract length
- **Multiple-tube model:** Each articulation is a series of tubes; each tube contributes its own resonances to the speech sound as a whole
- **Perturbation theory:** Start from the [ə] formants and see where the "constriction" (narrowing) is located with respect to the **location** of **pressure nodes/antinodes** for **each resonance**

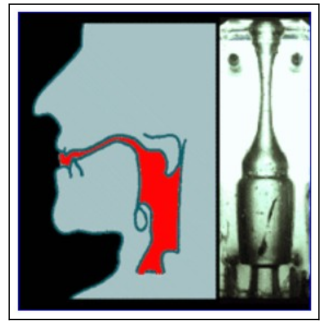
2. Perturbation theory check-in

[ɑ]



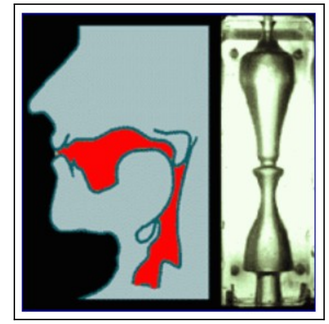
low back unrd

[i]



high front unrd

[u]



high back round

- Using the **multiple-tube model**, we can model vowel **vocal-tract shapes** as a ***series*** of **tubes**
- With **perturbation theory**, we can model vowel **vocal-tract shapes** as a **perturbation** (modification) of a ***uniform*** **tube**
- Both models are simplifications, but are useful ways of understanding and predicting speech acoustics

2. Perturbation theory check-in

- We can use our understanding of vowel articulations as **narrowings** in the vocal tract...
  - to model expected **deviations** in the **resonance frequencies** from those of a **uniform tube** ([ə])
  - and thereby **predict formants** of non-[ə] vowels

- Later in the course, we will also use perturbation theory to model **place-of-articulation** effects in consonant acoustics

2. Perturbation theory check-in

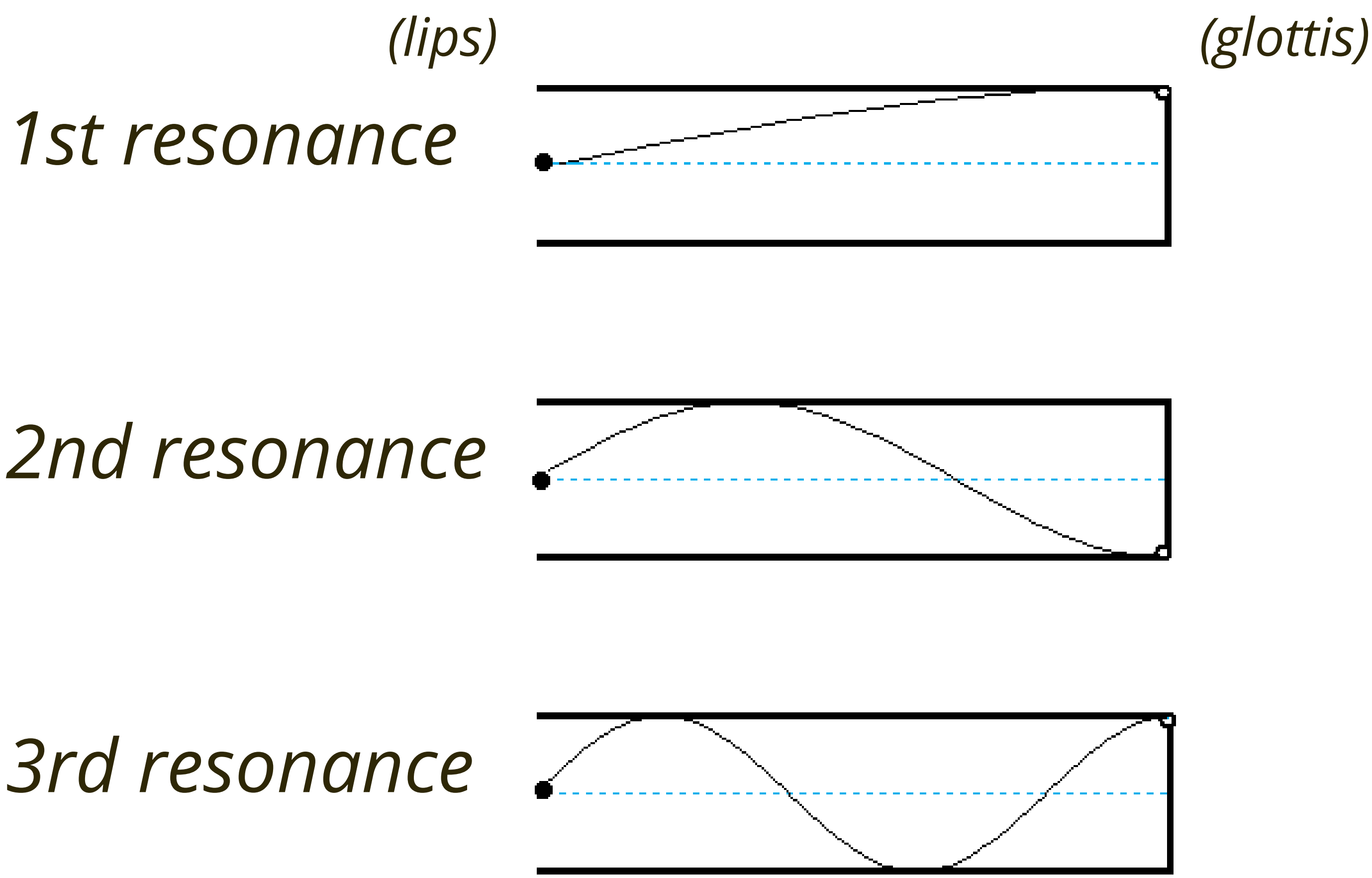
- First step: Model the formant frequencies of [ə] (uniform vocal-tract tube)
- Then: Predict how formant frequencies will differ in other speech sounds
    - Find **where** there is a narrow region in the vocal tract—where the uniform tube is “perturbed”
    - Determine how a perturbation at that vocal-tract location should **change** the resonance frequencies of the tube
        - Note: Consider each resonance separately

2. Perturbation theory check-in

- Reminders
  - Narrowing at the *lips* when a vowel is *round*
  - Narrowing at the *palate* when a vowel is *high* and *front*
  - Narrowing at the *velum* when a vowel is *high* and *back*
  - Narrowing at the *pharynx* when a vowel is *low* (especially if also *back*)

2. Perturbation theory check-in

- What we saw before: The first three resonances
  Where are *all* the **nodes** and **antinodes** for each?



2. Perturbation theory check-in

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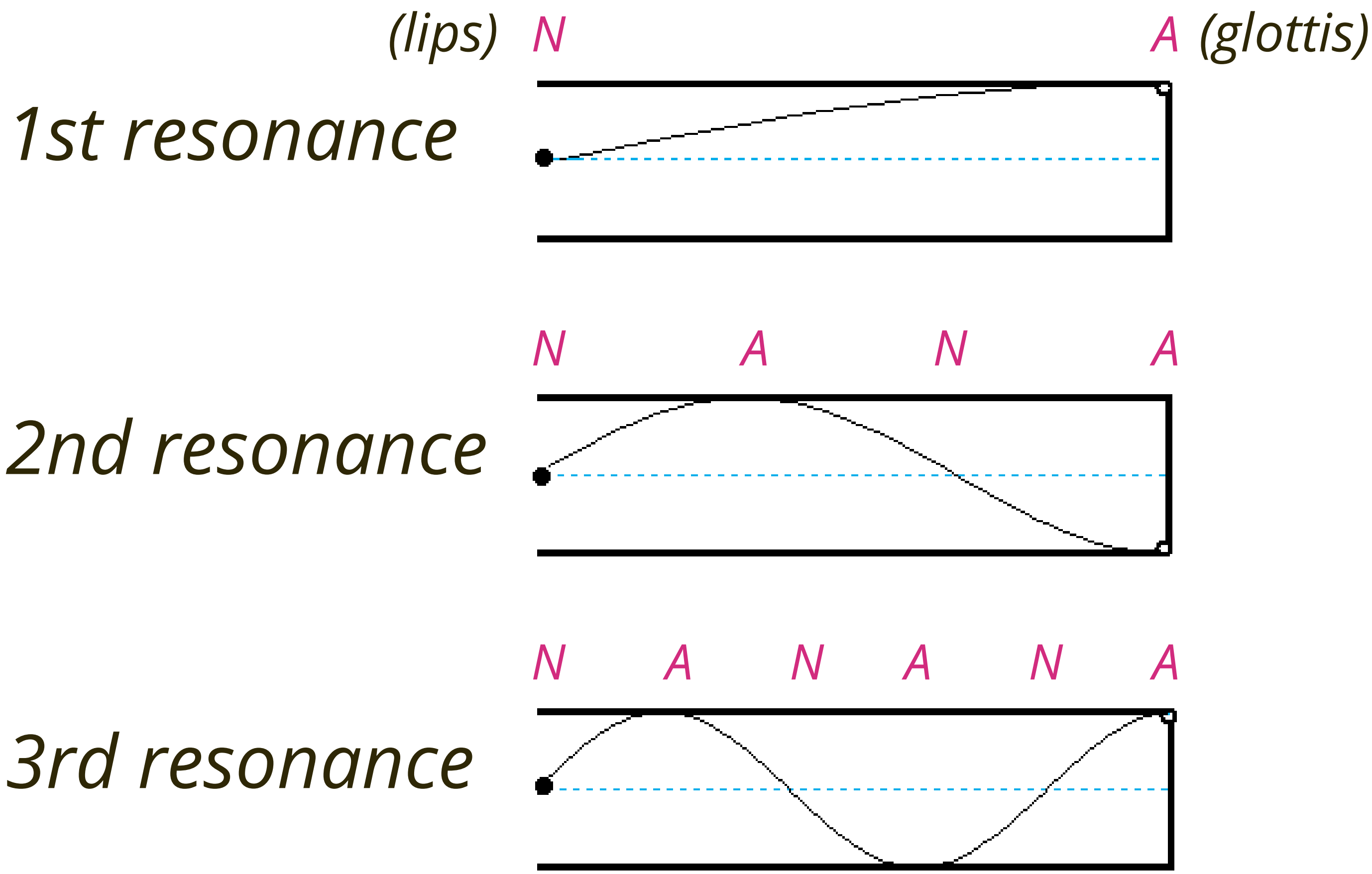
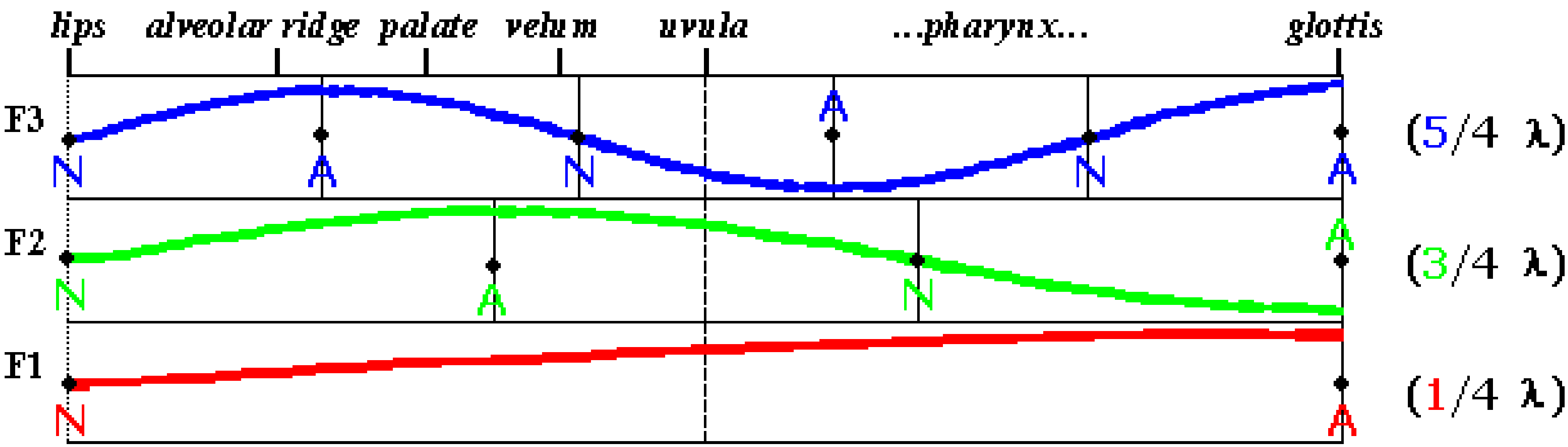


2. Perturbation theory check-in

- **Perturbation rules — MEMORIZE THIS**
  1. If there is a narrowing in the vocal tract near a velocity/displacement antinode = **pressure node**, the **formant frequency goes** ______.
  2. If there is a narrowing in the vocal tract near a **pressure antinode** (velocity/displacement node), **formant frequency goes** ______.
- Forming a constriction or narrowing in the vocal tract **affects each formant separately**

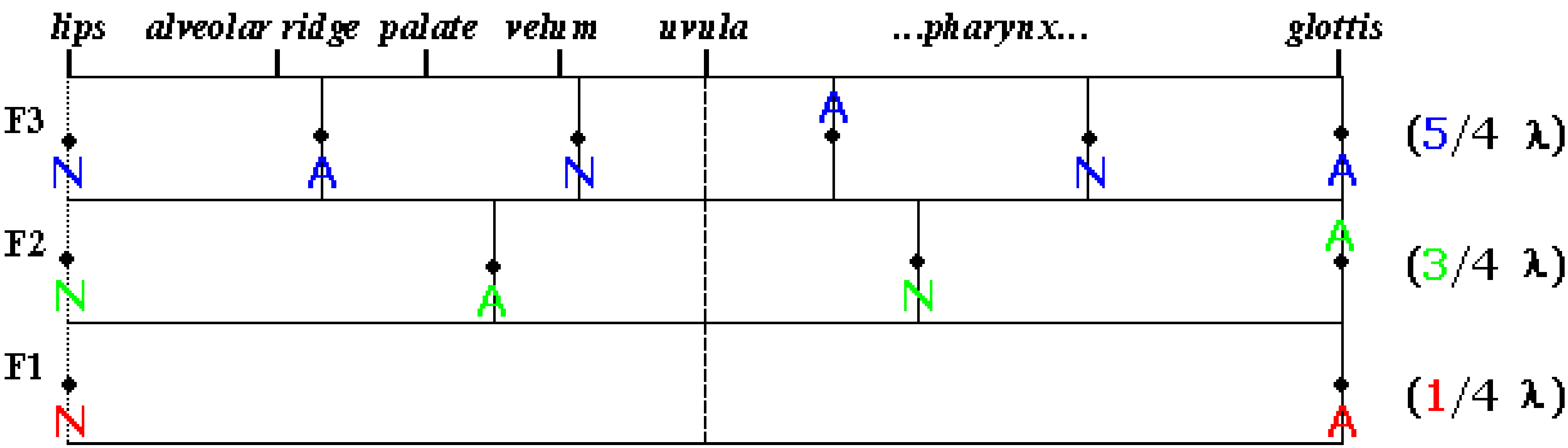
2. Perturbation theory check-in

- Articulatory landmarks in the vocal tract
  - Draw the first three standing (pressure) waves
  - Label their **nodes** and **antinodes**



2. Perturbation theory check-in

- Articulatory landmarks in the vocal tract
  - What we need to pay attention to is not the standing-wave diagram itself, but specifically where the **nodes** and **antinodes** are



2. Perturbation theory check-in

- Should the formant be higher (↑) or lower (↓) than the equivalent formant in [ə] when there is a narrowing as indicated?

	lips	palate	velum	pharynx
F3	○ ↑ ○ ↓	○ ↑ ○ ↓	○ ↑ ○ ↓	○ ↑ ○ ↓
F2	○ ↑ ○ ↓	○ ↑ ○ ↓	○ ↑ ○ ↓	○ ↑ ○ ↓
F1	○ ↑ ○ ↓	○ ↑ ○ ↓	○ ↑ ○ ↓	○ ↑ ○ ↓

2. Perturbation theory check-in

- Should the formants **in these vowels** be higher (↑) or lower (↓) than the equivalent formant in [ə]?

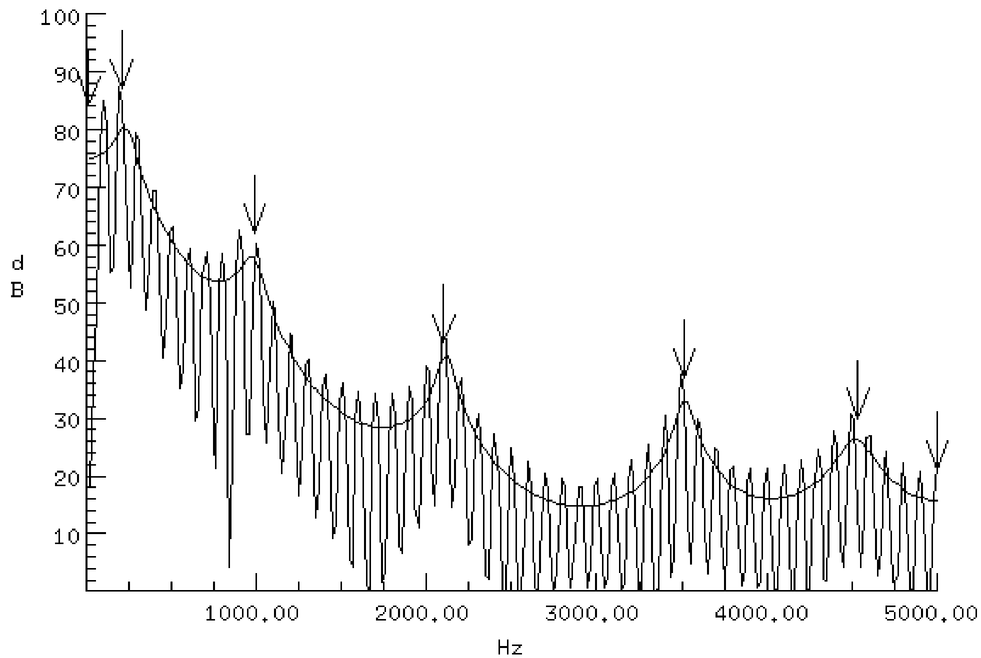
	[i]	[ɑ]	[u]
F3	◯ ↑ ◯ ↓	◯ ↑ ◯ ↓	◯ ↑ ◯ ↓
F2	◯ ↑ ◯ ↓	◯ ↑ ◯ ↓	*see below*
F1	◯ ↑ ◯ ↓	◯ ↑ ◯ ↓	◯ ↑ ◯ ↓

2. Perturbation theory check-in

- Why is it hard to make a prediction for F2 in [u] using perturbation theory?

2. Perturbation theory check-in

- Look at this [u] spectrum; formants are indicated with arrows (from U Delaware Speech Research)
  - What does F2 in [u] actually look like compared to [ə]? ([ə] produced by this synthesizer: F2=1550 Hz)



2. Perturbation theory check-in

Extension to **mid vowels**: [e], [o]

- [e] is less high and less front than [i]
  - Its formant frequencies are perturbed in the direction of [i], but not as far
- Likewise, [o] is less high and less back than [u]
  - Its formant frequencies are perturbed in the direction of [u], but not as far
  - Note: American English so-called “[u]” is more of a central vowel ([ʉ]) than a back one; AmEng [o] may be *further back* than [u]!

3. Lab #05

Due at class time on **F Sept 26**

- Use course materials (readings, slides, web demos)
- Use the new assigned reading
- Look at Lab #04 feedback
- Talk to your classmates
- Come to office hours

There may be **Lab #05 work time** on **W Sept 24**, depending on how class discussion goes