- **Vowel acoustics: Summing up**
- **Preparing for Lab #06: Research questions and hypothesis testing**

Background:

- Lab #4
- Lab #5

0. Course info — announcements & reminders

Schedule for this week

M Sept 19: Vowels—summary discussion
Preparing for Lab #06

W Sept 21: Lab #06 work time in classroom
(with partner group)

F Sept 23: Work time: Lab #06 or CITI training

- You may work in classroom or elsewhere
- Lab #06 due **F Sept 23, 3pm**
- If you are finished early with the lab, use the time to work on the CITI Training for Group 2/Social and Behavioral Research (officially due W Oct 12)

0. Today's discussion

- Review—Glottal source and vocal-tract filter
  - Wide-band vs. narrow-band spectra and spectrograms

- Relating traditional vowel descriptions to F1 and F2
  - Distinguishing [i e a o u] on spectrograms
  - Understanding where F1, F2 patterns come from

- Preparing for Lab #06

1. Glottal source and vocal-tract filter

Checking in on some concepts

- We can model [ə] as a uniform tube
  - Calculate the first (lowest) resonance frequency of the vocal-tract tube — does this tell us…

    1. the fundamental frequency of the [ə]?

    2. the lowest-frequency component on the spectrum of the [ə]?

    3. the lowest-frequency high-amplitude region on the spectrum of the [ə]?

    4. the first formant of the [ə]?

1. Glottal source and vocal-tract filter

Checking in on some concepts

- We can model [ə] as a uniform tube
  - Calculate the first (lowest) resonance frequency of the vocal-tract tube — does this tell us…

    ~~*1.* the fundamental frequency of the [ə]?~~ SOURCE

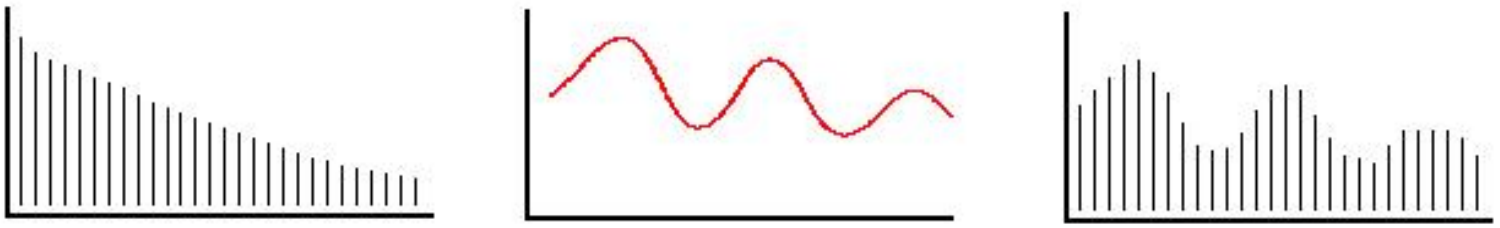
    ~~*2.* the lowest-frequency component on the spectrum of the [ə]?~~ SOURCE

    3. the lowest-frequency high-amplitude region on the spectrum of the [ə]? | *yes*! FILTER

    4. the first formant of the [ə]? | *yes*! FILTER

1. Glottal source and vocal-tract filter

- Here is a diagram of a vowel spectrum in the source-filter model of speech acoustics (adapted from K. Russell, U Manitoba)



  - Which graphic represents the **source**?
  - Which graphic represents the **filter**?
  - Which graphic represents the **vowel**?

- In general, how does a vowel's f_0 relate to its F1?

1. Glottal source and vocal-tract filter

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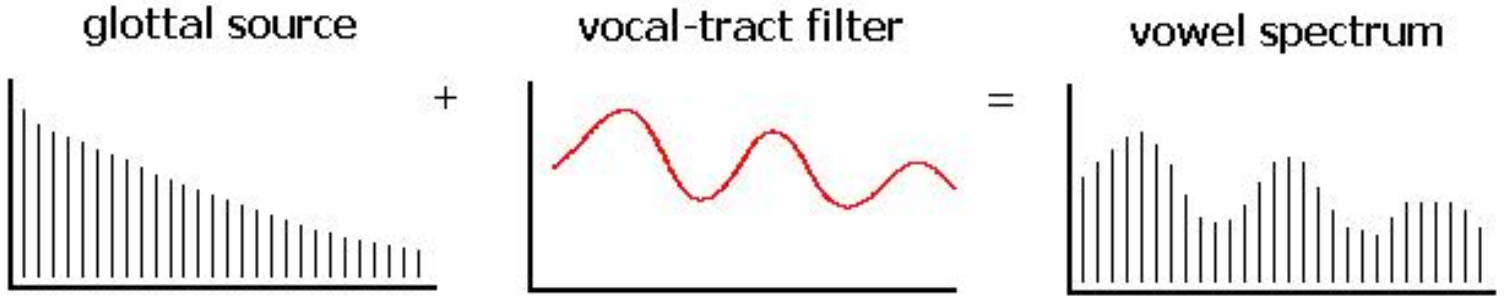


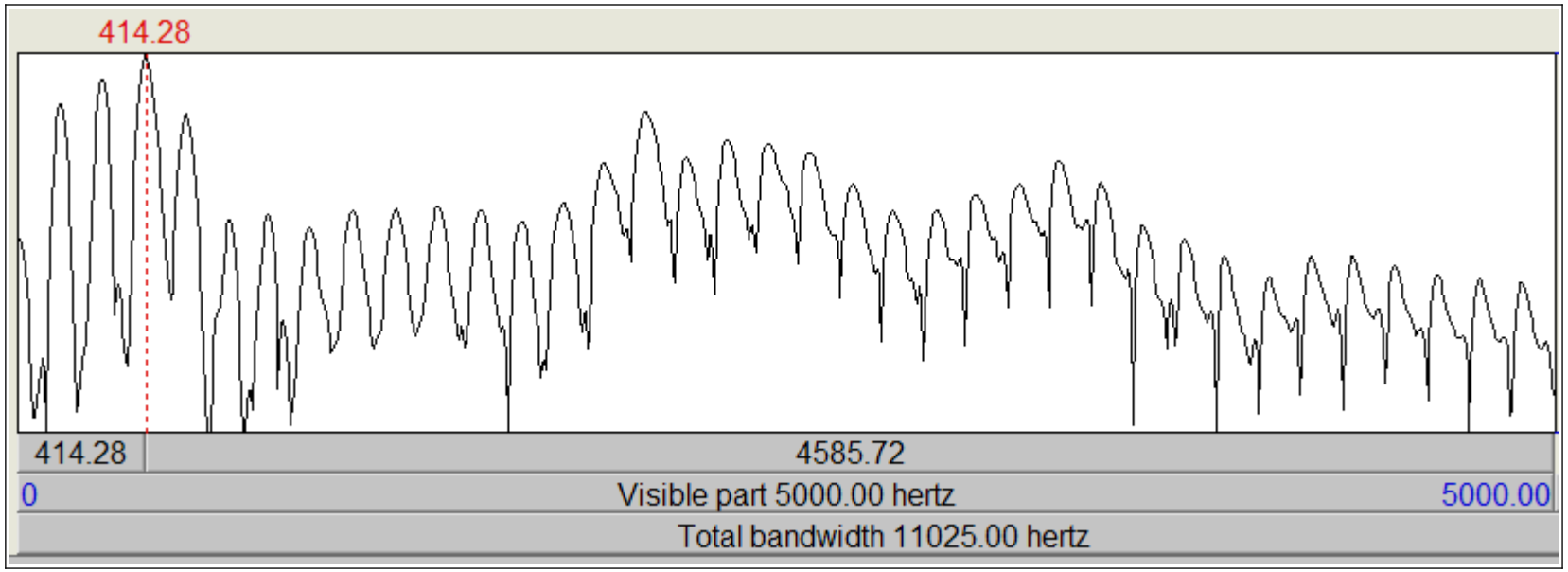
- In general, how does a vowel's f_0 relate to its F1?

  IT DOESN'T!

  - f_0 is determined by the _____
  - **F1** is determined by the _____

1. Glottal source and vocal-tract filter

- A spectrum from a naturally produced vowel:

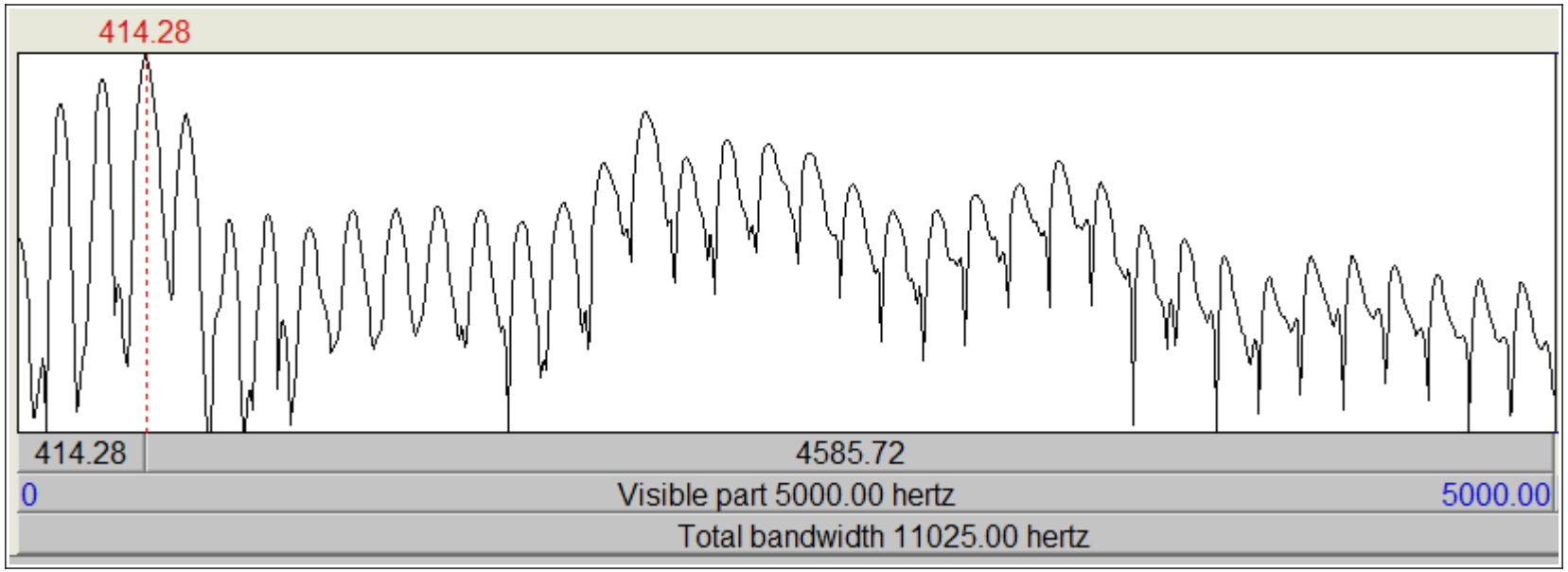


  - Where are the glottal-source components?
  - What is f_0?
  - What is F1, approximately?

(Value at cursor is about 414 Hz)

1. Glottal source and vocal-tract filter

- A spectrum from a naturally produced vowel:

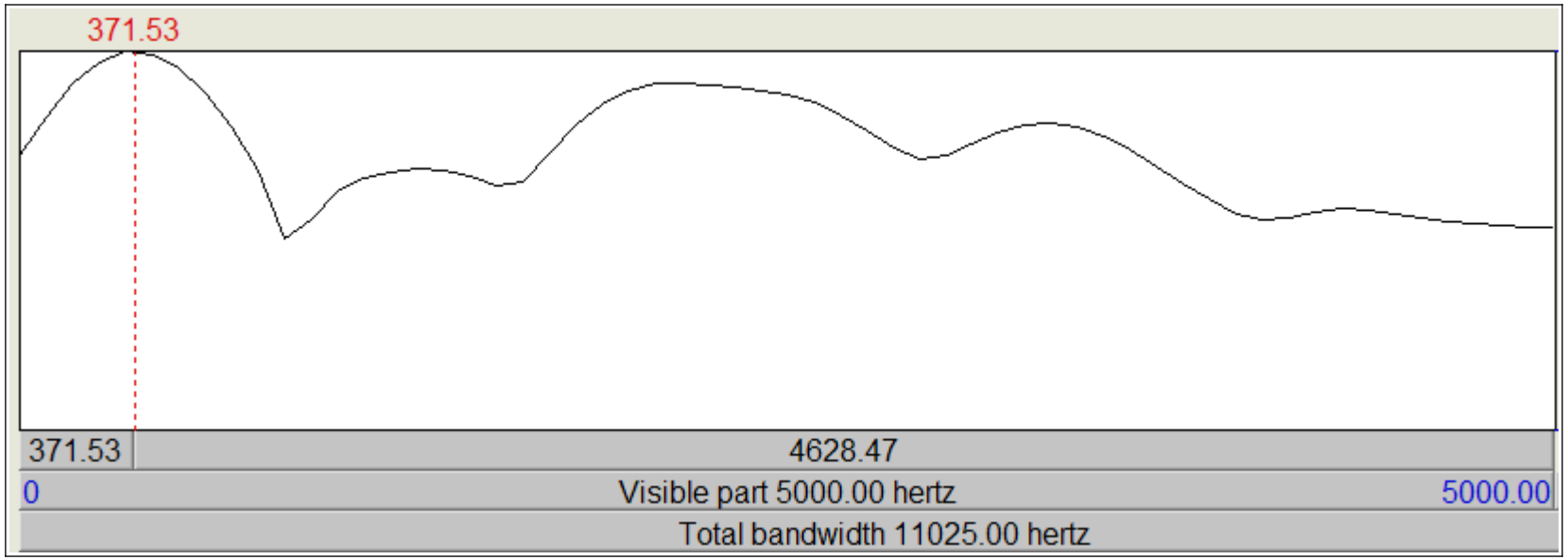


  - Where are the glottal-source components?
  - What is f_0? | 414 Hz / 3 = 138 Hz
  - What is F1, approximately? | 414 Hz

This is Hawai'ian [e] from *V&C*, Ch 3

1. Glottal source and vocal-tract filter

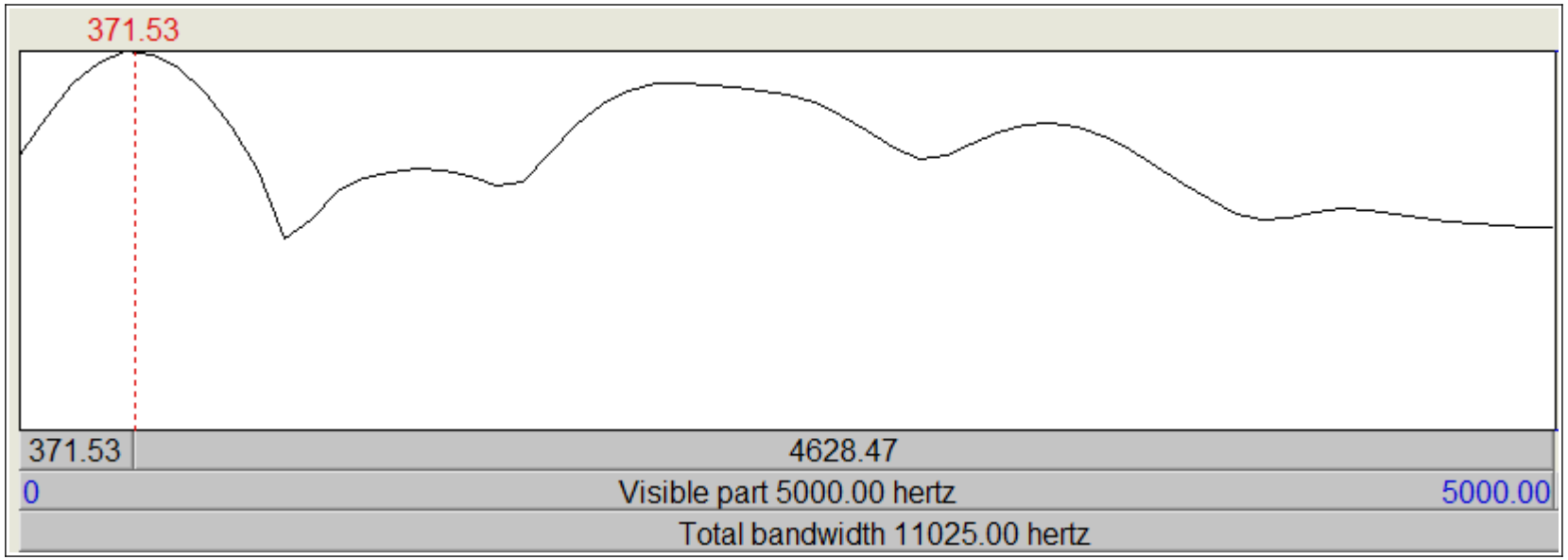
- A spectrum from the *same* vowel, *same* timepoint:



  - What is different about this spectrum?
  - What is the significance of 372 Hz?
  - Why 414 Hz before but 372 Hz here?

1. Glottal source and vocal-tract filter

- A spectrum from the *same* vowel, *same* timepoint:



  - What is different about this spectrum? | wide-band
  - What is the significance of 372 Hz? | F1
  - Why 414 Hz before but 372 Hz here? | narrowband spectrum (above) shows each glottal component; there wasn't any component exactly at F1=372 Hz; 414 Hz was the closest one

2. Vowel formants and spectrograms

- What is a **spectrogram**?

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- What is a **spectrogram**?

  A **spectrum** shows *amplitude by frequency*

  A **spectrogram** *turns the spectrum sideways* and adds the time dimension

  - **Frequency** is now on the *y* axis
  - **Amplitude** is now on the *z* axis (pointing out — darker gray means higher amplitude)
  - **Time** is on the *x* axis — think of lots of sideways spectra lined up to show change over time

2. Vowel formants and spectrograms

- What is a **spectrogram**?

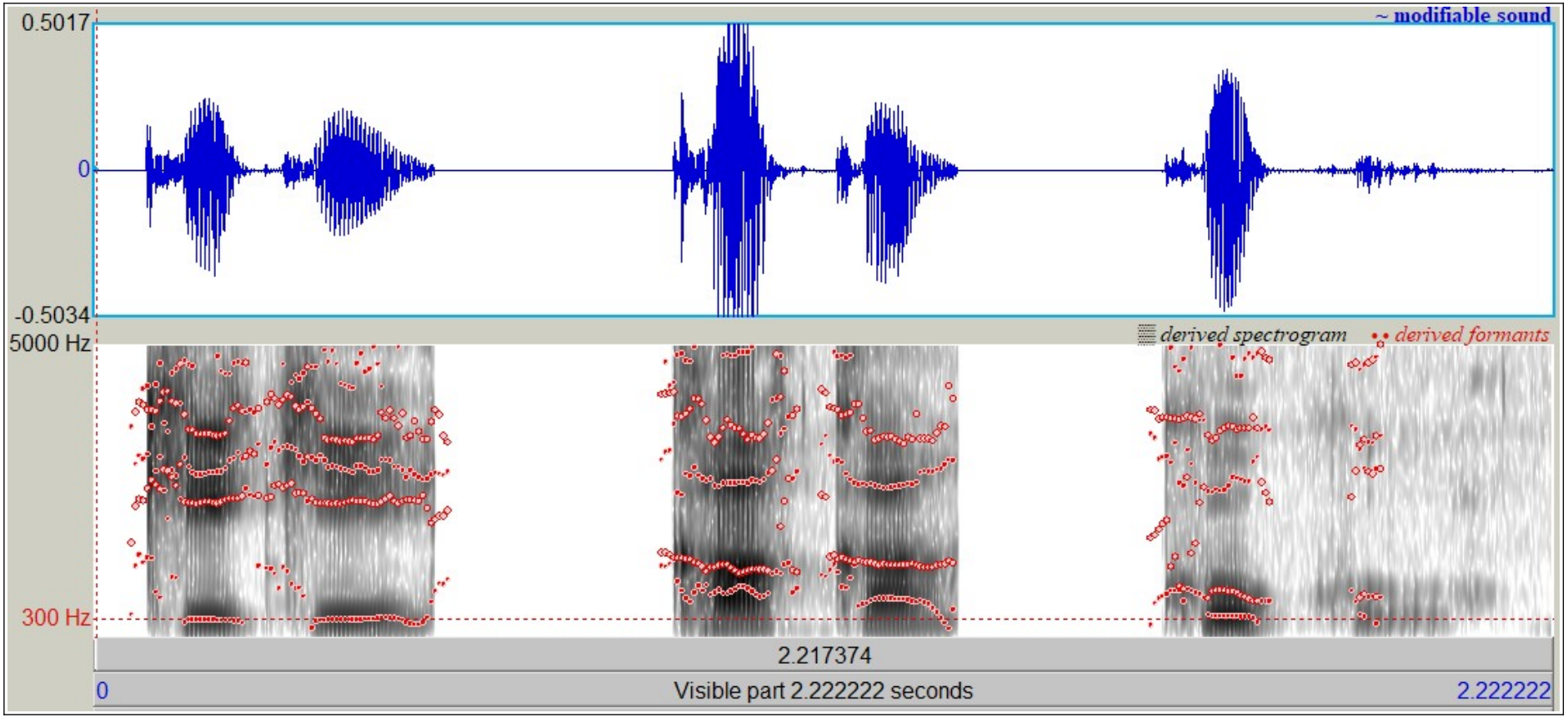
  A **spectrum** shows *amplitude by frequency*

  A **spectrogram** *turns the spectrum sideways* and adds the time dimension

- So…
  - We can use **narrow-band spectrograms** to look at **glottal components** over time
  - We can use **wide-band spectrograms** to look at **formants** (among other things) over time

2. Vowel formants and spectrograms

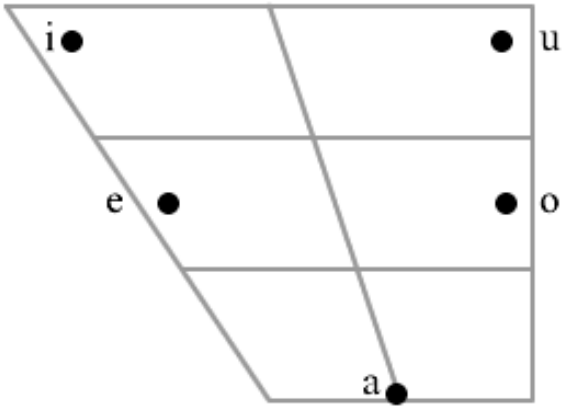
- The vowels [a i u] from Hawai'ian, from *V&C* Ch 3
  - Can you tell which is which? How?



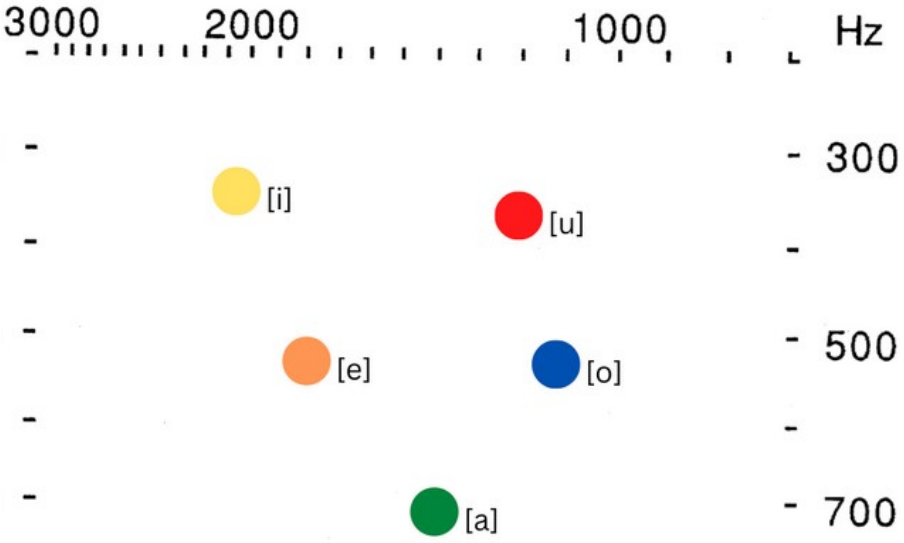
2. Vowel formants and spectrograms

- How do **vowel properties** relate to **formants**?
  - **F1** correlates…
  - **F2** correlates…

Traditional vowel chart



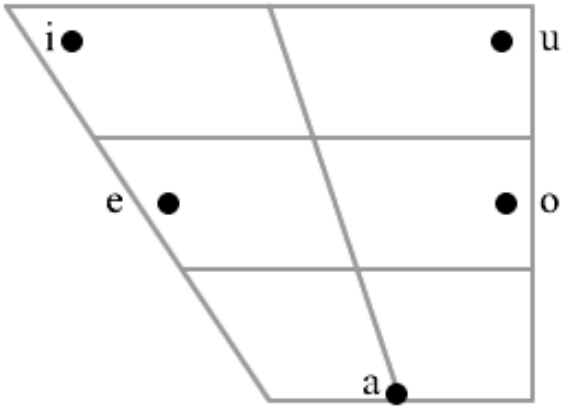
Swahili (Lab #05)



2. Vowel formants and spectrograms

- How do **vowel properties** relate to **formants**?
  - **F1** correlates *inversely* with **height**
  - **F2** correlates *inversely* with **backness**, as long as (**non-low**) back vowels are **round**

Traditional vowel chart



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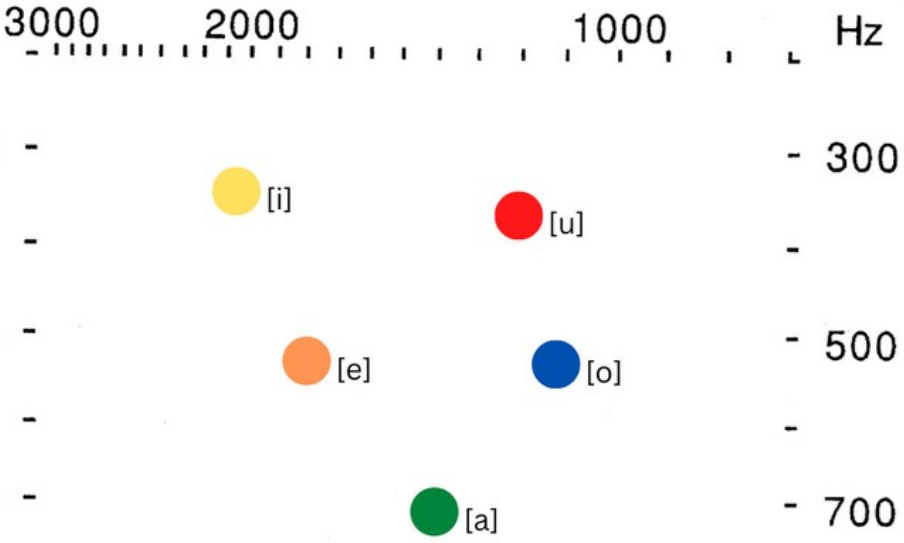

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- **Why?**

3. Predicting vowel formants

Multiple-tube model

- How do we predict vowel formants in this model?

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Multiple-tube model

- How do we predict vowel formants in this model?
  - What series of tubes models the vowel's articulation?
  - What are the resonance frequencies of those tubes?
  - Is there a Helmholtz resonance?

3. Predicting vowel formants

Perturbation theory

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Perturbation theory

- How do we predict vowel formants in this model?
  - Where are there constrictions in the vocal tract?
  - Do these raise or lower each formant as compared to [ə]?

3. Predicting vowel formants

- Use the perturbation "rules of thumb"
  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** _____.

- **Don't confuse** the **pressure** wave and the **velocity/displacement** wave!
  (review: "Standing Sound Waves", D. Russell, Penn State)

3. Predicting vowel formants

- Use the perturbation "rules of thumb"
  1. If there is a narrowing in the vocal tract near a velocity/displacement antinode = **pressure node**, the **formant frequency goes DOWN**.
  2. If there is a narrowing in the vocal tract near a **pressure antinode** (velocity/displacement node), **formant frequency goes UP**.

- **Don't confuse** the **pressure** wave and the **velocity/displacement** wave!
  (review: "Standing Sound Waves", D. Russell, Penn State)

3. Predicting vowel formants

- How do **traditional vowel properties** relate to **formants**?
  - **F1** correlates *inversely* with **height**
  - **F2** correlates *inversely* with **backness**, as long as (**non-low**) back vowels are **round**
    - Why is F2 low in [a] by perturbation theory?
    - Why is F2 low in [u] by perturbation theory?

    → Different reasons!

4. Research questions and hypothesis testing

- Lab #06: What do we predict, and why?
- How can we present our results to answer this question?