1. Introduction

Segmental representation
- Encodes spatial and temporal dimensions.
  - Spatial: how and where constrictions are formed in the vocal tract.
  - Temporal: sequencing, simultaneity, and partial overlap of constriction actions.

Questions:
- What kinds of segmental and sub-segmental temporal relations are needed in phonological representation?
- If temporal structure is enriched, what are the consequences for hierarchical structure below the syllable, such as
  - Segments and their internal structure
  - What gives rise to weight units?

1. Introduction

Classic root and feature based approach

<table>
<thead>
<tr>
<th>Root</th>
<th>Temporal: Sequencing, overlap</th>
</tr>
</thead>
<tbody>
<tr>
<td>[F]</td>
<td>Spatial: Constriction formation</td>
</tr>
</tbody>
</table>

- Phonological features are locus of spatial structure
- Root nodes are locus of temporal structure

Temporal organization is a relation among roots, not features.
1. Introduction

Classic view: Segment structure

- **Temporal dimension: Classic root-based approach**
  - Each segment has a root node.
  - Linear sequence of roots provides frame for **temporal sequencing** of features.
  - Within a single root node, features are not ordered.
    (e.g. Goldsmith 1976, Clements 1985, Sagey 1986, Lombardi 1990)

- **Weight dimension: Moraic approach**
  - Moras represent units of **weight** in a syllable.
  - Root nodes may be organized under moras to signify a segment’s weight contribution.
  - Segments that are not weight-contributing are not dominated by a mora (or they share a mora).
    (Hyman 1985, McCarthy & Prince 1986 et seq., Hayes 1989)

Road map

Sec. 2. Phonotactics involving rhotics in General American English
Sec. 3. Background: Bimoraic /ɹ/ 
Sec. 4. Real-time MRI data
Sec. 5. Analysis of temporal structure and implications
Sec. 6. Alternatives and closing
2. Phonotactics in English rimes

- **General American English (GenAm):** Typified by rhotic English varieties spoken in regions of U.S. midwest and west U.S (Wells 1982).
- GenAm tense/lax distinction corresponds to a quantity distinction.
  - Tense Vs and “true” diphthongs are 2µ
  - Lax Vs are 1µ (Halle & Mohanan 1985, Hammond 1997)
- Coda Cs are 1µ.

\[ \text{pep} \quad \text{camp} \quad \text{keep} \quad \text{*keemp} \]

---

2. Phonotactics Involving Rhotics in English Rimes

Special status of final coronal obstruents.
- Final coronal obstruents can be non-moraic in a syllable appendix (Sherer 1994).
- ‘Complex coda’ refers here to codas without a final coronal obstruent.

\[ \text{glimpse} \]

---

2. Phonotactics in English rimes

**GenAm syllable template predictions:**

*Only lax vowels before a complex coda.*

- Illustration with [m] and [l]; generally true of most coda Cs

Pronunciations after Hammond (1999) and CMU Pronouncing Dictionary (Weide 1995 with edits by Hayes). Words appearing in multiple cells are reported as having variants. Note: /e/, /o/ realized as [eɪ], [oʊ]
2. Phonotactics in English rimes

- No tense/lax vowel contrast before simple coda /ɹ/.
- Diphthongs attested before simple coda /ɹ/, but notJC coda.
- Only [a] and [ɔ] before JC coda.

<table>
<thead>
<tr>
<th>/ɹ/ - monophthongs</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVj0: peer pair</td>
</tr>
<tr>
<td>CVjCj: bar bore poor</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>/ɹ/ - diphthongs</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVj2: aɪ au ei</td>
</tr>
<tr>
<td>CVjCj: pyre our</td>
</tr>
</tbody>
</table>

Assumption: words like perk contain a long rhotic vowel or syllabic [ɹ] rather than a Vɹ sequence (Ladefoged & Maddieson 1996).

2. Phonotactics in English rimes

- Neutralization of tense/lax contrast before /ɹ/ suggests coda /ɹ/ is bimoraic.
- Implies that vowels in neutralizing contexts are short (lax).
- But if coda /ɹ/ is bimoraic
  1. Why do rimes with anJC (park, farm) and əJC (pork, form) not exceed the syllable template?
  2. Why can only /a/ and /ɔ/ precede an JC coda?
  3. Why are syllables with a diphthong plus simple /ɹ/ coda acceptable? (e.g. fire, hour)

3. Background: Bimoraic /ɹ/

Overview: Articulatory reasons for bimoraic /ɹ/

1. Coda /ɹ/ in GenAm involves a sequence of two lingual constrictions
   - **Coronal**: Tongue body raising
   - **Pharyngeal**: Tongue root retraction
   - Pharyngeal constriction precedes coronal constriction in coda.
     (Campbell et al. 2010 on NorthAm English /ɹ/; Gick et al. 2006 on Mandarin /ɹ/)
3. Background: Bimoraic /ɹ/

Overview: Articulatory reasons for bimoraic /ɹ/

2. /ɹ/ in GenAm has high coarticulatory dominance

- **Coarticulatory dominance** = degree of coarticulatory resistance and aggressiveness of a segment. (Recasens et al. 1997, Recasens & Rodriguez 2016)
- A consonant with higher coarticulatory dominance has greater effect on a neighboring vowel.
- To preserve contrasts in quality of a neighboring V, /ɹ/’s lingual articulations are phonologically organized in sequence to a non-retracted vowel rather than overlapping it. (Walker & Proctor 2013, Walker et al. 2016)

![Diagram of articulatory space](from Walsh Dickey 1997)

3. Background: Bimoraic /ɹ/

Phonological representation fitting with characteristics of /ɹ/

- **Gestures** are sub-segmental phonological units specified for
  - Articulator (e.g. lips, tongue tip, tongue body, velum)
  - Goal articulatory state (e.g. lip closure, tongue tip closure at alveolar ridge, open velum)
  - Blending strength (correlates with coarticulatory dominance) (Browman & Goldstein 1986 et seq., Saltzman & Munhall 1989, extensions in generative phonology by).

- **Temporal structure**: Two temporal relations for gestures
  - **Synchronous**: Simultaneous onset of gestures
  - **Sequential**: Onset of following gesture sequenced with release or offset of preceding gesture.

3. Background: Bimoraic /ɹ/

Root-based temporal structure

- If roots are the basis for temporal structure over sub-segments, and each segment has a single root, within-segment ordering over spatial elements is not predicted.
- Ex: traditional feature-geometric representation of a rhotic does not represent sequencing of its sub-segments. (See also Scobbie & Pouplier 2010)

3. Background: Bimoraic /ɹ/

Gestures in phonological grammar

- Temporal structure over gestures is constrained by grammar.

Coda weight

- A mora may be assigned for each gesture sequenced after a head vowel gesture in a syllable (= WEIGHT-BY-POSITION). (Browman & Goldstein 2000, Nam 2007; on concept of V and C head gestures see Gafos 2002 and Smith in prep.)
3. Background: Bimoraic /ɹ/

Link between moras and gesture sequencing in GenAm /ɹ/

- Sequential lingual constrictions (pharyngeal > coronal) in coda /ɹ/ executed over two moras.
- Predicts neutralization of V quantity distinction in rimes with /ɹ/.

\[ /ɪɹ/ \text{ ear} \]

\[
\begin{array}{ccc}
\mu & \mu & \mu \\
| & | & |
\end{array}
\]

\[ 1\text{-TB} \rightarrow 1\text{-phar} \rightarrow 1\text{-cor} \]

*Key: Sub-segments*

- 1-TB = tongue body constriction of /ɪ/
- /ɹ/-phar = tongue root retraction of /ɹ/
- /ɹ/-cor = tongue body raising of /ɹ/

Dashed arrow represents sequential relation

---

3. Background: Bimoraic /ɹ/

*Summing up:*

Gestural phonology approach enables implementation of insights about the sequential production of bimoraic /ɹ/ in GenAm, and its neutralizing effect on quantity (tense/lax) contrast in a preceding vowel.

---

4. Real-time MRI Study

*Some of our questions*

If coda /ɹ/ is bimoraic

1. Why do rimes with \( 
\begin{align}
& \text{sC (park, farm)} \quad \text{and} \\
& \text{sC (pork, form)}
\end{align}
\) not exceed the syllable template?

2. Why can only /a/ and /o/ precede an /s/ coda?
4. Real-time MRI study

**Real-time MRI technique**
(Narayanan et al. 2004)
- Entire vocal tract imaged in midsagittal plane.
- New complete image acquired every 80 msec, reconstructed as 23.2 frame/sec video (Bresch et al. 2008).
- Synchronized noise-reduced speech audio recording (Bresch et al. 2006).

[Image of MRI study]

http://sail.usc.edu/span/

4. Real-time MRI study

**Articulatory speech production study**

**Aim:** Investigate tongue shape during rhotics and vowels.
- Four native GenAm speakers (3 F, 1 M; pilot with 3 M).

**Stimuli**
- CVC words: /ʃ/ in onset or coda, non-liquid Cs are labial/labiodental
  - Exx: reap, rip, beer, bare, rob, bar
- All phonotactically possible vocalic environments
- Real words of English where possible
- Target words elicited 5 times in isolation (reps 2-4 analyzed)
  [Stimuli with /l/ and with liquids in additional contexts also acquired – analysis in progress.]

4. Real-time MRI study

**Vocal tract outline**
- Superimposed vocal tract outline generated by algorithm that automatically identifies air-tissue boundaries
- Manual correction where needed.
- Outline and semi-polar analysis grid (blue lines) form basis for analysis of articulations.
  (Proctor et al. 2010)

[Image of vocal tract outline]

Image frame at onset of closure for /ʃ/ in [əʃə] (pilot subject).

4. Real-time MRI study

**Identification of articulatory landmarks**
- Target frames hand-identified by analysts in each utterance.
- **Vocalic target:** Timepoint with maximally stable tongue dorsum at target posture.
- **Rhotic target:** Timepoint with maximally stable rhotic posture in acoustic interval for consonant.

[Image of articulatory tracking]

Articulatory tracking demo
4. Real-time MRI study

Vocal tract outlines

V target (green) and C target (blue)
(mean of 3 utterances)

4. Real-time MRI study: \(/\alpha/\) and V tongue shapes – F1

4. Real-time MRI study: \(/\alpha/\) and V tongue shapes – M1

4. Real-time MRI study: \(/\alpha/\) and V tongue shapes – F2

Some errors in edge tracking remain to be corrected here
4. Real-time MRI study: /ɹ/ and V tongue shapes – F3

<table>
<thead>
<tr>
<th>Posture</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>beer</td>
<td>'beer'</td>
<td>mean posture</td>
</tr>
<tr>
<td>bare</td>
<td>'bare'</td>
<td>mean posture</td>
</tr>
<tr>
<td>boor</td>
<td>'boor'</td>
<td>mean posture</td>
</tr>
<tr>
<td>bar</td>
<td>'bar'</td>
<td>mean posture</td>
</tr>
</tbody>
</table>

4. Real-time MRI study

**Summary**
- Less difference in tongue root stricture in [əɹ] and [ɔɹ] rhymes relative to other V̩ sequences.
- Among peripheral vowels, pharyngeal constriction for coda /ɹ/ most closely approximates that of non-high retracted [ə, ɔ].

4. Real-time MRI study: Connections to other varieties

**Affinities between /ɹ/ and non-high, non-front V̩s**
- Intrusive ‘r’ after [ə, ɔ, a] in many non-rhotic dialects of English.
- [j] or [w] inserted after high vowels.
- [j] the law is [lɔːɹiz]  
  the spa is [spaɹiz]
- [j] the key is [kiɹiz]  
  the pay is [perɹiz]
- [w] the zoo is [zuɹiz]  
  the show is [ʃuɹiz]

Data from Uffmann (2007). On intrusive /ɹ/ see Wells (1982), McMahon et al. (1994) and Krämer (2008); see Gick (1999) for an articulatory study and gestural analysis of liquid epenthesis.

- Old English ‘r’ before a C has a positionally determined reduction to “an [a]-like vocalized r” (Howell 1991: 53).

5. Analysis of Temporal Structure
5.1 Analysis of temporal structure

Proposal 1: Temporal structure in rimes with /ɹ/

- Temporal structure in rimes with /ɹ/ is sensitive to vowel quality.
- Pharyngeal constriction of /ɹ/ substantially overlaps with constrictions formation of highly similar vowels /ɑ, ɔ, (a)/.
- Such overlap does not occur for other peripheral vowels, which involve considerably distinct lingual shaping.
  - High coarticulatory dominance of /ɹ/ prevents its overlap with considerably distinct vowels, while maintaining vowel quality distinctions.

Proposal 2: Moraic contribution of /ɹ/

- Coda /ɹ/ variably maps to one or two moras, depending on the degree to which it can overlap with the nuclear vowel.

Questions

1. Why do rimes with /ɑɹC (park, farm) and /ɔɹC (pork, form) not exceed the syllable template?
2. Why can only /ɑ/ and /ɔ/ precede an J Coda?
3. Why are syllables with a diphthong plus simple /ɹ/ coda acceptable? (e.g. fire, hour)

- Insight gained from comparing temporal structure of syllables with coda /l/, which permit a richer range of vowel contrasts.

5.1 Analysis of temporal structure

Recall

- Neutralization of tense/lax contrast before /ɹ/ suggests that coda /ɹ/ is bimoraic, causing a preceding V to be short.

\[1\tilde{\text{ɪɹ}}\text{ı̈}*\text{ɪɹk}\]

5.1 Analysis of temporal structure

Weight-by-Position: A mora is assigned for each gesture sequenced after a head vowel gesture in a syllable.

Temporal structure of coda /l/:

- Dorsal retraction precedes Coronal tongue tip raising.
  (e.g. Sproat & Fujimura 1993, Browman & Goldstein 1995, Krakow 1999, Gick 2003)
- Coarticulatory dominance of GenAm [ɪ] < [ı] (encoded in blending strength). Lesser coarticulatory effect of /l/ on a preceding V.
- Hence, V-TB and I-dor can overlap and are not sequenced. Offset of each is coordinated to onset of I-cor, so /l/ adds only 1µ.

\[1\text{ɪ𝑙} \text{ɪ̈} \text{ɪɿ} \text{ɪɿ̈} \]
5.1 Analysis of temporal structure

• Long vowels are also possible with coda /l/, as are lax vowels before a complex IC coda.

\[
\begin{align*}
/1l/ & \rightarrow & \mu & \mu & \mu \\
| & \rightarrow & | \\
\text{i-TB} & \rightarrow & \text{l-cor} \\
\text{l-dor} & \rightarrow & \\
\end{align*}
\]

\[
\begin{align*}
/1k/ & \rightarrow & \mu & \mu & \mu \\
| & \rightarrow & | \\
\text{i-TB} & \rightarrow & \text{l-cor} \rightarrow \text{k-dor} \\
\text{l-dor} & \rightarrow & \\
\end{align*}
\]

5.1 Analysis of temporal structure

Diphthongs before coda /\i/ 

• Rimes with a “true” diphthong ([\ai], [\au]) and /\i/ expected to contain 4µ.

• In fact, speakers tend to rate words like fire and hour as 1.5 or 2 syllables in length (Lavoie & Cohn 1999, Cohn 2003, Cohn & Tilsen 2015).

• Other (C)V\i sequences usually judged as one syllable
  — Exx: peer, pear, par, pour
  — Vs that are lax or lack tense/lax contrast in this context plus /\i/

• Bimoraic representation of /\i/ is consistent with these patterns.
  — fire, hour would have an extra mora.
    (as proposed by Lavoie & Cohn 1999, Cohn 2003).
  — Monophthongs + /\i/ could conform with 3µ structure.

• Monophthong variants before /\i/ in American midland regions
  — fire [f\ai], tower [t\ar] or [t\au] (Wells 1982).

5.1 Analysis of temporal structure

Proposal: Special status of [\ai] and [\au]

• Like the temporal organization of coda /l/, the lingual retraction gesture of /\i/ can overlap /\a/ and /\e/.
  — /\i/ does not interfere in a neutralizing fashion with articulation of /\a/ and /\e/, due to similarity in their lingual retraction.

• As a result, coda /\i/ adds only 1µ to a syllable with /\a/ or /\e/.

\[
\begin{align*}
[\ai] & \rightarrow & \mu & \mu \\
| & \rightarrow & | \\
\alpha-\text{phar} & \rightarrow & \text{j-cor} \\
\text{j-phar} & \rightarrow & \\
\end{align*}
\]

\[
\begin{align*}
[\au] & \rightarrow & \mu & \mu & \mu \\
| & \rightarrow & | \\
\alpha-\text{phar} & \rightarrow & \text{j-cor} \rightarrow \text{k-dor} \\
\text{j-phar} & \rightarrow & \\
\end{align*}
\]

5.1 Analysis of temporal structure

Overlong syllables with coda /l/ 

• Some syllables with coda /l/ can also be rated as 1.5 or 2 syllables
  — Exx: peel, pale, pool, pile, owl, foil
  — Long Vs and diphthongs plus /l/

• Other (C)V\l sequences usually judged as one syllable
  — Exx: pill, bell, pal, pol, hull, pole, paul
  — Vs that are lax or lack a tense/lax contrast plus /l/

• In words rated as 1.5–2 syllables, /l/ behaves as potentially contributing 2µ.
5.1 Analysis of temporal structure

Connection to complex temporal structure of /l/

- Coda /l/ in GenAm involves a sequence of a dorsal gesture followed by a coronal gesture.
- Yet coda /l/ usually contributes 1µ, because its weaker level of coarticulatory dominance enables l-dor to overlap preceding V.
- In contexts where /l/ appears to potentially contribute 2µ, the nuclear vowel is or can be diphthongal, for some V as a realization of distinctive length:
  - [ii], [uw], [ei], [oi], [au], [oi]
- Glide portion of diphthong could be antagonistic to dorsal gesture of /l/, preventing overlap.
  - Antagonism in constriction degree, and for [i]/[j], in location of constriction.

Temporal structure for coda /ɹ/

- Within /ɹ/:
  - /ɹ-phar > /ɹ-cor
- V and /ɹ-cor: V-TB > /ɹ-cor
- V and /ɹ-phar: Coordination of V and /ɹ-phar is variable; depends on similarity. (For OT analysis: See appendix.)

Temporal structure for coda /l/

- Within /l/:
  - l-dor > l-cor
- V and l-cor: V-TB > l-cor
- V and l-dor: Coordination of V and l-dor is somewhat variable. Generally, l-dor may overlap preceding V, but it can be coordinated in sequence to a glide-final diphthong.

5.1 Analysis of temporal structure: Summary

Moraic structure

- Vowel gesture specified for one or two moras (short or long)
- Each gesture sequenced after V’s head gesture in rime gives rise to a mora.

Temporal relations involve partial segment behavior

- Gesture sequencing within a segment
- Crucial lack of sequencing of some gestures across segments

5.2 Implications for segments

Recall: Classic sub-syllabic hierarchical structure

Relation between gestural sequencing and moras

New claim: Weight by position is crucially non-segmental

- Gesture sequencing within a segment can give rise to µ (as in case of /ɹ-phar > /ɹ-cor in a word like beer).
- Partial overlap of segments due to lack of sequencing of some gestures may not give rise to µ (a-phar, /ɹ-phar in a word like bar).
5.2 Implications for segments

Where temporal structure resides
• Account of phonotactics presented in this talk relies on **temporal relations at gestural level**, not segmental level.
• Temporal role of root node insufficient and obviated. Shortcomings involve temporal structure **deployed over part of a segment**.

---

**Proposal**

Employ a gesture set-based approach to segment-hood

Eliminate root node

Inspired by set-based approach to feature classes (Padgett 2002) and other work that reduces segmental hierarchical structure (e.g. Steriade 1988, Hayes 1990).

---

5.2 Implications for segments

• Failure of node-based approach to partial feature class behavior:

<table>
<thead>
<tr>
<th>pul-un</th>
<th>*pul-lor</th>
<th>*pul-ler</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>Color</td>
<td>Color</td>
</tr>
<tr>
<td>[+back]</td>
<td>[+round]</td>
<td>[+back]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[+round]</td>
</tr>
</tbody>
</table>

- Set-based approach to partial feature class behavior
  - Feature class Color = def{[back], [round]}
  - SPREAD(Color):
    - For all features \( f \in \text{Color} \) in a prosodic word, if \( f \) is linked to any segment, it is linked to all segments.
    - For each \( f \in \text{Color} \) in the word, a violation is assigned for every segment to which that feature is not linked.

---

5.2 Implications for segments

Sets as an approach to partial group behavior
• Partial feature class behavior in Turkish (Padgett 2002).
• Class of Color features ([back], [round]) spreads in vowel harmony.
  - All members of class spread when target V is high.
  - Only [back] spreads when target V is non-high.
  - Spreading of [+round] to a non-high vowel is blocked by a general prohibition in Turkish native forms on \([o, ø]\) in a non-initial syllable.

<table>
<thead>
<tr>
<th>Stem</th>
<th>Gen. sg.</th>
<th>Nom. pl.</th>
<th>Gloss</th>
</tr>
</thead>
<tbody>
<tr>
<td>ip</td>
<td>ip-in</td>
<td>ip-ler</td>
<td>‘rope’</td>
</tr>
<tr>
<td>kiz</td>
<td>kiz-in</td>
<td>kiz-lar</td>
<td>‘girl’</td>
</tr>
<tr>
<td>jyz</td>
<td>jyz-yn</td>
<td>jyz-lar</td>
<td>‘face’</td>
</tr>
<tr>
<td>pul</td>
<td>pul-un</td>
<td>pul-lar</td>
<td>‘stamp’</td>
</tr>
</tbody>
</table>

High target Nonhigh target

---

5.2 Implications for segments

• Reduction of hierarchical structure
  - “Bottle-brush” structure; no feature-geometric nodes.

[+son] [-nasal]

[+high] Root [+voice]

[+back] [+round]

- In [pul-lun], all features of Color class can spread.
- In [pul-lar], only back feature of Color class can spread (due to prohibition on non-initial [o]).
- SPREAD(Color) favors the maximal spreading of Color features possible, while respecting prohibition on non-initial [o], favoring [pul-lar] over *[pul-ler]
5.2 Implications for segments

Proposal: Segments as gesture sets

• Take set-based approach to partial segment behavior.
  – Each segment composed of a set of gestures, no root node.
    (Possibility considered by Padgett 2002: 98-99)
• Input contains linear order over gesture sets.
• Output represents temporal coordination relations over gestures
  (synchronous, sequential) within and across segmental sets.
  – Enforced by phonological grammar.
  – Temporal coordination owing to input linear order over gesture
    sets is violable, with a violation computed for each gesture in
    the set.
  – Allows partial segment behavior in temporal dimension.

5.2 Implications for segments

Next steps
• Consider other segment-based phenomena in light of set-based
  approach
  Exx: Deletion, insertion, metathesis
  – Constraints driving these phenomena would target segment
    sets of gestures.
  – Full-segmental behavior represents full enforcement of relevant
    constraints.
  – Partial-segmental behavior also predicted; possibly phenomena
    like debuccalization, featural migration
  – Perhaps some phenomena previously analyzed as segmental
    could be analyzed as involving single gestures, such as
    epenthetic glottal stops and fricatives.

6. Alternatives and Closing
6.1 Alternatives

One-root, one temporal node
- Falls short for representing intra-segmental phonological sequencing.

Node-based intra-segmental sequencing
- Various proposals have been made to obtain within-segment sequencing of sub-segments via a sequence of structural nodes.
  - **Aperture Theory**: Sequences of aperture positions (closure and release) in stops (Steriade 1992, 1993a,b, 1994).
  - **Q-theory**: Segments as tripartite sequences of quantized subsegments (Shih & Inkelas 2014, Inkelas & Shih to appear).

6.1 Alternatives: Two-root approach
- Two-root analysis employs a sequence of two root nodes under a single skeletal position.
- This approach can represent temporal ordering *internal to a segment*.
- Applied to */ɹ/ and */l/ in GenAm codas:

  ![Diagram](image)

  - **[Pharyngeal]**
  - **[Coronal]**
  - **[Dorsal]**
  - **[Coronal]**

6.1 Alternatives

Node-based intra-segmental sequencing
- Problems presented by partial segment behavior involving coda liquid phonotactics:
  - Segments that are partially overlapped and partially sequenced with another segment
  - Computation of weight-by-position
- Issues illustrated here with two-root approach.

6.1 Alternatives: Two-root approach
- Capitalizing on its segment-internal sequencing, the bimoraic character of */ɹ/* would be attributed to its two-root structure.
- However, tying moraic structure to sequenced root nodes in the rime overpredicts bimoracity.
- Faulty predictions about some rimes with a coda liquid.
  - Why does */ɹ/* not pattern as bimoraic following */ɑ/* and */ɔ/*?
  - Why does */l/* not usually pattern as bimoraic?
6.1 Alternatives: Two-root approach

- Whether skeletal slots, roots or some other node identifies segments, spatial elements are ordered across segments.
- Fails to represent overlap between V and pharyngeal sub-segment of coda /ɹ/, and likewise between V and dorsal sub-segment of /l/, where non-sequence sub-segments belong to separate segments.

```
/ɑ/

x

root

[Pharyngeal]

[Coronal]

/ɹ/

x

root

root

[Pharyngeal]

[Coronal]

Spreading [Pharyngeal] from two-root /ɹ/ predicts it will remain bimoraic
```

6.1 Alternatives: Sonority-based moraicity

- Sonorant coda Cs can be moraic in some languages, in contrast to obstruents.
- Analyzed with constraint requiring a µ to dominate [+son] (Zec 1995).
- Could perhaps be adapted to GenAm rhotics to enforce bimoraicity over coda /ɹ/, as the most sonorant coda segment.

Problems
- **Empirical:** Fails to predict that moraic contribution of /ɹ/ will be sensitive to preceding vowel
  - Expect bimoraic /ɹ/ following /ɑ/ and /ɔ/.
- **Conceptual:** Misses connection to sequencing of lingual constrictions in coda /ɹ/.
  - Not clear why coda /ɹ/ must be bimoraic, while various more sonorant vocalic segments can be mono-moraic.

6.2 Closing: Representing temporal structure

- **Phonotactics** involving temporally complex coda liquids motivate representing temporal structure at level of sub-segments.
  - Two basic temporal relations: synchronous, sequential
  - Fits with gestures as representation of sub-segmental units
- **Root node** as locus of temporal structure fails to make appropriate predictions about temporal coordination and context-dependent moraicity of segments with sequential sub-segments.
- **Partial segment behavior** with respect to temporal organization of sub-segments within and across segments can be addressed by representing segments as gestural sets, rather than node-based.
- **Moraic structure** induced through weight-by-position is understood as based on sequencing among sub-segments, not a count over root nodes, or some other structural slots.
Appendix

Sketch of OT analysis of temporal structure of rimes with /ɹ/
(For fuller details, see handouts from mini-course)

- Sensitive to quality of nuclear vowel

Constraints

- **3μ**
  Assign a violation to every syllable with more than 3 moras

- **Seq-Vɹ**
  Assign a violation for any lingual retraction gesture of /ɹ/ that is not in a sequential temporal relation with an immediately preceding non-retracted head vowel gesture.

- **Weight-by-Position**
  Assign a violation to every gesture in a syllable that lacks an associated mora that is sequenced directly or by transitivity after a head vowel gesture.

---

### Appendix

Trimoraic structure for an [ɪ] rime: Bimoraic /ɹ/ and enforced short V

<table>
<thead>
<tr>
<th>/ɪːɹ-ɹ/</th>
<th>ear</th>
<th>3μ</th>
<th>WBP</th>
<th>Seq-Vɹ</th>
<th>Max-μ</th>
</tr>
</thead>
<tbody>
<tr>
<td>i-TB₁⁽³⁾ J-cor₂ J-phar₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>*</td>
</tr>
</tbody>
</table>

(= TB₁⁽³⁾ Pal Nar₁ TB Rais₂ TR Retr₃)

| | | | | | |
|---|---|---|---|---|
| a. | μ | μ | μ | i-TB⁻→ J-phar⁻→ J-cor |  |  | * |
| b. | μ | μ | μ | i-TB⁻→ J-phar⁻→ J-cor |  |  | *! |
| c. | μ | μ | μ | i-TB⁻→ J-phar⁻→ J-cor |  |  | *! |
| d. | μ | μ | μ | i-TB⁻→ J-phar⁻→ J-cor |  |  | *! |
**Appendix**

Trimoraic structure for an [aʊk] rime: /ɪ/ adds just one μ

<table>
<thead>
<tr>
<th>/ɑᵢːkᵢː</th>
<th>ark</th>
<th>a-phar₁ j-cor₂ j-phar₃ k-dor₃</th>
<th>3μ</th>
<th>Max-Seg</th>
<th>Seq-Vj</th>
<th>Max-μ</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. → [aʊk]</td>
<td>μ</td>
<td>μ</td>
<td>μ</td>
<td>a-phar→ j-cor → k-dor</td>
<td>j-phar→</td>
<td>μ</td>
</tr>
<tr>
<td>b. [aʊːk]</td>
<td>μ</td>
<td>μ</td>
<td>μ</td>
<td>μ</td>
<td>μ</td>
<td>a-phar → j-phar → j-cor → k-dor</td>
</tr>
<tr>
<td>c. [aʊː]</td>
<td>μ</td>
<td>μ</td>
<td>μ</td>
<td>a-phar → j-phar → j-cor</td>
<td>μ</td>
<td>*!</td>
</tr>
</tbody>
</table>