The evolution of phonotactic distributions in the lexicon

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Workshop on Variation, Gradience and Frequency in Phonology
Stanford, July 8, 2007
Multiple levels of representation:
phonology and phonetics are separate but connected

- Semantic representations
- Phonological representations
- Phonetic representations

- ‘meaning’
- |underlying form|
- /surface form/
- [auditory form]
- [articulatory form]

- Lexicon
- Phonetics-phonology interface
Multi-level bidirectionality: local connections

‘meaning’

lexical constraints

|underlying form|

faithfulness constraints

/surface form/

structural constraints

cue constraints

[auditory form]

sensorimotor constraints

[articulatory form]

articulatory constraints


(bidirectionality by: Smolensky 1996; Tesar 1997; Boersma 1998, 2005)
Parallel multi-level bidirectionality: local connections but global evaluation

The task of the listener: comprehension

The task of the speaker: production

‘meaning’

|underlying form|

/surface form/

[auditory form]

[articulatory form]

(multi-level parallelism by: Boersma 2005; Apoussidou 2007)
Previous simulation result 1 (Boersma & Hamann 2007): emergent auditory dispersion without teleological devices

If acquisition optimizes the ranking of cue constraints for *comprehension*, then in *production* these same cue constraints (with the same rankings) will lead to a repulsive force between the phonological elements in auditory space. Within several generations, this will lead to a stable balance between auditory contrast and articulatory ease.

Required for this to work: bidirectionality (OT/HG).
Previous simulation result 2 (Boersma 2006): emergent markedness without markedness constraints

**If** acquisition optimizes the ranking of cue and faithfulness constraints for *comprehension*, **then** faithfulness will end up being ranked higher for infrequent than for frequent phonological elements. In *production* this leads to a differential phonological activity of these elements (e.g. [lab] > [cor]; [+round] > [–round]).

Required for this to work: bidirectionality & parallelism (OT/HG).
Previous simulation result 3 (Boersma 2006): emergent licensing-by-cue and positional faithfulness

If acquisition optimizes the ranking of cue and faithfulness constraints for comprehension, then faithfulness will end up being ranked higher for phonological elements with good than for those with poor auditory cues. In production this leads to differential phonological activity: plosive place > nasal place. No P-map required.

Required for this to work: bidirectionality & parallelism (OT/HG).
Today we go all the way up: lexical selection in OT/HG

(separation of meaning and underlying form: Apoussidou 2007)
1. Perceptual merger in reanalysis

The first source of lexical skewings is obvious in any (not necessarily parallel) bidirectional multi-level model, namely, innocent misapprehension (e.g. Ohala 1981, Blevins 1994). Well, it is obvious only in a model with multiple levels (it requires at least the auditory, surface, and underlying forms).

Example:

Auditory [æ] and [ɒ] are closer together than [ɛ] and [ɔ]. They may be so close together that a child cannot hear them apart. She will then assign them to the same category, say /a/.

This selective merger will lead to vowel inventories with fewer place distinctions for low than for mid vowels.
1. Perceptual merger in reanalysis: the parent

<table>
<thead>
<tr>
<th>Comprehension</th>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘horse’</td>
<td>‘horse’</td>
</tr>
<tr>
<td></td>
<td>‘river’</td>
</tr>
<tr>
<td>/æ/</td>
<td>/æ/</td>
</tr>
<tr>
<td>[æ]</td>
<td>[æ]</td>
</tr>
<tr>
<td>#æ#</td>
<td>#æ#</td>
</tr>
<tr>
<td>#ɒ#</td>
<td>#ɒ#</td>
</tr>
</tbody>
</table>


1. Perceptual merger in reanalysis: the child

<table>
<thead>
<tr>
<th>Comprehension</th>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘horse’</td>
<td>‘horse’</td>
</tr>
<tr>
<td></td>
<td>‘river’</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>[æ]</td>
<td>[a]</td>
</tr>
<tr>
<td>[a]</td>
<td>[a]</td>
</tr>
<tr>
<td>[a]</td>
<td>[a]</td>
</tr>
</tbody>
</table>

‘horse’ /a/ ‘river’ /a/
1. Perceptual merger in reanalysis: evolution

<table>
<thead>
<tr>
<th>æ</th>
<th>ð</th>
<th>a</th>
<th>a</th>
</tr>
</thead>
</table>

Speaker generation 1 100% 0%
Speaker generation 2 0% 100%

<table>
<thead>
<tr>
<th>æ</th>
<th>ð</th>
<th>a</th>
<th>a</th>
</tr>
</thead>
</table>

Population generation 1 80% 20%
Population generation 2 60% 40%
Population generation 3 40% 60%
Population generation 4 20% 80%

Ultimately, this leads to underlying forms that connect to:
auditory forms that contrast well with others

(by merger, not by chain shift; cf. De Boer 1999, Oudeyer 2006)
2. Lexical and cue (and/or faithfulness) constraints

Example:

Proto-Indo-European had two underlying forms meaning ‘water’, namely |#wodr#| and |#akʷa#|.

In Proto-Germanic, regular phonological sound changes changed these into |#watr#| and |#a:#|.

The increased difficulty of mapping an utterance-internal auditory [a:] to the meaning ‘water’ in comprehension will lead (at least in a bidirectional model) to a bias against choosing the underlying form |#a:#| in production. This bias may overcome any lexical preference for |#a:#| if evaluation is parallel across multiple levels.
2. Lexical and cue constraints: vertical tableau

The solid lines depict the optimal path both in OT (minimize maximum problem) and in HG (minimize sum of problems).
2. Lexical and cue (and faith) constraints: acquisition

The shift under discussion is most likely to occur in languages where most words start with a consonant (a fact that itself can be explained if syllables are costly) and where most word boundaries are realized as syllable boundaries.

Children who grow up in such an environment will rank high two constraints (both ranked at ‘10’ on slide 14):

1. the cue constraint *[CV]/C.V/ (Cornulier 1981);
2. the ‘faithfulness’ constraint /./[#]

Illustration: in French, ‘water’ is still |#o#|. But in French the constraint /./|#| is ranked low, because that is required by the independent processes of liaison and elision.
2. Lexical and cue constraints: evolution

Learners who optimize their *comprehension* must interpret their parents’ *production* biases as lexical preferences:

<table>
<thead>
<tr>
<th></th>
<th>#watr#</th>
<th>#a:#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation 1</td>
<td>20%</td>
<td>80%</td>
</tr>
<tr>
<td>Generation 2</td>
<td>40%</td>
<td>60%</td>
</tr>
<tr>
<td>Generation 3</td>
<td>60%</td>
<td>40%</td>
</tr>
<tr>
<td>Generation 4</td>
<td>80%</td>
<td>20%</td>
</tr>
</tbody>
</table>

Ultimately, this leads to underlying forms that connect to:

a. auditory forms with auditory salience;

b. auditory forms that contrast well with others.

(by chain shift, not merger; cf. Wedel 2004, 2006 in exemplar theory, and Boersma & Hamann 2007 in OT)
3. Lexical and articulatory constraints

Example: suppose a language has two forms meaning ‘grandfather’: |#!uŋ!aʰa#| and |#o:pa#|.

[!V] requires a synchrony of apical and dorsal gestures, whereas [pV] requires just a single uncritically timed labial gesture.

The higher difficulty of pronouncing |!uŋ!aʰa| as compared to |o:pa| leads to a bias against choosing the underlying form |#!uŋ!aʰa#| in production. This bias may overcome any lexical preference for |#!uŋ!aʰa#|, but only if evaluation is parallel across multiple levels (in a serial model, articulation can have no influence on the earlier process of lexical selection in production).
The solid lines depict the optimal path both in OT (easily) and in HG (with some effort, because of the double violation of *![V]).
3. Lexical and articulatory constraints: acquisition

In an environment where clicks occur but are not predominant, a child would learn to rank *[!V] >> *[pV].

Illustration: in !Xû, where clicks are predominant, ‘grandfather’ is [#!uŋ!aʔa#] (Snyman 1970: 54).
3. Lexical and articulatory constraints: evolution

Learners who optimize their *comprehension* must interpret their parents’ *production* biases as lexical preferences:

<table>
<thead>
<tr>
<th></th>
<th>#!uŋ!a³a#</th>
<th>#o:pa#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation 1</td>
<td>80%</td>
<td>20%</td>
</tr>
<tr>
<td>Generation 2</td>
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<td>60%</td>
</tr>
<tr>
<td>Generation 4</td>
<td>20%</td>
<td>80%</td>
</tr>
</tbody>
</table>

Ultimately, this leads to underlying forms that connect to:
articulatory forms that are easy to pronounce.
4. Lexical and sensorimotor constraints

Example: in the history of English, the underlying form |#kni:#| ‘knee’ turned into |#ni:#|. The two underlying forms may have coexisted for some time.

The low audibility of dorsal plosive cues before /n/ in comprehension leads to a bias against choosing the underlying form |#kni:#| in production, at least in a bidirectional model. This bias may overcome any lexical preference for |#kni:#|, but only if evaluation is parallel across multiple levels (in a serial model, low-level sensorimotor knowledge can have no influence on the earlier process of lexical selection in production).
4. Lexical and sensorimotor constraints: vertical tableau

The solid lines depict the optimal path both in OT and in HG.
4. Lexical and sensorimotor constraints: acquisition

Sensorimotor learning in a noisy environment will lead to the knowledge that a pronounced [k]_{Art} before [n]_{Art} is likely not to generate any dorsal plosive cues.

In other words, the sensorimotor constraint

\[*[\text{tongue-body closure/}_{-}\text{n}]_{\text{Art}}[\text{dorsality \& plosion/}_{-}\text{n}]_{\text{Aud}}\]

which can be abbreviated as

\[*[k/_{-}\text{n}]_{\text{Art}}[k/_{-}\text{n}]_{\text{Aud}}\]

will end up being ranked high.
4. Lexical and sensorimotor constraints: evolution

Learners who optimize their *comprehension* must interpret their parents’ *production* biases as lexical preferences:

<table>
<thead>
<tr>
<th></th>
<th>#kni:#+</th>
<th>#ni:#+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation 1</td>
<td>80%</td>
<td>20%</td>
</tr>
<tr>
<td>Generation 2</td>
<td>60%</td>
<td>40%</td>
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<tr>
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</tr>
<tr>
<td>Generation 4</td>
<td>20%</td>
<td>80%</td>
</tr>
</tbody>
</table>

Ultimately, this leads to underlying forms that connect to:

a. articulatory forms with predictable auditory results (salient sounds, and Stevens’ “quantal theory”);

b. auditory forms with unambiguously recoverable articulations (salient and contrastive sounds).
If both OT and HG work, which is best?

Comparison of convergence of learning algorithms as a function of the number of levels of representations:

<table>
<thead>
<tr>
<th></th>
<th>Categorical OT(^1)</th>
<th>Stoch.OT(^3)</th>
<th>Stoch.HG(^8,9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(EDCD(^2))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>two levels</td>
<td>100%(^2)</td>
<td>97%(^7,9)</td>
<td>100%(^9)</td>
</tr>
<tr>
<td>three levels</td>
<td>60%(^5)</td>
<td>70%(^6)</td>
<td>80%(^9)</td>
</tr>
</tbody>
</table>

\(^1\)Prince & Smolensky 1993; \(^2\)Tesar 1995; \(^3\)Boersma 1997; \(^4\)Soderstrom, Mathis & Smolensky 2006; \(^5\)Tesar & Smolensky 2000; \(^6\)Boersma 2003; \(^7\)Pater to appear; \(^8\)Boersma & Escudero to appear; \(^9\)Boersma & Pater in progress
The correct learning algorithm...

is the one whose misconvergences coincide with those of humans.
The crucial leap of thought: the Input

From Prince & Smolensky (1993) on, the Input and Richness of the Base have been thought to be located in Underlying Form. I propose they are both instead located in Auditory Form for comprehension, and in Meaning for production.
Conclusion

Parallel bidirectional multi-level constraint satisfaction predicts six types of lexical skewings:

1. auditory contrast by selective merger;
2. auditory contrast by chain shift;
3. auditory salience;
4. articulatory ease;
5. auditory predictability;
6. articulatory recoverability.

(Some cases discussed in this talk could be due to several of these causes, not just to the cause(s) proposed in the example tableaus)

My suspicion: there aren’t any more types of lexical skewings.
References


