A Gradient Harmonic Grammar Account of Lexically-Conditioned Phonetic Variation

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Lexically-Conditioned Grammatical Patterns

• **Categorical:** Japanese phonotactics (Ito & Mester, 1999)
  – Nasal-voiceless obstruent clusters (*mp) banned only in Yamato stratum.

• **Variable:** Finnish (Anttila, 2002)
  – Variability: vowel mutation (a->o) vs. deletion.
  – Selection of mutation vs. deletion vs. variation is morpheme-specific.

• **Defining feature:** Non-gradient
  – Input: Conditioned by lexical *categories*.
  – Output: Alternations among *categorically distinct* variants.
Lexically-Conditioned Phonetic Variation

• **Lexical frequency/predictability**: High frequency/more predictable forms are *reduced* relative to low frequency/less predictable forms.
  - Shorter durations; more centralized vowels; elision/lenition (and->n; of->uh). (see Aylett & Turk, 2006, for a recent review)

• **Neighborhood density**: Words phonologically similar to many lexical items are *hyperarticulated* relative to words similar to few lexical items.
  - Vowels in high vs. low density words are less centralized in F1/F2 space
    • (Munson, in press; Munson & Solomon, 2004; Wright, 2004)
  - Similar effects for consonants.
Lexically-Conditioned Phonetic Variation

- Voiceless stops in words that have a minimal pair neighbor (e.g., cod-god) show enhanced VOTs relative to stops in phonetically matched words that do not (e.g., cop-*gop). (Baese & Goldrick, 2007)

![Graph showing VOT ratio for initial consonants p, t, and k with minimal pairs and no minimal pairs, with significance markers.](image-url)
Lexical and Phonetic Gradience

- Current grammatical accounts of lexical effects on sound patterns capture categorical phenomena.

- Understanding lexically-conditioned phonetic variation requires incorporating gradience.
  - Conditioning factors (frequency, density) are gradient.
  - Phonetic effects (vowel space dispersion; VOT expansion) are gradient.
Gradient Harmonic Grammar Account of Lexically-Conditioned Phonetic Variation

• Gradience of phonetics.
  – Output candidates allow for gradient activation.
  – (following Flemming, 2001; Gafos, 2002, and other work in Articulatory Phonology)

• Gradience of conditioning lexical factors.
  – Variation in activation of representations in the lexicon.
  – Focus: Neighborhood density.

• Lexically-conditioned phonetic variation
  – Constraint interaction in Gradient Harmonic Grammar is sensitive to gradient variation in activation of both input and output representations.
  – (see Gafos & Benus, 2006, for an alternative approach within a dynamical systems framework)
Gradient Lexical Factor: Neighborhood

Feedback activates lexical representation of neighbor. Non-target phonological representations become active.

Contrasting, highly similar segments compete for same position in string.

To resolve competition, target segment must grow in activation so as to inhibit competitor.

- Enhanced activation: Stronger input to Harmonic Grammar
  - Word without minimal pair neighbor: Weaker competition, so no need to enhance activation of input.

(Meyer & Gordon, 1985; Yaniv et al., 1990)
Harmonic Grammars

• Connectionist precursor to Optimality Theory
  – (Legendre et al. 1990; Smolensky & Legendre, 2006; see also Pater et al., 2007)

• Output of grammar is candidate with highest *harmony*.
  – Harmony = sum of weighted constraint violations.

<table>
<thead>
<tr>
<th>/g/</th>
<th>*[+voi]:−2</th>
<th>ID(voi):−1</th>
<th>HARMONY</th>
</tr>
</thead>
<tbody>
<tr>
<td>--&gt; [k]</td>
<td></td>
<td>−1</td>
<td>−1</td>
</tr>
<tr>
<td>[g]</td>
<td>−2</td>
<td></td>
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Graphical Depiction of Harmony Differences

Harmony Disadvantage

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Gradient Harmonic Grammars

• Representations: Gradient patterns of activation in range \{0,1\} over sets of symbolic representational units.

• Default activation levels: 0.1 / 0.9.
  – [+voi]: 0.9 Neutral articulation level for voiced
  – [+voi]: 0.99 Hyperarticulated voiced

• As in connectionist networks (Smolensky, 2006) Harmony reflects gradient activation levels.
  – *[+voi]: Weight: –1
  – Output: [+voi]:0.9 Harmony ≈ –1 * 0.90 ≈ –0.90
  – Output: [+voi]:0.99 Harmony ≈ –1 * 0.99 ≈ –0.99

• Critical factor for lexically conditioned phonetic variation: Gradience in input influences calculation of Harmony.
Calculating Harmony: Faithfulness

- Constraint: \textbf{ExpressVoice: Weight} = -4.1
  - Penalizes outputs that do not maximally express input.
  - Following example above (cop/cod) assume voiceless input.

- Harmony contribution:
  - Weight \ *
    - Constraint strength
    - \(1 - \text{activation of } [-\text{voi}]\) \ *
      - Prefers hyperarticulated to normal articulation level
    - Activation of /k/
      - Preference is stronger if input is more highly activated (e.g., cod vs. cop)
Calculating Harmony: Markedness

- Constraint: MinimizeEffort: Weight = –1
  - Penalizes outputs with high levels of activation.

- Harmony contribution:
  - Weight *
    - Constraint strength
    - (activation of [–voi]) *
      - Prefers normal articulation level to hyperarticulated
    - 0.9
      - General ‘bias value’ for markedness constraints
        (maintain symmetry with Faithfulness constraints)
Calculating Harmony: Unit Harmony

• Assumption: Neutral activation level is 0.9 / 0.1
  – NOT 1.0 / 0.0

• To enforce the neutral activation level: *Unit* harmony term
  – Penalizes outputs with extreme values.
  – Penalizes **both** 1.0 and 0.0
  – See Appendix D for details.
Weakly Activated Input -> Normal Articulation

- Although Faithfulness prefers hyperarticulated candidate, the combined influence of Markedness and Unit Harmony prevent it from being the most harmonic form.
- (see Appendix B for Tableaux)
Because harmony is weighted by activation of input, increasing the input’s strength increases the impact of Faithfulness.

Hyperarticulated form is now more harmonic.
Lexically Conditioned Phonetic Variation

- Because Harmony is sensitive to gradient activation levels, changes to the activation of input representations alters the harmony of output forms.
  - Neighbors increase activation of phonological representations in the lexicon.
  - Harmony contribution of Faithfulness constraints increases.
  - Can cause a hyperarticulated output representation to be more harmonic than one with normal articulation levels.
Implications for Theories of Phonetic Variation

• Above: Neighborhood density induces hyperarticulation
  – Expanded vowel space, enhanced VOTs.

• Neighborhood density also enhances *coarticulation*
  – E.g., greater nasalization on /ae/ in ‘ban’
  – Similar results for V-V coarticulation (Scarborough, 2003, 2004)
  – Not clearly predicted by simple hyperarticulation theory
    • In anticipatory nasalization, why are features of consonant hyperarticulated, rather than hyperarticulating properties of the target vowel /ae/?

• In Gradient Harmonic Grammar, this can be understood as a consequence of constraint ranking.
Case Study: Anticipatory Nasalization

• **Trigger** of nasalization: **Consonant** features
  – Phonetic realization of consonant reflects underlying nasality.
  – i.e., ExpressNasal > MinimizeEffort
  – Following above, causes hyperarticulation for words in dense neighborhoods.
Effect on Nasalization Target: Vowel Features

- Harmony contribution of faithfulness constraint (ExpressOral) increases due to enhanced activation of vowel input (see above).
- Harmony contribution of markedness constraint: \( *V[\text{oral}]N: \)
  - Weight \( * [1 – \text{activation of nasal feature on vowel}] * \)
  - Activation of nasal feature on consonant
    - Harmony contribution of markedness also increases due to hyperarticulation of nasal features on consonant.
- Both are strengthened; which dominates?
  - Because coarticulation is present:
    - \( *V[\text{oral}]N > \text{ExpressOral} \)
  - Same proportional strengthening of Markedness and Faithfulness will provide a greater numerical benefit to Markedness.
• Although Markedness prefers hyper coarticulation candidate, the combined influence of Faithfulness and Unit Harmony prevent it from being the most harmonic form.

• (see Appendix C for Tableaux)
• Increase in input increases impact of faithfulness, but also causes hyperarticulation of nasal—providing an even bigger numerical benefit to markedness.
Gradient Harmonic Grammar

• Incorporating gradience into grammar
  – Gradience in representations in both input (modulation by lexical factors) and output (phonetic variation).
  – Gradience at both levels influences constraint interaction.

• Provides an account of Lexically-Conditioned Phonetic Variation
  – Influence of lexical factors on expression of underlying features
  – Influence of lexical factors on coarticulation

• Gradient representations may provide a means to capture opaque process interactions (see Appendix A for discussion).
Thanks

• Sound Lab and Phonatics Discussion Group at Northwestern

• NIH DC00797 for support

• Talk slides, papers, posters…
  – http://ling.northwestern.edu/~goldrick
Appendix A: Implications for Theories of Opacity

• Variation in activation as a model of phonological opacity.
• ‘Counterbleeding’
  – Since harmony is determined by multiplying activations, partially activated structures can influence harmony.
  – Prediction: Phonetics should reflect partially activated structures.
    • See Benus & Gafos (2007): ‘Transparent’ vowels in Hungarian
• ‘Counterfeeding’
  – A weakly activated structure may have less of an influence on harmony than a strongly activated structure.
  – Prediction: Phonetics should reflect weakening.
    • See Gouskova & Hall (in press): Epenthetic vowels in Lebanese Arabic.
# Appendix B: Hyperarticulation Tableaux

Tableau B1. Input without minimal pair neighbor (e.g., cop)

<table>
<thead>
<tr>
<th>Weight</th>
<th>Express Voice</th>
<th>Minimize Effort</th>
<th>Unit Harmony</th>
<th>Total Harmony</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input with no minimal pair /k/: 0.9</td>
<td>-4.1</td>
<td>-1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-voiceless output [–voice]: 0.1</td>
<td>-3.321</td>
<td>-0.090</td>
<td>-1.104</td>
<td>-4.515</td>
</tr>
<tr>
<td>--&gt; Voiceless output [–voice]: 0.9</td>
<td>-0.369</td>
<td>-0.810</td>
<td>-1.104</td>
<td>-2.283</td>
</tr>
<tr>
<td>Hyperarticulated voiceless output [–voice]: 0.99</td>
<td>-0.037</td>
<td>-0.891</td>
<td>-1.373</td>
<td>-2.301</td>
</tr>
</tbody>
</table>
Appendix B: Hyperarticulation Tableaux

Table B2. Input with minimal pair neighbor (e.g., cod)

<table>
<thead>
<tr>
<th>Weight</th>
<th>Weight</th>
<th>Express Voice</th>
<th>Minimize Effort</th>
<th>Unit Harmony</th>
<th>Total Harmony</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input with minimal pair /k/:0.99</td>
<td>–4.1</td>
<td>–1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-voiceless output [–voice]:0.1</td>
<td>–3.653</td>
<td>–0.090</td>
<td>–1.373</td>
<td>–5.116</td>
<td></td>
</tr>
<tr>
<td>Voiceless output [–voice]:0.9</td>
<td>–0.405</td>
<td>–0.810</td>
<td>–1.373</td>
<td>–2.588</td>
<td></td>
</tr>
<tr>
<td>-- Hyperarticulated voiceless output [–voice]:0.99</td>
<td>–0.040</td>
<td>–0.891</td>
<td>–1.642</td>
<td>–2.573</td>
<td></td>
</tr>
</tbody>
</table>
Appendix C: Hyper Coarticulation Tableaux

Table C1. Input in sparse neighborhood (e.g., strand)

<table>
<thead>
<tr>
<th>Weight</th>
<th></th>
<th></th>
<th>Unit Harmony</th>
<th>Total Harmony</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input in sparse neighborhood /aen/:0.9</td>
<td>*V[oral]N</td>
<td>Express Oral</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No coarticulation [+nas]:0.1</td>
<td>–2.187</td>
<td>–0.090</td>
<td>–1.104</td>
<td>–3.381</td>
</tr>
<tr>
<td>--&gt; Normal coarticulation [+nas]:0.75</td>
<td>–0.608</td>
<td>–0.675</td>
<td>–0.867</td>
<td>–2.150</td>
</tr>
<tr>
<td>Hyper coarticulation [–voice]:0.9</td>
<td>–0.243</td>
<td>–0.810</td>
<td>–1.104</td>
<td>–2.157</td>
</tr>
</tbody>
</table>

Note: Candidates show [nas] of vowel. For all candidates, consonant [nas] = 0.9
Appendix C: Hyper Coarticulation Tableaux

Tableau C2. Input in dense neighborhood (e.g., band)

<table>
<thead>
<tr>
<th>Weight</th>
<th>–2.7</th>
<th>–1</th>
<th>Unit Harmony</th>
<th>Total Harmony</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input in dense neighborhood /ae/n/:0.99</td>
<td>*V[oral]N</td>
<td>Express Oral</td>
<td>Unit Harmony</td>
<td>Total Harmony</td>
</tr>
<tr>
<td>No coarticulation [+nas]:0.1</td>
<td>–2.406</td>
<td>–0.099</td>
<td>–1.642</td>
<td>–4.147</td>
</tr>
<tr>
<td>Normal coarticulation [+nas]:0.75</td>
<td>–0.668</td>
<td>–0.742</td>
<td>–1.405</td>
<td>–2.815</td>
</tr>
<tr>
<td>--&gt; Hyper coarticulation [–voice]:0.9</td>
<td>–0.267</td>
<td>–0.891</td>
<td>–1.642</td>
<td>–2.800</td>
</tr>
</tbody>
</table>

Note: Candidates show [nas] of vowel. For all candidates, consonant [nas] = 0.99
Appendix D: Unit Harmony Function

• From Movellan & McClelland (1993)

• For unit $i$ with activation $a_i = -[a_i \ln(a_i) + (1-a_i) \ln(1-a_i) - \ln(0.5)]$

• Total unit harmony is sum over all units
  – Including ‘bias’ unit for markedness constraints (e.g., 0.9 term in MinimizeEffort constraint)
References

References