Nasal harmony in functional phonology

Paul Boersma, University of Amsterdam, http://www.fon.hum.uva.nl/paul/
handout, 30 January, 1999

§1 *Three grammar models*

(1) *Structuralist*: |underlying| → /phonemic/ → [phonetic]

(2) *Generative*: |underlying| → [phonetic]

(3) *Functional*: |underlying| → [phonetic] → /phonemic/

(4) *In functional terms*:
|perceptual specification| → [articulatory implementation] → /perceptual output/

§1.1 Modular grammars include a discrete surface representation

(5) Structuralist modularity

|morphophonemic|
↓ phonology
/autonomous phonemic/
↓ phonetic implementation
[phonetic]
→ sound

Argument for //: perception of "same" and "different" (Bloomfield 1933: 128; Hockett 1965: 194) → contrastivity → phonemes vs. allophones.

(6) An intuitive grammar model (a majority at this conference?)

|output of the lexicon| (underlying form)
↓ postlexical phonology
/discrete phonological surface structure/
↓ phonetic implementation
[continuous articulatory utterance]
→ sound

Arguments for //: feeling, belief, intuition, counterbleeding opacity.

The arguments by Hale & Reiss (1998)

(7) Hale & Reiss (1998): no grammar of performance

|underlying representation|
↓ phonology
/output of grammar/
↓ performance system and body
[output of body]
→ sound

Argument: the grammar is about mental states and cannot control the output of the body,

(8) Charles Reiss (Optimality List, April 27, 1998): “If I don’t start flossing, all my teeth may fall out — my pronunciation will change, but my phonology won’t.”

Before loss of teeth:
|s|
↓ grammar
/s/
↓ body
[s]
→ sound

After loss of teeth:
|s|
↓ grammar
/s/
↓ body
[θ]
→ sound

(9) Hale & Reiss’s paradox: a monostratal model would show a sudden grammar change:

Before loss of teeth:
|s|
↓ grammar
[s]
→ sound

After loss of teeth:
|s|
↓ grammar
[θ]
→ sound

This is incompatible with the idea that the grammar is about mental states, which should not change suddenly as a result of a performance problem.

§1.2 Monostratal grammars combine postlexical phonology and phonetics

Three criteria for the phonology/phonetics divide fail.

(10) Optionality and pragmatical conditioning in "phonemic" postlexical phonology.

a. Normal Dutch: |aːn+pɑsə| → [aːmpɑsə] (80%) or [aːnpɑsə] (20%).
b. Clear Dutch: |aːn+pɑsə| → [aːmpɑsə] (20%) or [aːnpɑsə] (80%).

(11) Language-specific"allophonic" variation (Dutch):

a. Mid back vowel is high before nasals: [ɦʊnt] 'dog'.
b. Mid back vowel is low before non-nasals: [ɦɔk] 'kennel'.

Conclusion: phonetic implementation belongs in the grammar (where else?),

(12) Halle's (1959: 22) argument applied to Dutch (no phonemic /g/):

morphophonemic	autonomous phonemic	phonetic
wɪt + buk	wɪdbuk	wɪdbuk
zɑk + duk	zɑkduk	zɑgduk

Problem: an obviously single rule is spread across two modules.

(13) Early generativist conclusion (Chomsky 1964: 88; Postal 1968: 3–314; C&H 1968: xx):

Phonology/phonetics divide is artificial → the grammar must be monostratal:

|systematic phonemic|
↓ phonology & phonetic implementation
[phonetic]
→ sound

§1.3 Functional grammars distinguish articulation and perception

(14) Assumption shared by supporters of phonemics and opponents of modularity:
If there is a discrete phonologial surface structure,
then it must be located between the underlying form and the phonetic surface form.

E.g. Harris (this conference): “phonology is directly transduced to the external auditory and articulatory devices without having to pass through some additional categorial level”, so he rejects “the existence of an independent level of categorical phonetics”.

(15) But the real arguments in §1.1 and §1.2 were:
a. In favour of a discrete phonological surface structure (perception).
b. Against an intermediate level between phonology and phonetics (artificial).

(16) **But there is no contradiction. We can heed both desires.**
Just distinguish articulation and perception:

|output of the lexicon| (= perceptual specification = underlying form)
↓ postlexical phonology & phonetic implementation
[continuous articulatory utterance]
→ sound
↓ perception grammar
/discrete phonological surface structure/ (= perceptual output)

There is a discrete surface level, but it is not intermediate between the phonology and the phonetics.

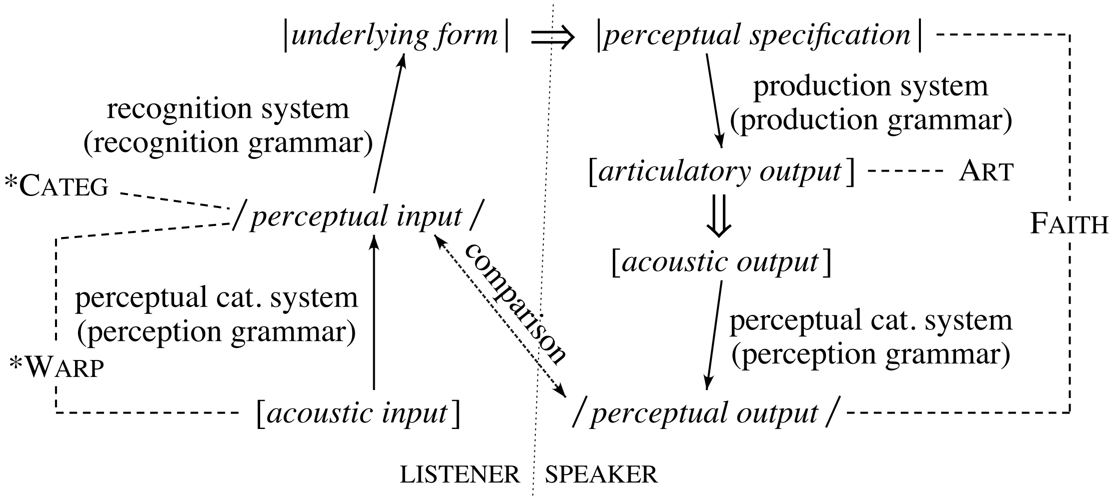
(17) The model solves Reiss’ paradox:

Before loss of teeth:	*After loss of teeth:*	*After relearning:*
|s|	|s|	|s|
↓ production	↓ production	↓ production
[groove]	[groove]	[lateral groove]
↓ perception	↓ perception	↓ perception
/s/	/θ/	/s/
→ sound	→ sound	→ sound

(18) The main properties of the production grammar are:
a. The grammar determines the articulatory output.
b. Production is ultimately perception-oriented, like all human behaviour (Powers 1973).

§2 The complete grammar model

(19) The complete grammar as defended in Boersma (1998):



§2.1 The production grammar and its local rankings

(20) Evaluation of articulatory candidates and their perceptual results

|*spec*|	A	B
☞ [art_1] /$perc_1$/		*
[art_2] /$perc_2$/	*!	

(21) Articulatory constraints (ART) evaluate aspects of minimization of effort, e.g.

*GESTURE (*articulator*: *gesture* / *distance*, *duration*, *precision*, *velocity*):
Do not perform a certain *gesture* with a certain *articulator*, along a certain *distance*, for a certain *duration*, and with a certain *precision* and *velocity*.

plus constraints against: synchronization, coordination.

They enter the grammar from below as soon as a motor-perception relation is acquired.

Fixed local ranking: higher if *distance*, *duration*, *precision*, or *velocity* is greater, and everything else stays equal.

Otherwise: free ranking: a ***global*** effort measure only predicts cross-linguistic tendencies.

(22) Faithfulness constraints (FAITH) evaluate aspects of minimization of confusion, e.g.

*REPLACE (*feature*: $value_1$, $value_2$ / *condition* / *left-env* _ *right-env*):
Do not replace a specified value ($value_1$) on a perceptual tier (*feature*) with a different value ($value_2$), under a certain *condition* and in the environment between *left-env* and *right-env*.

plus constraints against: insertion, deletion, loss of simultaneous or sequential relations.

Fixed local ranking: higher if $value_1$ and $value_2$ are further apart or if the condition or the environment contribute to a smaller amount of confusion, and everything else stays equal.

Otherwise: free ranking: a ***global*** confusion measure predicts cross-linguistic tendencies.

(23) Interaction: nasal place assimilation

|an+pa|	*REPLACE (place / _ V)	*REPLACE (pl / plosive / _ C)	*GESTURE	*REPLACE (pl / nasal / _ C)
[anpa] /anpa/			*!	
☞ [ampa] /ampa/				*
[anta] /anta/	*!			

(24) Plosives immune to nasal place assimilation

|at+ma|	*REPLACE (place / _ V)	*REPLACE (pl / plosive / _ C)	*GESTURE	*REPLACE (pl / nasal / _ C)
☞ [atma] /atma/			*	
[apma] /apma/		*!		
[atna] /atna/	*!			*

No NASSIM (context-dependent structural constraint), because effort of tongue gesture does not depend on whether the velum is down. Instead, there are context-dependent faithfulness constraints, because perceptual confusion does depend on the plosive/nasal distinction.

(24a) Articulation-perception interaction in Sign Language of the Netherlands

|high hand, fingers down, palm down|	*DELETE (fingers down)	*DELETE (high hand)	*GESTURE (upper arm up)	*DELETE (palm down)
[upper arm up, stretch wrist] /high hand, fingers down, palm down/			*!	
☞ [lower arm up, flex base] /high hand, fingers down, palm front/				*

Not speech-specific, not language-specific, but the general perceptual control loop.

§2.2 The perception grammar and its local and global rankings

(25) Functions of the perception grammar

a. Evaluate *faithfulness*.
b. Perceive ourselves, to *learn* to imitate other speakers.
c. Listen (***perceptual input***) to others (***acoustic input***), for learning.
d. Listen to others, for comprehension with the ***recognition system***.

(26) Evaluation of perceptual candidates

[acoustics]	A	B
☞ /$perc_1$/		*
/$perc_2$/	*!	

(27) Perception grammar contains constraints for categorization, e.g.

*WARP (*feature*: *ac*, *perc* / *condition*):

Do not perceive an acoustic value (*ac*) on a perceptual tier (*feature*) as a different value (*perc*), under a certain *condition*.

Fixed local ranking: higher if the perceptual distance between *ac* and *perc* is greater → least violated *WARP constraint thus usually determines the resulting perceptual category.

(28) Simultaneous abstraction (e.g. /m/ = labial nasal) and sequential abstraction:

OBLIGATORYCONTOURPRINCIPLE (*f*: *x*; cue_1 | *m* | cue_2)

A sequence of acoustic cues cue_1 and cue_2 with intervening material *m* is heard as a single value *x* on the perceptual tier *f*.

(29) LINECROSSINGCONSTRAINT (*f*: *x*; cue_1 | *m* | cue_2)

A sequence of acoustic cues cue_1 and cue_2 with intervening material *m* is not heard as a single value *x* on the perceptual tier *f*.

Both originated in generative phonology as inviolable constraints on representations. In functional phonology, they are violable.

(30) Local rankings of OCP

a. Higher if the sequential combination of cue_1 and cue_2 is more common.
b. Lower if there is more intervening material.

(31) Local rankings of LCC

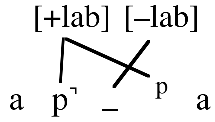
a. Lower if the sequential combination of cue_1 and cue_2 is more common.
b. Higher if there is more intervening material.

a. |apa| means “low vowel followed by labial plosive followed by low vowel”.
b. [apa] means “low tongue, open jaw, adducted vocal folds, contracting lungs, and a lip closing & opening gesture”.

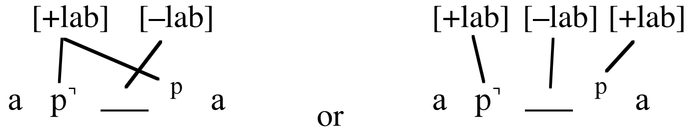
c. Acoustic result [[a p˺ _ ᵖ a]] means "high F1, labial closure transition, silence, labial release burst, high F1".
d. If labial closure transition, silence, and labial release burst tend to co-occur very often, the perception grammar will abstract away from this acoustic detail and perceive these three acoustic cues as a single "labial plosive" (nearly universal):

acoustics: [[a p˺ _ ᵖ a]]	OCP (place: labial; transition | silence | burst)	LCC (place: labial; transition | silence | burst)
/ap˺_ᵖa/ (labial tier: –|+|–|+|–)	*!	
☞ /apa/ (labial tier: –|+|–)		*

(33) The winner violates a line-crossing constraint ("_" means silence):

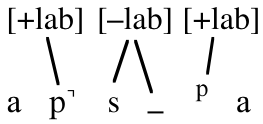


(34) More intervening material (longer silence): factorial typology:



Also [m_p]: perceive as a single [labial] in Japanese, so that both cues contribute to the perception of the whole.

(35) Still more intervening material: OCP nearly universally dominated:



§2.3 The recognition grammar

(36) Recognition of an ambiguous word (disregarding syntactic context):

/mɪst/	FAITH (nasal)	FAITH (labial)	*LEX (|mɪst| / 'train')	*LEX (|mɪs+d| / 'train')	*LEX (|tɪkɪt| / 'train')	FAITH (voice)
|mɪst| 'mist'			*!			
☞ |mɪs+d| 'missed'				*		*
|tɪkɪt| 'ticket'	*!	*			*	

Conclusion: different grammars for production and comprehension, contra Smolensky (1996), whose proposal does not work in the case of phonological alternation.

§3 Nasal harmony, type A

(37) Rightward nasal spreading in Malay (Piggott 1992)

[mãj̃ãn] ‘stalk’ /j/ is a ***target*** (it’s ***nasalizable***)
[mãkan] ‘eat’ /k/ is a ***blocker*** (it’s ***opaque***)

(38) Typology of nasalizable segments (Piggott 1992)

glides	*liquids*	*fricatives*	*plosives*	*language example*
–	–	–	–	Sundanese
+	–	–	–	Malay, Warao
+	+	–	–	Ijo, Urhobo
+	+	+	–	Applecross Gaelic

(39) Implicational universals

a. If glides can be nasalized, so can vowels and laryngeals.
b. If liquids can be nasalized, so can glides.
c. If fricatives can be nasalized, so can liquids.
d. Plosives cannot be nasalized.

§3.1 Functional analysis of type-A nasal harmony

(40) Glides undergo nasal spreading in Malay (*MOVE = “postpone any velum movement”)

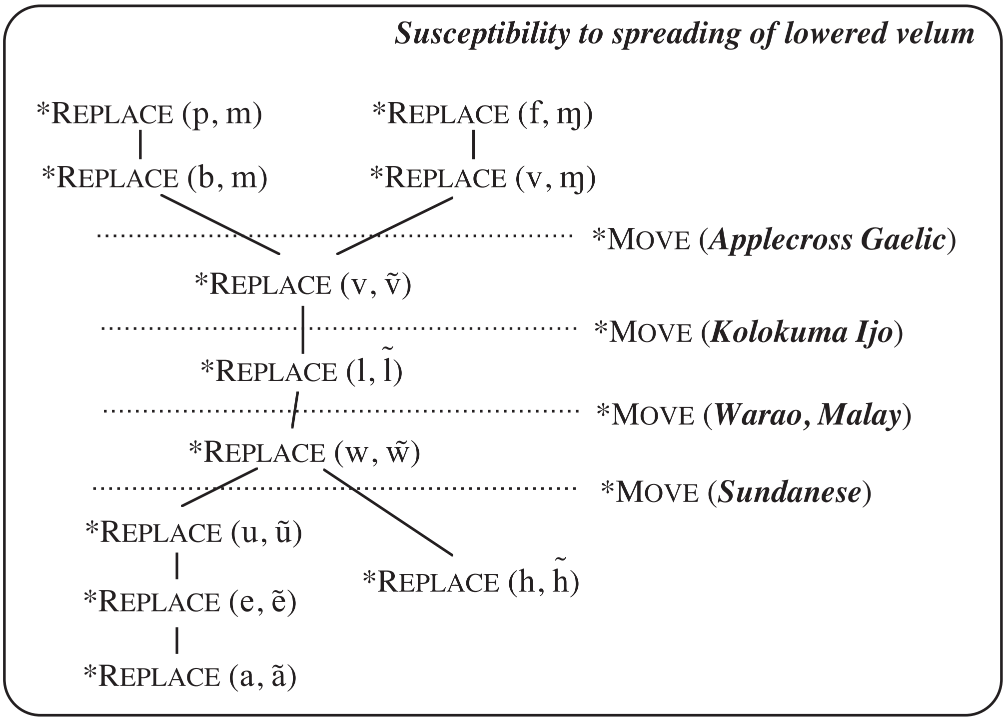
|maja|	*REPLACE (nas: –, + / liquid)	*MOVE	*REPLACE (nas: –, + / glide)
[mãja] /mãja/		*!	
☞ [mãj̃ã] /mãj̃ã/			*

*REPLACE locally ranked according to the acoustic influence of the nasal side branch (Cohn 1993).

(41) Liquids block nasal spreading

|mara|	*REPLACE (nas: –, + / liquid)	*MOVE	*REPLACE (nas: –, + / glide)
☞ [mãra] /mãra/		*	
[mãr̃ã] /mãr̃ã/	*!		

(42)



(43) Plosives block nasal spreading in Malay

|maka|	*REPLACE (k, ŋ)	*MOVE
☞ [high velum etc.] /mãka/		*
[low velum etc.] /mãŋã/	*!	

*REPLACE (k, ŋ) is equivalent to the conjunction *DELETE (plosive) & *INSERT (sonorant).

(44) Fricatives block nasal spreading in most languages

|masa|	*REPLACE (s, n)	*MOVE
☞ [high velum etc.] /mãsa/		*
[low velum etc.] /mãnã/	*!	

(45) Nasalized fricatives reported for Applecross Gaelic:

|masa|	*REPLACE (s, n)	*MOVE	*REPLACE (s, s̃)	*GESTURE (special trick)
[high velum etc.] /mãsa/		*!		
[low velum etc.] /mãŋã/	*!			
☞ [special trick] /mãs̃ã/			*	*

(46) Alternative account of Malay: faithfulness-only

|maka|	*INSERT (nasal)	*REPLACE (k, ŋ)	MAXDURATION (nasal)	*REPLACE (j, j̃)
[maka] /maka/			***!	
☞ [mãka] /mãka/			**	
[mãŋã] /mãŋã/		*!		
[mãkã] /mãkã/	*!		*	

(47) **How did phonology become so perfect?**

a. The grammar directly expresses innate functional principles (defended here).
b. Humans have been exposed to such a large selection pressure that the substantive details of the innate Universal Grammar have become perfect during the course of evolution (challenged here).
c. A super-engineer gave us language in a single, inspired stroke (ignored here).

(48) Empirical claim: **there are no arbitrary universals** (Boersma, to appear):

a. All universal phonology is directly functional.
b. All arbitrary phonology is language-specific.

Contra all generative theories of autosegmental phonology and feature geometry.

§3.2 Walker's (1998) approach to type A

(49) Walker's hierarchy of nasalizability

*NASOBSSTOP >> *NASFRICATIVE >> *NASLIQUID >>
>> *NASGLIDE >> *NASVOWEL >> *NASSONSTOP

(50) Walker's account of Malay

maka	IDENT-IO (±sonorant)	*NASOBSSTOP	SPREAD (nasal)	*NASVOWEL
maka			***!	
☞ mãka			**	*
mãk̃ã		*!		**
mãŋã	*!			**

Problems:

a. *NASOBSSTOP is a filter constraint [+nas, –cont, –son] against an impossible sound.
  a1. In FunPhon superfluous, because no articulatory candidate produces it.
  a2. Universally inviolable, so it can never contribute to factorial typology.
b. A faithfulness constraint is still needed to rule out [mãŋã], so we need structural and faithfulness constraints. The functional approach only needs faithfulness constraints.

§3.3 Sonority hierarchy and type A

The hierarchies in (42) and (49) are reminiscent of the ***sonority hierarchy***, and indeed the sonority scale has come up in at least one account of nasalizability (Gnanadesikan 1995).

Problem:

a. In the nasalizability hierarchy, /h/ patterns with the vowels (no oral constriction).
b. In the syllabification hierarchy, /h/ patterns with the fricatives (voiceless noise).

Solution:

Distinguish articulation (glottal like vowels) from perception (noisy like fricatives).

Conclusion:

The sonority hierarchy, being universally useful, is a good candidate for innateness.
However, it has directly functional exceptions, needed in only a few languages, so that we must conclude that it is not an arbitrary universal.
The rarity must have given us little time to select it during evolution.
Hence, the hierarchies are not likely to be innate.
→ UG contains no substantively detailed principles.

3.4 Piggott's (1992) account of type A

(51) Piggott's principles of nasal harmony (simplified):

a. The class of blockers must constitute a natural class with the nasal consonants.
Nasals are ***stops***, so one of those classes must be the class of stops: /m/, /n/, /p/, /t/, which accounts for the blockers in Applecross Gaelic.
Nasals are also ***consonantal***, so depending on whether glides are consonantal, we have the classes /m/, /n/, /p/, /t/, /f/, /s/, /l/, /r/ (Warao) and /m/, /n/, /p/, /t/, /f/, /s/, /l/, /r/, /j/, /w/ (Sundanese).
And nasals are ***sonorant***, so we would expect the class /m/, /n/, /l/, /r/, /j/, /w/, i.e. a language in which obstruents are targets, but sonorants block!
b. The class of blockers must not be limited to sonorants.
This ad-hoc exception rules out the third possibility in (51a).
c. There is a natural class called ***non-approximant consonants***.
This ad-hoc class consists of /m/, /n/, /p/, /t/, /f/, /s/, accounting for Ijo.

Problem:

(51b) and (51c) are specific to the problem of type-A nasal harmony.

Conclusion:

(51b) and (51c) are advantageous to only a very small minority of languages.
Unlikely to have had any chance of emerging during a few hundred generations.

Solution:

Encode function directly in the grammar.

4 Nasal harmony, type B

(52) Type-B nasality contrasts in Barasano (Piggott 1992)

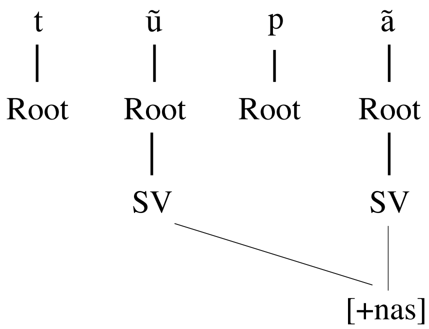
[–nasal]	[+nasal]
a, u	ã, ũ
w, j	w̃, j̃
l, r	l̃, r̃
ᵐb	m
s	s
t, k	t, k

4.1 Transparency of plosives

Guaraní:

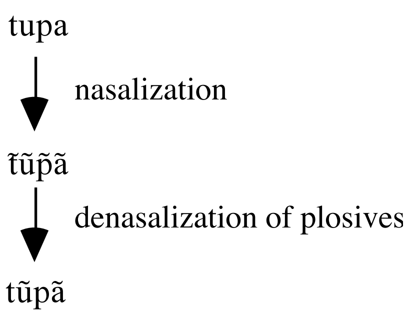
[tupa] ‘bed’
[tũpã] ‘god’
*[tupã]
*[tũpa]

(53) Piggott’s spreading along the Spontaneous Voicing tier (locality condition)



Piggott & Van der Hulst’s (1997) reanalysis as spreading on the syllable level allows them to account for the fact that all sonorants in syllables with nasalized vowels are nasalized themselves, and for the similarity with vowel-harmony processes.

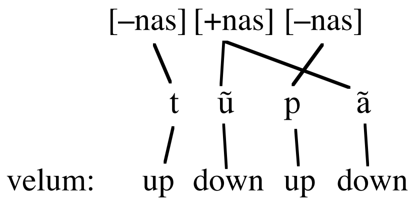
(54) Walker’s derivation of transparency, simplified from a sympathy account (McCarthy 1998), also heeding locality:



(55) Perception grammar: perceiving nasality across a plosive

acoustics: [tũpã]	OCP (nas: +; Ṽ | plosive | Ṽ)	LCC (nas: +; Ṽ | plosive | Ṽ)
perception: [–nas] [+nas] [–nas] [+nas] / t ũ p ã	*!	
☞ perception: [–nas] [+nas] [–nas] / t ũ p ã ([+nas] linked to ũ and ã, crossing [–nas] linked to p)		*

(56) Asymmetry between articulation and perception



4.2 Why all sonorants are nasalizable in type-B languages

(57) Type-B nasality contrasts (Barasano)

[–nasal]	[+nasal]	
a, u	ã, ũ	[low/high vowel, +son]
w, j	w̃, j̃	[back/front glide, +son]
l, r	l̃, r̃	[lat/trill, +son]
^{m}b	m	[stop, +son] (following Piggott 1992)
s	s	[fricative, –son]
t, k	t, k	[plosive, –son]

(58) Faithfulness handling

a. All the specified features surface faithfully in oral as well as in nasal words.
b. The sonorant stops violate *INSERT (half a nasal) in oral words.
c. The obstruents violate *DELETEPATH (nasal).

(59) Nasalizing a liquid (or vowel or glide)

|ara + *nasal*|	*DELETE (*any feature*)	*DELETEPATH (half a nasal)	*INSERT (half a nasal)	*GESTURE (velum)
☞ [ãr̃ã] /ãr̃ã/				
[ãrã] /ãrã/		*!*		**

(60) Nasalizing a sonorant stop

|a[+son,stop]a + *nasal*|	*DELETE (*any feature*)	*DELETEPATH (half a nasal)	*INSERT (half a nasal)	*GESTURE (velum)
☞ [ãmã] /ãmã/				
[ã^{m}bã] /ã^{m}bã/		*!		**
[ãbã] /ãbã/	*!	**		**

(61) Oralizing a sonorant stop

|a[+son,stop]a|	*DELETE (*any feature*)	*DELETEPATH (half a nasal)	*INSERT (half a nasal)	*GESTURE (velum)
[ama] /ama/			**!	**
☞ [a^{m}ba] /a^{m}ba/			*	**
[aba] /aba/	*!			

(62) Nasalizing a plosive (or fricative)

|a[–son,plos]a + *nasal*|	*DELETE (*any feature*)	*DELETEPATH (half a nasal)	*INSERT (half a nasal)	*GESTURE (velum)
[apa] /apa/		**		
☞ [ama] /ama/	*!*			**

Summary: *DELETE (segmental feature) >> FAITH (nasal) >> *GESTURE (velum)

(63) **Problem**: what if type-B languages are like type-A languages in that they do have underlying oral segments?

a. [ãr̃ã] violates *INSERTPATH (nasal).
b. *GESTURE (velum: up & down / fast).>> *INSERTPATH (nasal)
c. *GESTURE >> *MOVE: always two movements vs. sometimes one.
Plus speed needed because the raising and lowering gestures will overlap.

The horse-distance hierarchy, compared to the apple-pear difference

horse - ant
horse - duck
horse - dolphin
horse - rhino
horse - cow ↑
horse - deer apple-pear
horse - donkey ↓

Thus, the ranking *GESTURE (velum: up & down / fast) >> *INSERTPATH (nasal) may well be near-universal. The reader is advised to try to produce a non-nasal liquid between two nasalized vowels.

Conclusion

Generative accounts of nasal harmony have to take recourse to ad-hoc natural classes, exceptions to exceptions, grammaticization of constraints against unproducable perceptual output, functional exceptions to innate hierarchies, feature geometry, and derivation. If all these things were really needed, UG would be full of substantive phonological detail. However, the functional approach to phonology can account for the facts of nasal harmony without assuming anything but general properties of human motor behaviour and perception. This is compatible with the view that the phonological part of the innate language device does not contain much more than: the cognitive abilities of categorization, abstraction, wild generalization, and extrapolation; the storage, retrieval, and access of arbitrary symbols; a stochastic constraint grammar; a gradual learning algorithm; laziness; the desire to understand others; and the desire to make oneself understood.

References

Archangeli, Diana & Douglas Pulleyblank (1994). *Grounded phonology*. Cambridge: MIT Press.
Bloomfield, Leonard (1933). *Language*. New York: Henry Holt.
Boersma, Paul (1998). *Functional phonology: Formalizing the interactions between articulatory and perceptual drives* [*LOT International Series* **11**]. PhD dissertation, University of Amsterdam. The Hague: Holland Academic Graphics. [http://www.fon.hum.uva.nl/paul/diss/] *available for free from the author a.l.a.s.l.*
Chomsky, Noam (1964). *Current issues in linguistic theory*. The Hague: Mouton.
Chomsky, Noam & Morris Halle (1968). *The sound pattern of English*. New York: Harper and Row.
Cohn, Abigail (1993). The status of nasalized continuants. In Marie K. Huffman & Rena Krakow (eds.), *Nasals, nasalization, and the velum. Phonetics and phonology*, Vol. 5. San Diego: Academic Press. 329–367.
Gnanadesikan, Amalia (1995). *Markedness and faithfulness constraints in child phonology*. Manuscript, University of Massachusetts. [Rutgers Optimality Archive **67**, http://ruccs.rutgers. edu/roa.html]
Halle, Morris (1959). *The sound pattern of Russian*. The Hague: Mouton.
Hale, Mark & Charles Reiss (1998). Formal and empirical arguments concerning phonological acquisition. *Linguistic Inquiry* **29**: 656–683.
Hockett, Charles. F. (1965). Sound change. *Language* **41**: 185–205.
McCarthy, John J. (1998). *Sympathy and phonological opacity*. Ms. Universaity of Massachusetts, Amherst. [Rutgers Optimality Archive, http://ruccs.rutgers. edu/roa.html]
Piggott, Glyne (1992). Variability in feature dependency: The case of nasality. *Natural Language and Linguistic Theory* **10**: 33-78.
Piggott, Glyne & Harry van der Hulst (1997). Locality and the nature of nasal harmony. *Lingua* **103**: 85–112.
Postal, Paul M. (1968). *Aspects of phonological theory*. New York: Harper and Row.
Powers, William T. (1973). *Behavior: The control of perception*. Chicago: Aldine.
Prince, Alan & Paul Smolensky (1993). *Optimality Theory: Constraint interaction in generative grammar*. Rutgers University Center for Cognitive Science Technical Report **2**.
Saussure, Ferdinand de (1916). *Cours de linguistique générale*. Edited by Charles Bally & Albert Sechehaye in collaboration with Albert Riedlinger. Paris: Payot & C^{ie}. [2nd edition, 1922]
Walker, Rachel (1998). *Nasalization, neutral segments, and opacity effects*. PhD dissertation, University of California, Santa Cruz.