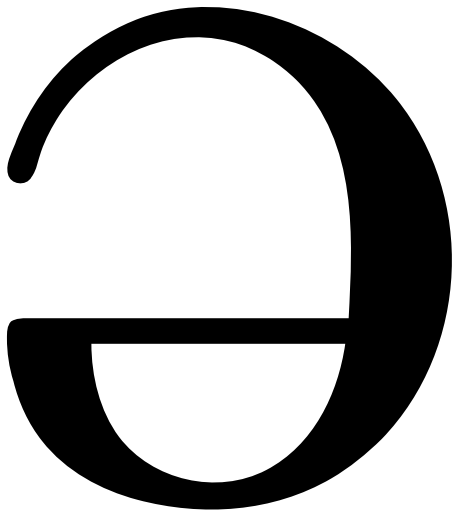


The emergence of auditory contrast

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GLOW 30, Workshop on Segment Inventories
Tromsø, April 11, 2007

An application of the theory of auditory dispersion developed in
Boersma & Hamann (2007: “The evolution of auditory contrast”)
to the two-dimensional case of vowels



F2 $\xrightarrow{\quad \text{ɪ} \quad}$

F2 $\xrightarrow{\quad \text{u} \quad \text{ɪ} \quad}$

F2 $\xrightarrow{\quad \text{u} \quad \text{ɪ} \quad \text{ɪ} \quad}$

(Flemming 1995)

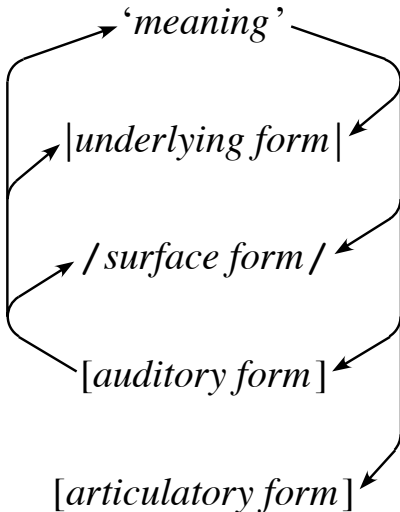
F1 $\xrightarrow{\quad \text{I} \quad \text{ɐ} \quad}$

F1 $\xrightarrow{\quad \text{i} \quad \text{“e”} \quad \text{a} \quad}$

F1 $\xrightarrow{\quad \text{i} \quad \text{e} \quad \text{ɛ} \quad \text{a} \quad}$

Phonology and phonetics separate but connected

The task of the listener:
comprehension



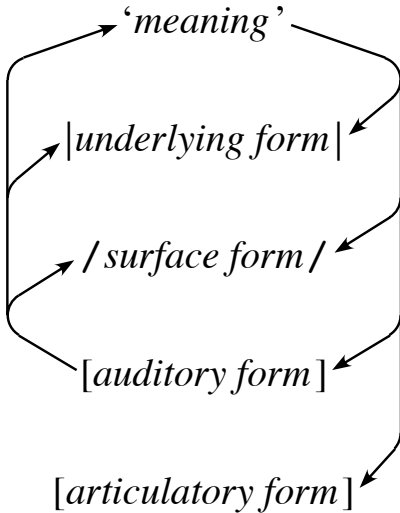
The task of the speaker:
production

Required assumptions

- Bidirectional use of constraints and their rankings
(Smolensky 1996; Tesar & Smolensky 2000;
Pater 2004; Apoussidou & Boersma 2004)
- Learners first optimize comprehension, then just produce
(Boersma 2006 “prototypes”; Boersma & Hamann 2007)
- Lexicon-driven learning of perception
(Boersma 1997; Escudero & Boersma 2001; F. Eisner 2006)
- Stochastic OT + Gradual Learning Algorithm
(Boersma 1997; Boersma & B. Hayes 2001)
- Parallel multi-level evaluation
(Boersma 2005 “*h*-aspiré”; Apoussidou 2006)
- Phonological elements emerge during acquisition
and have arbitrary relations to the phonetics
(Boersma 1998; Blevins 2004; Mielke 2004;
Boersma, Escudero & R. Hayes 2003; Morén today)

Perception maps AudF to SF

The task of the listener:
comprehension



The task of the speaker:
production

Cue constraints

(assumption of arbitrary phonetic-phonology relations:)

- Any phonology element (e.g. /a/, /i/) can be connected to any auditory value (backness 0 to 100, height 0 to 100):

*/a/[bk0]	*/i/[bk0]	*/a/[hi0]	*/i/[hi0]
*/a/[bk1]	*/i/[bk1]	*/a/[hi1]	*/i/[hi1]
...	...	...	...
*/a/[bk99]	*/i/[bk99]	*/a/[hi99]	*/i/[hi99]
*/a/[bk100]	*/i/[bk100]	*/a/[hi100]	*/i/[hi100]

- The typology has to follow from acquisition and evolution, not from factorial permutation of constraints.
- In acquisition, all cue constraints start at the same height.

Adult perception tableau

(from Boersma & Escudero 2004)

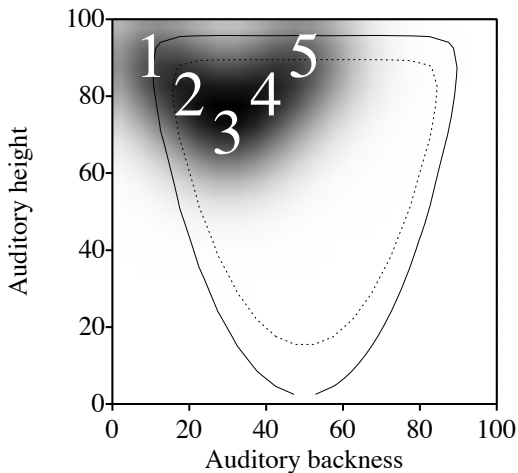
[bk15, hi80]	*/a/ [hi80]	*/u/ [bk15]	*/o/ [bk15]	*/e/ [hi80]	*/i/ [hi80]	*/e/ [bk15]	*/i/ [bk15]
/a/	*!						
/e/				*!		*	
 /i/					*		*
/o/			*!				
/u/		*!					

Child's lexicon-driven perceptual learning

Lexicon tells the child: “you should have perceived /i/”

[bk15, hi80]	*/a/ [hi80]	*/u/ [bk15]	*/o/ [bk15]	*/i/ [hi80]	*/e/ [hi80]	*/e/ [bk15]	*/i/ [bk15]
/a/	*!						
 /e/					←*	←*	
✓ /i/				*!→			*→
/o/			*!				
/u/		*!					

Environment for Generation-1 learners

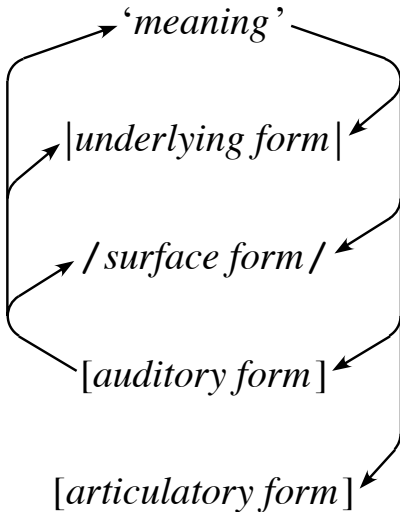


Acquiring optimal perception

- Initial state of acquisition: all cue constraints ranked at 100.0, correct lexicon in place (I admit: a slightly unnatural situation).
- Then: lexicon-driven learning of perception by OT + GLA.
- The cue constraints end up being ranked in such a way that every possible auditory event (backness-height combination) is most often classified (by the listener) as the phonological category (/1/, /2/, /3/, /4/, /5/) that was most likely intended by the speaker.
- Thus, the listener becomes a *maximum-likelihood listener*, or more precisely, a *probability-matching listener* (Boersma 1997, Escudero & Boersma 2001).
- This is good, because this minimizes confusion.

‘Production’ (version 1) maps SF to AudF

The task of the listener:
comprehension



The task of the speaker:
production

‘Production’ with cue constraints only

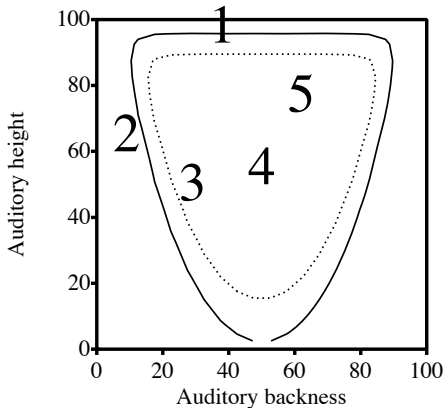
(assumption of bidirectional use of constraints and rankings)

(assumption of first optimize perception, then just produce)

The average incoming /2/ is [bk20, hi80], but:

/2/	*/2/ [hi0]	*/2/ [hi20]	*/2/ [bk80]	*/2/ [bk20]	*/2/ [hi80]	*/2/ [bk9]	*/2/ [hi65]
[bk20, hi80]				*!	*		
[bk20, hi65]				*!			*
[bk9, hi80]					*!	*	
 [bk9, hi65]						*	*

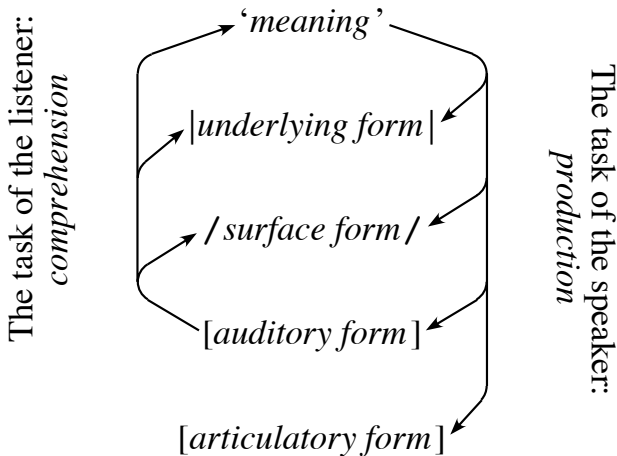
The ‘prototype’ effect



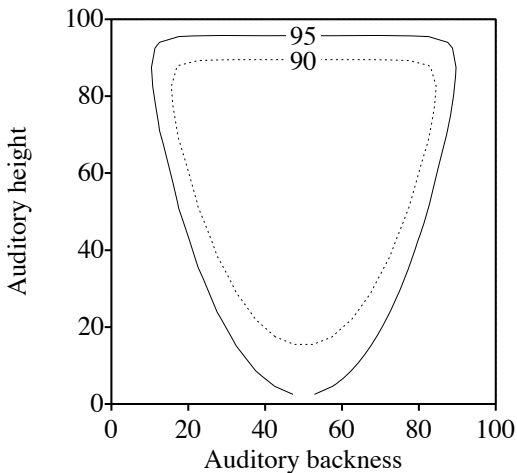
(observed in the lab by e.g. Johnson, Flemming & Wright 1993;
modelled in OT for the 1-dimensional case by Boersma 2006)

Real production maps SF to AudF + ArtF

(assumption of parallel multi-level evaluation)



Rankings of articulatory constraints

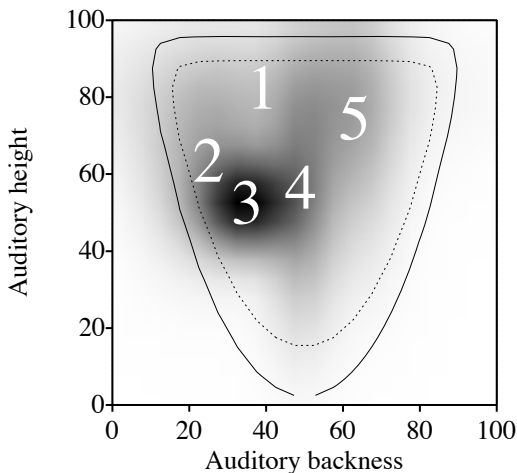


Production with cue constraints and articulatory constraints

/2/	*/2/ [hi0]	*[bk9, hi65]	*[bk9, hi80]	*/2/ [bk20]	*/2/ [hi80]	*/2/ [bk9]	*/2/ [hi65]
[bk20, hi80]				*	*!		
 [bk20, hi65]				*			*
[bk9, hi80]			*!		*	*	
[bk9, hi65]		*!				*	*

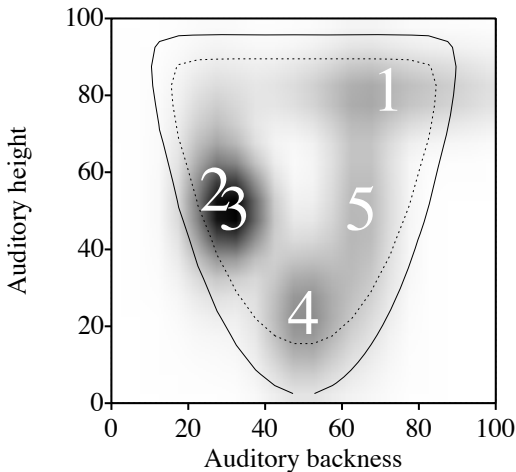
- The articulatory effect counteracts the prototype effect a bit (modelled for the 1-dimensional case by Boersma 2006).

Production of Generation-1 learners

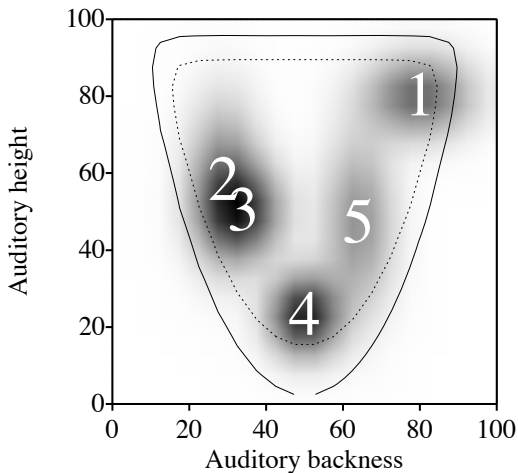


Evolution: production of Generation-2 learners

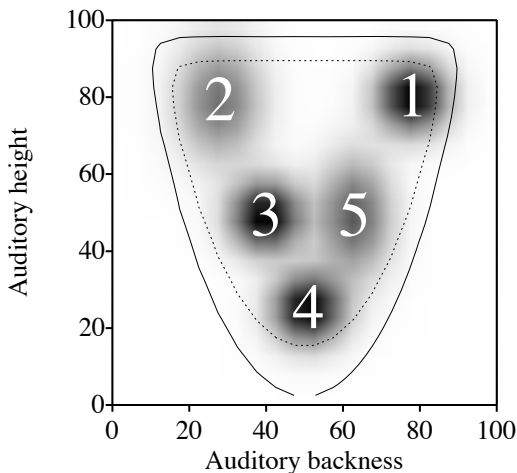
(for the 1-dimensional case see Boersma & Hamann 2007)



Production of Generation-3 learners



Production of Generation-5 learners



Comparison of inventory models

- Markedness accounts: do not go through for [i].
- Computing optimal inventories (Lindblom; Ten Bosch 1991): teleological; no connection to phonological phenomena.
- MINDIST constraints (Flemming; Padgett 2003; Sanders 2003): teleological.
- Clustering (De Boer 1999; Oudeyer 2006): non-teleological; but no repulsion, hence no chain shifts.
- Use the prototype effect of exemplar theory (Blevins 2004:285): non-teleological, but not yet shown to work; little connection to phonology yet; possibly problematic in more dimensions.
- Multi-level bidirectional OT (Boersma & Hamann 2007): non-teleological; connected to phonology via SF and OT; shown to work; scales linearly with number of dimensions.

Conclusion

Auditory dispersion is taken care of in the phonology-phonetics interface, in a way compatible with phonological theory.

**Auditory dispersion is seen to emerge non-teleologically,
if we assume multi-level bidirectionality.**

For a technically detailed account of the one-dimensional case, look next week on Rutgers Optimality Archive for:

“The evolution of auditory contrast”
by Paul Boersma & Silke Hamann