Emergent feature structures

*Harmony systems in exemplar models of phonology*

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Exemplar Models

- Phonological structure emerges from generalizations over the phonetic detail of speech as experienced by a speaker-hearer
  
  (Bybee and Hopper 2001; Lacerda 2003; Lindblom 1999; Pierrehumbert 2003)

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Emergent syllables

- Structures defined over sequences of phone-level units (e.g., syllables) emerge from the statistical relationship between those units: transitional probabilities

  \[
  Vitevitch & Luce, 1999, 2004
  \]

Other emergent phonotactics

- Other phonological sequencing constraints can be modeled in a similar way:
  
  - High transitional probability between units (e.g., phones) that co-occur with statistical regularity
  
  - Low transitional probability between units that co-occur less frequently or not at all

No Structure, No Constraints

- Exemplar models posit no *a priori* formal or representational properties to the emergent phonological units or to the sound patterns that are defined over co-occurring units (Lindblom 1999).

- Any regularities in the sound patterns that occur across languages should follow from similarities in the phonetic substance underlying the sound patterns, and/or in the mechanisms for speech processing that are common to all speakers.

The generative tradition...

- The exemplar model perspective is in stark contrast to much of the research in the generative phonology tradition, where sound patterns are determined by well-formedness constraints on phonological structures.

- Feature structures for “segmental” processes

- Syllable structures for phonotactics

- Metrical structures for stress
Question for today

• What is the role of structural constraints in accounting for sound patterns in representational models such as generative phonology?
• Focus: Vowel Harmony

More questions

• Can harmony processes be modeled without recourse to a priori phonological structure?
• Are the structures that serve to characterize and constrain harmony processes emergent structures?

Preview of the argument

1. The generative model of harmony is a representational account based on feature structures which predicts uniformity across different kinds of harmony systems;
2. A typological study of harmony reveals non-uniformity;
3. Non-uniformities may have bases in speech processing and phonotactic learning;
   – suggests an evolutionary account, where harmony develops from phonetic precursor patterns of variation

Preview of the argument

4. Harmony can be modeled without feature structures in an exemplar model;
5. In exemplar phonology, the extended “feature structures” of harmony systems are emergent from associations between lexical categories and phone- and feature-level categories.

1. The Representational Model of Harmony

Harmony:
A phonotactic constraint that creates a dependency between two or more elements in a phonological domain.
Harmonizing elements must share the same specification for the harmonic feature.

[F]  \[X X X X X\]  adjacent elements
\[F\]  \[X X X X X Z Z Z Z\]  non-adjacent elements
**Turkish Back/Front Vowel Harmony**

<table>
<thead>
<tr>
<th>N. root</th>
<th>plural</th>
<th>accusative</th>
<th>gloss</th>
</tr>
</thead>
<tbody>
<tr>
<td>dal</td>
<td>-lar</td>
<td>-u</td>
<td>'branch'</td>
</tr>
<tr>
<td>kol</td>
<td>-lar</td>
<td>-i</td>
<td>arm'</td>
</tr>
<tr>
<td>kuyz</td>
<td>-lar</td>
<td>-u</td>
<td>daughter'</td>
</tr>
<tr>
<td>kul</td>
<td>-lar</td>
<td>-u</td>
<td>slave'</td>
</tr>
<tr>
<td>yel</td>
<td>-ler</td>
<td>-i</td>
<td>wind'</td>
</tr>
<tr>
<td>gül</td>
<td>-ler</td>
<td>-ü</td>
<td>sea'</td>
</tr>
<tr>
<td>dğ ul</td>
<td>-ler</td>
<td>-i</td>
<td>'tooth'</td>
</tr>
<tr>
<td>gül</td>
<td>-ler</td>
<td>-ü</td>
<td>rose'</td>
</tr>
</tbody>
</table>

Phonological theory provides a very general **representational** model of harmony as feature expansion.

Harmony is a special case of **assimilation**.

\[ \ldots F \ G \ldots \rightarrow \ldots F \ F \ldots \]

| i[n]- operable |
| i[m]- possible |
| i[n]-complete |

**Generalization over triggers**

- Any single feature can harmonize.

\[ [F] \]

\[ X \ X \ X \ X \ [F_1 X_1 X_1 X_1]_F \]

with spreading with feature domains

**Generalization over targets**

- All elements in the harmony path should participate in harmony. Failure is due to feature incompatibility and the "No Crossing" constraint

\[ [+F] \]

\[ X \ Z \ X \ Z \ X \]

\[ Z \text{ elements are not affected} \]

\[ \text{because they are phonetically incompatible with } [F], \text{ and they block further extension of } [F] \]

**Generalization over domain**

- The harmony domain is a morpho-syntactic or prosodic unit.

- **Harmony extends rightward/leftward from the 'trigger' to the end of the syllable, stress foot, or word.**

- **Mechanism:** constraints on "spreading" or on the alignment of the feature structure with word edges.

**Constraints on harmony?**

- Cross-linguistic regularities
  - Locality: "no skipping"
  - Domain alignment

- More are modeled directly through constraints on extended feature structures (or on the rules that create them).

- Co-harmonies: backness & roundness

- Restrictions on targets and triggers
Predictions

1. Any feature can spread from any segment: no asymmetries in triggers
2. All segments are targeted, subject to feature compatibility
3. The unmarked harmony process will spread the harmony feature (directionally) to the word edge.

Testing the Predictions

• Attested harmony systems are much more constrained than predicted by the phonological model.
  – the unmarked process is never observed!
• Evidence from typological studies:
  – Round harmony (Kaun 1995)
  – Lingual harmonies (Linebaugh 2007): Height vs. Backness harmony

2. Typological evidence

Non-uniformity of harmony systems

Lingual Harmonies (Linebaugh 2007)

• BH in Uralic (Finnish, Hungarian, Samoyed) and Altaic (Turkic, Mongolian, Tungusic)
  – All vowels participate*
  – Bidirectional (backing and fronting)
  – No morphological or prosodic limitations on triggers, targets;
  – Harmony operates within morphemes;
  – Harmony domain is the entire Word.

*Even 'neutral' vowels trigger harmony, and exhibit low-level coarticulatory variation.

Lingual Harmonies (Linebaugh 2007)

• BH elsewhere: Chamorro, Kera, Tunica, Macuxi, Wikchamni
  – Only a subset of vowels participate;
  – Targets are not also triggers (Dominant/Recessive harmony);
  – Morphological or featural limitations on triggers, targets;
  – Harmony is not characteristic of all or most words.

Lingual Harmonies (Linebaugh 2007)

• HH: Bantu, Romance, and others
  – Bidirectional harmony is rare. Many cases of lowering only, raising only, or both systems in the same language;
  – Complete or partial height assimilation;
  – Asymmetrical triggering effects of front and back vowels in HH;
  – HH may or may not extend to prefixes, affixes.
3. Sources of asymmetry across harmony systems

Speech Processing
Phonotactic Learning

Constraints on speech production

- Asymmetries between backness and height harmonies are also observed in speech production (Linebaugh & Cole 2005)
  - Behavioral evidence
  - Acoustic evidence

Speeded Production Experiments: Spanish


Hypothesis: vowel harmony facilitates production through the priming of features between harmonizing elements.

Method: Self-paced, speeded repetition (4 sec.) of a phrase consisting of two CVCV nonsense words in one of three vowel harmony conditions with the vowels /i,e,o,u/. C = {b,t,k}

Example trials:
HH: "bibu la bobo"
BH: "teti la tuto"
DD: "koki la keku"

Speeded Production Experiments: Spanish


HH: height harm., back disharm. i-u, u-i, e-o, o-e
BH: height disharm., back harm. i-e, e-i, u-o, o-u
DD: height disharm., back disharm. i-o, o-i, u-e, e-u

Speeded Production Experiments: Spanish

12 Wd-1 sequences * 3 Wd-2 sequences * 3 Cs = 108 phrases

Subjects: 20 UIUC graduate students (11 F, 9 M), L1 Spanish (10 from Spain, 9 from S. America); ages 21-40.

Coding: subject responses were recorded and later coded for rate (syll/sec) and errors (production of incorrect V). A subset of the data (400 trials, 8 subj.) was coded by a 2nd coder, with 92.5% agreement.

Results: Repeated-measures ANOVA shows significant effect of harmony condition on number of errors (F(2,38)=11.6, p<.001), but no effect on rate.
Tukey post-hoc: BH < DD, HH

Speeded Production Experiments: Korean

Oh & Cole 2006; in prep.

A replication of the Spanish study, with the same vowels, and the tense consonants /pp,tt,kk/.

108 phrases: CVCV nín CVCV

20 subjects (L1 Korean)

Results: similar to Spanish findings!
- Significant effect of harmony condition on number of errors (F(2,38)=10.19, p<.001). No effect on rate.
- Tukey post-hoc: BH < DD, HH
Speeded Production Experiments: English

Cole & Khasanova 2002

A replication of the Spanish study with the same vowels, and the consonants /b,g,k/.

Only the BH condition was tested. The diphthongization of the tense, mid vowels [ej, ou] renders all "mid" vowel sequences height-variable.

96 trials (48 BH, 48 D); 24 subjects (English monolinguals)

Results: Two-tailed t-tests show significant effect of BH on error rates for all consonants: /b/ (t=1.721, p<0.05), /k/ (t=3.089, p<0.01) and /g/ (t=1.877, p<0.05). No significant effect of harmony on speech rate across consonants.

Summary: Production studies

Results from 3 languages show a facilitative effect of Back Harmony on fast speech production, with no corresponding effect on Height Harmony.

Why the asymmetry?

Possible differences between BH and HH in:

Coarticulation
Articulatory complexity

V-to-V coarticulation: acoustic evidence

Prior studies establish significant effects of adjacent vowel context on V quality, as measured by variation in F1, F2. Fowler 1981, Beddor et al. 2002

V-to-V coarticulation appears to condition greater variability in F2 compared to F1, suggesting articulatory accommodation in the back/front dimension more than in the height dimension.

Is the degree of coarticulation correlated with the facilitative effect on speech production?

Acoustic studies of V-to-V coarticulation

Evidence from the Spanish speeded production data

Linebaugh & Cole, in prep.

• Vowels from the first repetition of “CVCV la CVCV”
• 108 tokens each of /i,e,o,u/ (36 tokens in each harmony context)
• 6 speakers
• measurements: F1, F2 (Bark)

Acoustic studies of V-to-V coarticulation

Evidence from English real word production

Cole, Linebaugh, McMurray & Munson, 2007

• 9 speakers
• Measurements are taken from V1 in the context of V2 in word strings: CV1C # CV2C

  I love "mud eater" as a title.

  She said "tech oxygen" all the time.

• F1, F2 (Hertz) values are measured for /i,e,u,o/ using Praat (Burg algorithm).
Acoustic studies of V-to-V coarticulation
Evidence from English real word production

Cole, Linebaugh, McMurray & Munson, 2007

Results:
• Data pooled across all 9 speakers
• Across all the V2 contexts, F2 is more variable than F1.
• The pattern of V1 variation in F1 and F2 is predicted by coarticulation with V2.

Summary: Acoustic studies (1)

Acoustic measures of F1, F2 provide evidence of V-to-V coarticulation in Spanish and English.

F2 is in general more variable than F1.
F1 and F2 variation is predicted from coarticulation with the vowel in the adjacent syllable.

Summary: Acoustic studies (2)

The asymmetry in F1 and F2 variation as a function of coarticulation mirrors the asymmetry in the speeded production experiment:
V-to-V coarticulation:
  F2 variation > F1 variation
  back coarticulation > height coarticulation
Speeded production:
  BH facilitation > HH facilitation
Implications: perceptual evidence for BH may be more robust, less variable.

Evidence from phonotactic learning

Evidence for implicit learning of Consonant and Vowel Harmony patterns based on brief auditory experience with an artificial language (adult subjects).

Measures of reaction time in speeded repetition tasks reveal asymmetries in learning. There is a bigger benefit from learning for harmony constraints that restrict perceptually similar sounds.
A learning advantage for phonotactic constraints that reduce perceptual confusability.

Interim Summary

• The representational model of harmony makes the wrong predictions about the uniformity of harmony for different harmonizing features.
• Asymmetries observed in a typological study may have bases in processes of speech processing (production, perception) and phonotactic learning.
• Is there a better model? Do we still need extended feature structures for harmony?

4. Harmony in exemplar phonology
- a proposal
Coarticulation, then Harmony

- Harmony develops as a phonotactic constraint from patterned coarticulation
  - due to patterns of articulator coordination (gesture overlap, spatial reduction or enlargement of gestures).
- The generally local nature of harmony (no skipping) follows from its basis in coarticulation.

Harmony as a statistical pattern

- The co-occurrence patterns of harmony systems can be modeled in the transitional probabilities between segments that share the harmony feature (Newport & Aslin 2004)

Turkish: A very simple model

High transitional probabilities between vowels that share the backness property. [All vowel pairs are linked bi-directionally; not all transitions are shown]

Low transitional probabilities between vowels that differ in backness. [All vowel pairs are linked bi-directionally; not all transitions are shown]

Resonance (Grossberg 1986)

As the speech input is processed, there is activation of phonetically similar phone- and feature-level units stored in the exemplar lexicon.

Activation travels from these units “up” to the word-level units that include the sounds.

The up-and-down pattern of activation between sound-level units and word-level units is called Resonance.

A pattern of strong resonance between a specific word unit and a set of activated sound-level units results in the identification of the word.
Resonance in Turkish: very simply

Resonance relates a Word to a set of sound units

...and derives harmony vowel classes over the lexicon

Activation of a harmonic family

The harmony domain...

The links between between the WORD and one harmonic sound category produces strong activation as the analog of multiple association
Future Research

• Test generalization of sound pattern over the Word domain in an implementation.
  – Koo (2007, UIUC PhD) implemented a Simple Recurrent Network that can learn harmony patterns, and tested the role of perceptual confusability in the learning task.

• Define the mechanism for the development of a stable phonotactic pattern from patterned phonetic variation
  – In progress, with Bob McMurray (U Iowa)