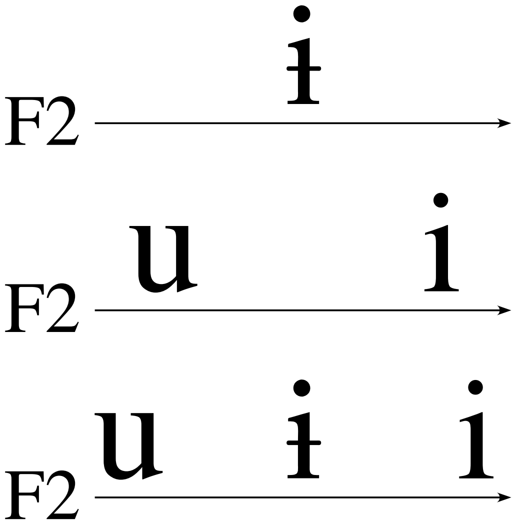
The emergence of auditory contrast

Paul Boersma, University of Amsterdam
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 ə



(Flemming 1995)

ɪ ɐ

F1 $\longrightarrow$

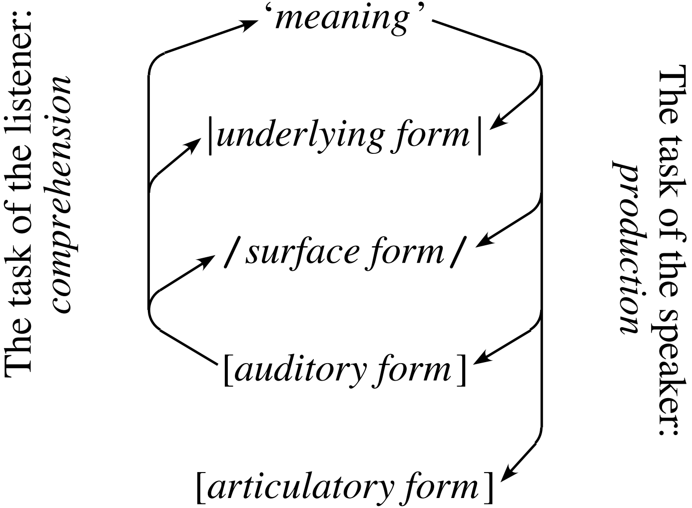
i “e” a

F1 $\longrightarrow$

i e ɛ a

F1 $\longrightarrow$

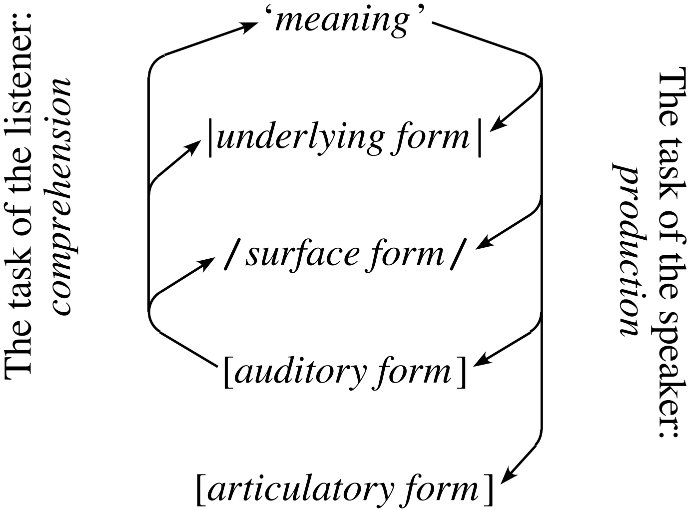
Phonology and phonetics separate but connected



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



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)

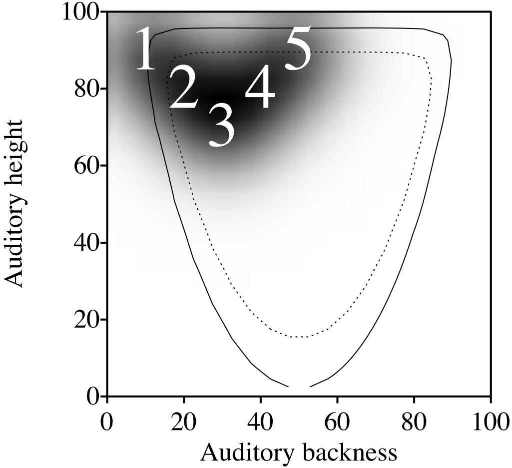
[bk15, hi80]	*/a/ [hi80]	*/u/ [bk15]	*/o/ [bk15]	*/e/ [hi80]	*/i/ [hi80]	*/e/ [bk15]	*/i/ [bk15]
/a/	*!						
/e/				*!		*	
☞ /i/					*		*
/o/			*!				
/u/		*!					

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



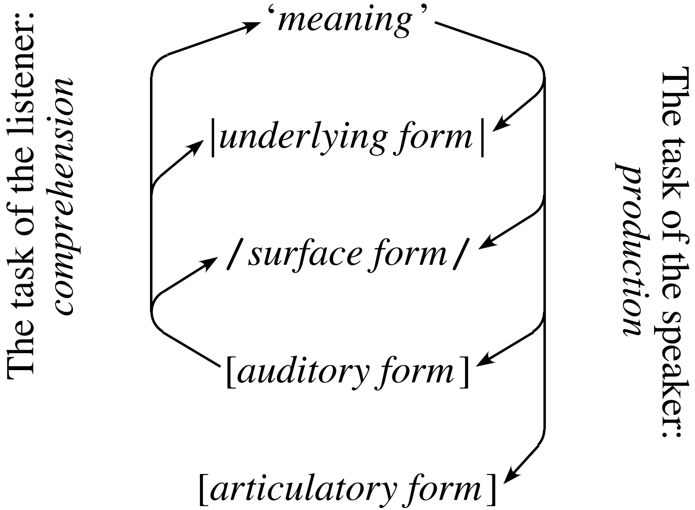
Acquiring optimal perception

- 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



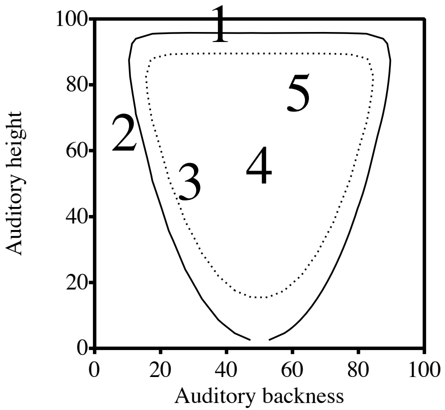
‘Production’ with cue constraints only

(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]						*	*

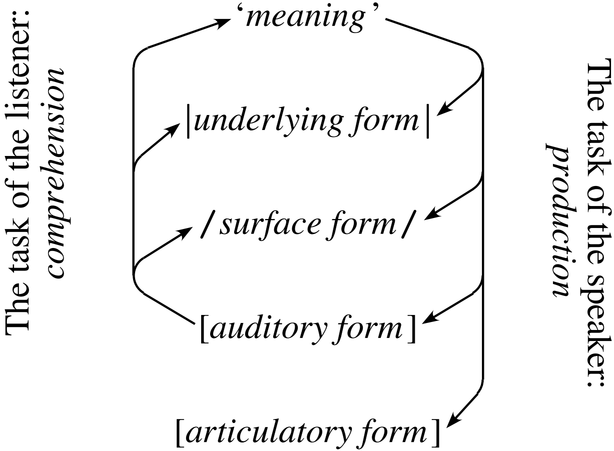
The ‘prototype’ effect



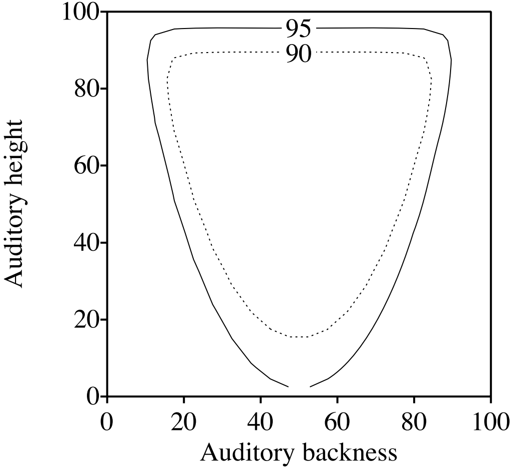
(observed in the lab by e.g. Johnson, Flemming & Wright 1993; modelled in OT for the 1-dimensional case by Boersma 2006)

Real production maps SF to AudF + ArtF

(assumption of parallel multi-level evaluation)



Rankings of articulatory constraints

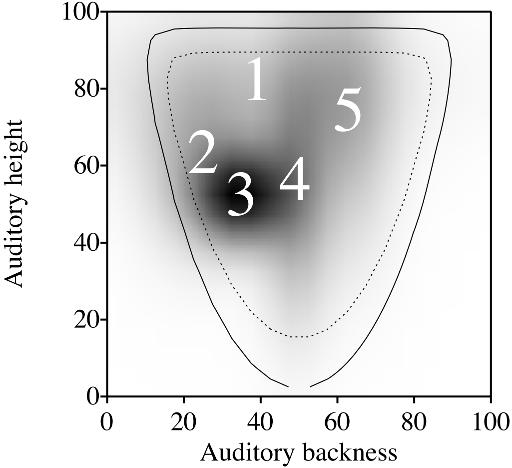


Production with cue constraints and articulatory constraints

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

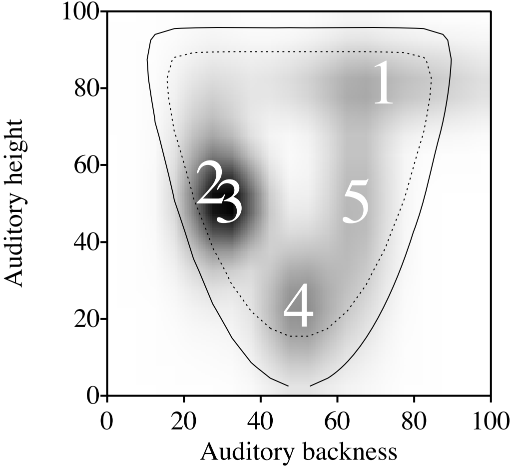
- The articulatory effect counteracts the prototype effect a bit (modelled for the 1-dimensional case by Boersma 2006).

Production of Generation-1 learners

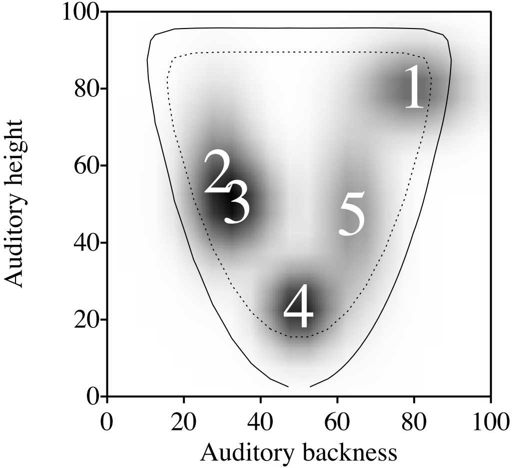


Evolution: production of Generation-2 learners

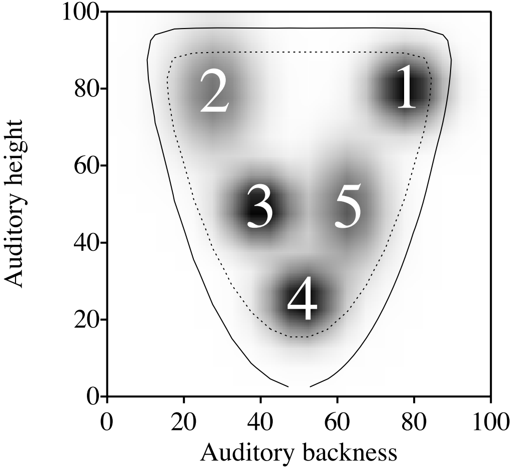
(for the 1-dimensional case see Boersma & Hamann 2007)



Production of Generation-3 learners



Production of Generation-5 learners



Comparison of inventory models

- Markedness accounts: do not go through for [ɨ].
- 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