24.914
Language Variation and Change
Phonetic grammar and gradual change
Analyzing gradual phonetic change as grammar change

- As discussed earlier, if sound change is grammar change, it follows that sound change is regular
  - Phonology and phonetics govern the pronunciation of all words.
- But we didn’t spell out how to analyze gradual phonetic change as grammar change.
  - E.g. gradual fronting of [u] before coronals

Hawkins & Midgeley
2005, JIPA
Analyzing gradual phonetic change as grammar change

• As discussed earlier, if sound change is grammar change, it follows that sound change is regular.
  – Phonology and phonetics govern the pronunciation of all words.
• But we didn’t spell out how to analyze gradual phonetic change as grammar change.
  – E.g. gradual fronting of [u] before coronals.
• Gradual fronting of [u] cannot be analyzed as re-ranking Ident(back) with respect to *[+back][coronal].
  – It must be a result of a change in phonetic grammar.
• What does phonetic grammar look like?
Fronting of /u/ between coronals

- /u/ has a higher F2 (is fronter) between coronal consonants /dud/ than in a neutral context, e.g. /hu/.
Fronting of /u/ between coronals

• The magnitude of this fronting effect varies between languages
  – F2 in /dud/ - F2 in /(h)u/
• 4 speakers of each language, 2 male, 2 female.
• Also recorded words with /i/ between coronals (e.g. /tit/).
• All word spoken in segmentally matched carrier phrases.
• What is the difference between the phonetic grammars of these languages?

![Mean undershoot (Hz)]

<table>
<thead>
<tr>
<th>Language</th>
<th>Mean Undershoot (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>English</td>
<td>450</td>
</tr>
<tr>
<td>French</td>
<td>250</td>
</tr>
<tr>
<td>German</td>
<td>100</td>
</tr>
<tr>
<td>Hindi</td>
<td>200</td>
</tr>
</tbody>
</table>
Vowel fronting by coronals

- Similar results on English, French, German from Strange et al (2007).
Consonant-Vowel coarticulation

- F2 trajectory in a CVC sequence is a compromise between
  - achieving the F2 targets for consonants \((L_1, L_2)\) and vowel \((T)\)
  - avoiding fast movement between the two.

- Minimization of effort: movements with higher peak velocity are more effortful, other things being equal (Nelson 1983, Perkell 1997).
  - Peak velocity is proportional to displacement (e.g. Kent & Moll 1972)
  - Constraint: \(F2_C = F2_V\)
    - For convenience, this constraint is formulated in acoustic terms

\[
\begin{align*}
F2_{C1} & \quad \text{F2}\_\text{c1} \\
F2_C & \quad \text{F2}\_\text{c} \\
F2_V & \quad \text{F2}\_\text{v} \\
T & \quad \text{T} \\
L_1 & \quad \text{L1} \\
L_2 & \quad \text{L2}
\end{align*}
\]
Consonant-Vowel coarticulation

• The tongue body moves forward in anterior coronals (alveolars, dentals) to facilitate formation of the tongue tip constriction (Manuel & Stevens 1995, Öhman 1966).
  – Alveolar stops have high values for $L$
• So in a coronal-back V sequence the tongue body has to move from front to back.
  – High $L$ to low $T$
• Can result in undershoot of the target for the back vowel.
Consonant-Vowel coarticulation

• Given $T$ and $L_2$, select $F_{2v}$ and $F_{2c_2}$ so as to minimize violation of the following constraints (Flemming 2001):

  **MINEFFORT:** \[ F_{2c_1} = F_{2v}, \quad F_{2v} = F_{2c_2} \quad w_E(F_{2v} - F_{2c_n})^2 \]

  **IDENTV:** \[ F_{2v} = T \quad w_V(T - F_{2v})^2 \]

  **IDENTC(REL):** \[ F_{2c_1} = L_1 \quad w_C(L_1 - F_{2c_1})^2 \]

  **IDENTC(CLO):** \[ F_{2c_2} = L_2 \quad w_C(L_2 - F_{2c_2})^2 \]

  - $F_{2c_2}$ is $F_2$ measured at the closure of $C_2$
Consonant-Vowel coarticulation

- Unfortunately we could not make comparable measurements of $F_{2c1}$ across languages because C1 differed in VOT, so we will model the VC transition, using just three constraints
  - Or equivalently: we will assume $L_1=L_2$ and $w_{C1}=w_{C2}$

  **MINEFFORT:** $F_{2v} = F_{2c2}$ \[w_E(F_{2v}-F_{2c2})^2\]

  **IDENTV:** $F_{2v} = T$ \[w_v(T-F_{2v})^2\]

  **IDENTC(CLO):** $F_{2c2} = L_2$ \[w_{C2}(L_2-F_{2c2})^2\]
Consonant-Vowel coarticulation

- Given $T$ and $L_2$, select $F_{2V}$ and $F_{2C_2}$ so as to minimize violation of the following constraints:
  
  **MINEFFORT:** $F_{2V} = F_{2C_2}$ \quad $w_E(F_{2V} - F_{2C_2})^2$

  **IDENTV:** $F_{2V} = T$ \quad $w_V(T - F_{2V})^2$

  **IDENTC(CLO):** $F_{2C_2} = L_2$ \quad $w_{C_2}(L_2 - F_{2C_2})^2$

- These constraints conflict where $T$ and $L$ differ
- Resolving conflict: minimize summed constraint violations
  \[
  H = w_E(F_{2V} - F_{2C_2})^2 + w_V(T - F_{2V})^2 + w_{C_2}(L_2 - F_{2C_2})^2
  \]
  
  - $w_i$ are positive weights
CV coarticulation - analysis

- Optimal values for $F2_C$, $F2_V$ as a function of $L$, $T$:

$$F2_C = -u_c(L - T) + L$$

$$F2_V = u_v(L - T) + T$$

$$u_c = \frac{w_e w_v}{w_e w_c + w_v w_c + w_e w_v}$$

$$u_v = \frac{w_e w_c}{w_e w_c + w_v w_c + w_e w_v}$$

- The interval between $L$ and $T$ is divided into three parts by $F2_C$ and $F2_V$
  - C undershoot
  - V undershoot
  - transition

- In the proportions $w_e w_v:\ w_e w_c:\ w_v w_c$
Typological variation

• The constraints are universal, but their relative weights may vary.
• $L$ and $T$ may vary across languages.
  – Assume that these require an independent analysis - e.g. optimization of inventory of contrasting segments.
• Apply this line of analysis to the differences between the languages in the study.
  – Need to estimate $T$, $L_2$ and the constraint weights for each language
Applying this analysis to the /u/-fronting data

- Estimate vowel target $T$ from realization of /u/ in the ‘neutral’ context (e.g. [hu], [u]).
- $T$ for /u/ is substantially higher in English than in the other languages:

<table>
<thead>
<tr>
<th>Language</th>
<th>Target of /u/ (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>English</td>
<td>1079</td>
</tr>
<tr>
<td>French</td>
<td>786</td>
</tr>
<tr>
<td>German</td>
<td>755</td>
</tr>
<tr>
<td>Hindi</td>
<td>736</td>
</tr>
</tbody>
</table>
Estimating $L$

- The model correctly derives the generalization that, for a given $C$, $F2_C$ is a linear function of $F2_V$
  \[
  F2_C = \frac{w_E}{w_C+w_E} F2_V + \frac{w_C}{w_C+w_E} L
  \]
  
- $L$ is the value of $F2_C$ where it equals $F2_V$
Estimating $L$

- Locus of coronal C2 differs substantially between the languages:
  
<table>
<thead>
<tr>
<th>Language</th>
<th>Locus of C2 (Hz)</th>
</tr>
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<tbody>
<tr>
<td>English</td>
<td>2192</td>
</tr>
<tr>
<td>French</td>
<td>2086</td>
</tr>
<tr>
<td>German</td>
<td>1793</td>
</tr>
<tr>
<td>Hindi</td>
<td>1690</td>
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Estimating constraint weights

- Given L we can calculate C undershoot.
- Languages differ in the absolute and proportional values of C2 undershoot, V undershoot and size of F2 transition from V to C2.
- In terms of the constraint-based analysis, the differences in proportions correspond to differences in the constraint weights.
- C undershoot $w_{V}w_{E}$ : Transition $w_{C}w_{V}$: V undershoot $w_{C}w_{E}$
Cross-linguistic variation in constraint weights

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<tr>
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<th>$w_E$</th>
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<tr>
<td>English</td>
<td>0.26</td>
<td>0.22</td>
<td>0.52</td>
</tr>
<tr>
<td>French</td>
<td>0.50</td>
<td>0.14</td>
<td>0.37</td>
</tr>
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<td>German</td>
<td>0.74</td>
<td>0.15</td>
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- It is the ratios of the weights that matter.
  - Set $w_V + w_C + w_E = 1$ to create a unique solution.
- These weights are calculated ignoring the contribution of C1, so $w_C$ and $w_E$ are overestimated.
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- French and German have higher values for $w_V$ - these languages contrast front [y] with back [u], English and Hindi do not.
  - Note that this difference is not apparent in the V undershoot measures.
  - According to the analysis, $V$ undershoot $= \frac{w_E w_C}{w_E w_C + w_E w_V + w_C w_V} (L - T)$
- Hindi has low V undershoot because $L$ is low in Hindi compared to the other languages.
- The system of vowel contrasts relates to $w_V$, not raw undershoot.
Cross-linguistic variation in constraint weights

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- German has a higher value for $w_V$ than French. German /y/ seems to have lower F2 than French /y/ (Strange et al 2007) - i.e. closer to /u/.
  - In our data: French 2124 Hz, German 1725 Hz
Cross-linguistic variation in constraint weights

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Possible reasons for weight differences:
- German has a much lower value of $w_E$ than other languages, but German /u/ was longer.
- For a given magnitude of movement, peak velocity is lower if movement duration is longer.
Sound change as grammar change

• Gradual change in the magnitude of vowel fronting can be analyzed as gradual change in constraint weights.
• But why do constraint weights change?

• Can word frequency effects arise if sound change is grammar change?