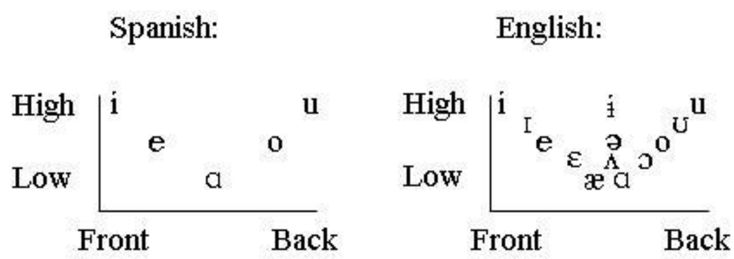
On the functional relevance of gradience and variation to the acoustic dispersion of phonological contrasts

Daniel Silverman

1. Introduction: setting the theoretical and methodological scene

- Symmetry and dispersion of contrastive elements have long been noted by phonologists and phoneticians.

1.



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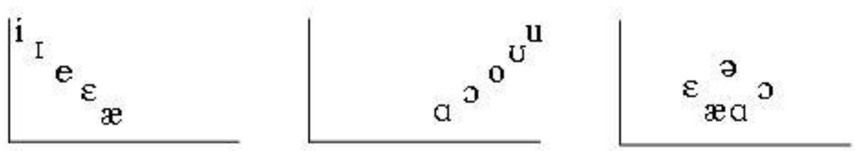


- Martinet (1952), Hayes (1996): cognitive pressure towards systemic symmetry.
- Sapir (1925): asymmetrically distributed elements possess a "psychological aloofness from all other members of the system."
- Kingston and Diehl (1994): Speakers choose different pronunciations of a phoneme in order to optimize conveying the contrast in each context that it occurs.
- Kingston (2002): "Speakers must be altruists."

- Shifting the locus of the mechanism
  -from speaker to listener
  -from the synchronic to the diachronic
  -from the teleological to the evolutionary.

PROBABILITY MATCHING

- Animals perform sophisticated statistical analyses as they navigate the world around them, e.g. in foraging, they match their behavior in terms of likelihood of payoff.
- Similar statistical calculations underlie aspects of human linguistic behavior, in that the nature and extent of variation in speech is indeed largely matched as listeners become speakers.
- Variable vocalic nasalization: different languages vary in different ways (Clumeck 1976).
- Ohman (1966), Manuel (1999)

- Optional use of certain morphemes is probability-matched across speakers (in real-world speech: Poplack 1980, in lab experiments: Hudson and Newport 1999)

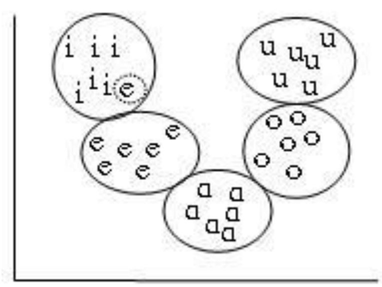
EXEMPLAR THEORY

- Perceptual categories are defined as the set of all experienced instances of the category, such that variation among tokens actually contributes to the categorical properties themselves.
- Mikołaj Kruszewski (1881):

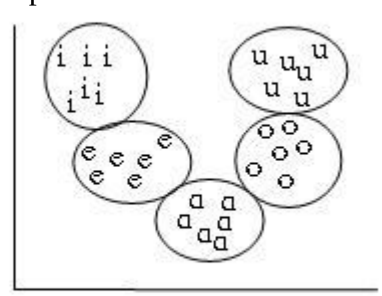
  "…In the course of time, the sounds of a language undergo changes. The spontaneous changes of a sound depend on the gradual change of its articulation. We can pronounce a sound only when our memory retains an imprint of its articulation for us. If all our articulations of a given sound were reflected in this imprint in equal measure, and if the imprint represented an average of all these articulations, we, with this guidance, would always perform the articulation in question approximately the same way. But the most recent (in time) articulations, together with their fortuitous deviations, are retained by the memory far more forcefully that the earlier ones. Thus, negligible deviations acquire the capacity to grow progressively greater…"

PROBABILITY MATCHING PROMOTES CATEGORY SEPARATION AND PHONETIC STABILITY

3. Vowel production:

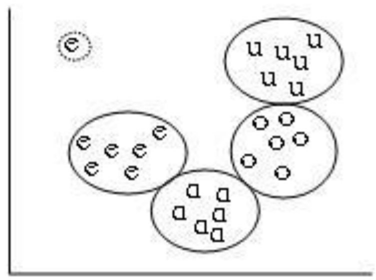


4. Vowel perception:

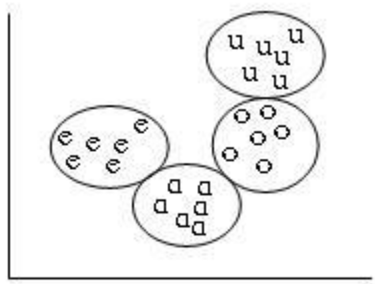


PROBABILITY MATCHING PROMOTES CATEGORY SEPARATION AND PHONETIC *CHANGE*

5. Vowel production:



6. Vowel perception:



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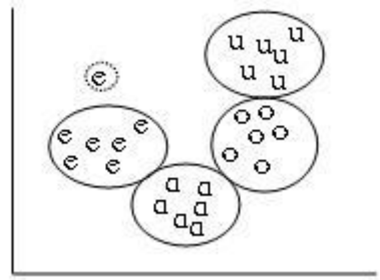
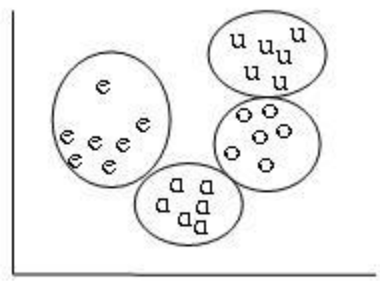
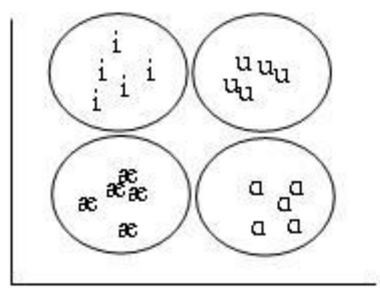


8. Vowel perception:



9. Newly evolved system:



- "Pre-aspiration"—[ʰp, ʰt, ʰk]—is usually employed as a cover term for a variety of configurations: [fp, çt, xk], [axk, içk], [aːt]~[aʰt]
- Why are pre-aspirates so rare?
- What accounts for their diachronic instabilty?

	variation (schematic):	language examples:
(A)	[^{h}p, ^{h}t, ^{h}k]	Icelandic (?), Oraibi Hopi
(B)	[^{h}p, ^{h}t, ^{h}k] ~ [fp, çt, xk]	Tarascan, Gaelic, Stockholm Swedish, Lule Sami, Toreva Hopi (?), Fox
(C)	[i^{h}t, a^{h}t] ~ [içk^j, axk]	Harris Gaelic, Barra Gaelic, Stockholm Swedish
(D)	[xp, xt, xk]	Red Point Gaelic, Goajiro, Härjedalen Swedish
(E)	[V^{h}p, V^{h}t, V^{h}k] ~ [Vːp, Vːt, Vːk]	Tarascan, Gaelic, Ojibwa, Cree, West Norwegian (Jæren), Hopi, Goajiro
(F)	[fp, çt, xk] ~ [Vːp, Vːt, Vːk]	Hopi, Goajiro
(G)	[st, sk] ~ [^{h}t, ^{h}k]	Mazatec
(H)	[ˈV^{h}t]/[ˈVçt] ~ [Vt]	Tarascan, Ness Gaelic, Bernera Gaelic, Scandinavian, Hopi

- Pre-aspiration is remarkably unstable both synchronically and diachronically
- Genuine across-the-board pre-aspiration is extremely rare (A)
- When present, pre-aspirated stops typically vary with spirant-stop clusters (B,C)
- This spirant is typically homorganic to the following stop (B)
- The spirant is sometimes influenced by the preceding vowel quality (C)
- In some cases pre-aspiration is often implemented as a velar spirant (D)
- Alternatively, pre-aspiration/pre-spirantization may vary with vowel length (E,F)
- Pre-aspiration may diachronically derive from [s]-stop clusters (G)
- It is often the case that pre-aspirates/spirants are limited to stressed domains (H)

Phonetic sources of pre-aspirates’ diachronic instability: aerodynamic, acoustic, and auditory disadvantages of pre-aspirated stops

- Post-aspirates: the transition interval from a voiceless stop into a following vowel is an especially salient acoustic event which involves the pressurized expulsion of air that has been trapped behind the oral occlusion.
- The resulting high volume and velocity of particle flow produces an especially robust acoustic signal (at the burst, and the interval immediately following) which is particularly well-suited to bear contrastive information.
- Laryngeal articulations thus gravitate, or “bind” (Kingston 1985, 1990) to this site so that they may be realized with comparatively heightened acoustic salience, thus increasing the likelihood of unambiguous cueing to listeners.

- Pre-aspirates do not possess a stop closure immediately preceding the laryngeal abduction, there is no build-up of pressure to increase particle flow during the laryngeal.

- On the contrary, a continuation of the preceding vowel results in a further depletion of aerodynamic resources during this critical interval.
- Given the absence of a robust burst, the noise associated with “h” sounds is not so saliently present in the signal.
- Short-term adaptation: the auditory nerve fires less robustly as the same sound continues to be produced over time.

variability

s-stop cluster:
[sp, st,sk]

↓

loss of oral
stricture:
[^{h}p, ^{h}t, ^{h}k]

↙ or ↘

loss of
aspiration:
[(:)p, (:)t, (:)k]

re-introduction
of oral stricture:
[fp, çt, xk]

variability

variability

variability

2. EXEMPLIFICATION: TRIQUE LABIAL HARMONY

- Trique is a Mixtecan language of the Otomanguean group, spoken by about 23,000 people in the states of Oaxaca, Guerrero, and Puebla, Mexico (Grimes 2003).

The diachrony—and limits—of Trique trans-velar spreading

10. Trique segment inventory:

p	t			k
b	d			g
	ts	tʃ	ʈʂ	
	s	ʃ	ʂ	
	z	ʒ	ʐ	
m	n			
	l			
w		j		

iː				uː
	e(ː)		o(ː)	
		a(ː)		

ʔ,h

11. Trique trans-velar spreading:

nukʷah	strong	dukʷa	possessed house
dugʷah	to twist	zugʷi	(name)
ʒugʷa	to be twisted	dugʷe	to weep
dugʷane	to bathe (someone)	rugʷi	peach
rugʷah	hearth stones	dugʷi	together with, companion

12. Trique round vowel - alveolar sequences:

rune	large black beans	utah	to anoint
utʃe	to get wet	utʃi	to nurse
uta	to gather	duna	to leave something
gunah	to run	rudaʔa	stone rolling pin
ʒutʃe	hens, domestic fowl	gunɨ	to hear

13. Trique disyllabic root classes with respect to the distribution of labiality

$C_1V_1C_2V_2$ Classes:	# of subclasses:
C V C V	72
C^w V C V	6
C V^w C V	11 (C_2 is never velar)
C V C^w V	17 (C_2 is a plain labial in 10 subclasses, a labialized velar in 7)
C V C V^w	20
C^w V^w C V	0
C^w V C^w V	0
C^w V C V^w	0
C V^w C^w V	31 (V_1 is always [u]; C_2 is virtually always [w] or a labialized velar)
C V^w C V^w	15 (V_1 and V_2 are identical in all but one entry)
C V C^w V^w	0
C^w V^w C^w V	0
C^w V^w C V^w	0
C^w V C^w V^w	0
C V^w C^w V^w	0

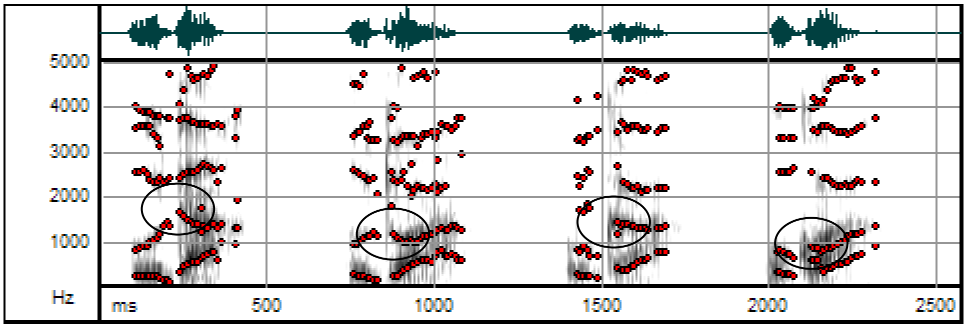
C^w V^w C^w V^w 0

14. Phonetic underpinnings

- Historically,Trique had *uk and *ut, but not *uk^w (nor *ut^w) (Longacre 1957, 62)
- Why should a labial glide have evolved in the *uk context?
- The tongue and lips are mutually independent articulators. Given their independence, both articulators may be active simultaneously.
- It is reasonable to assume that the lip-rounding gesture characteristic of [u] may have variably perseverated into the dorsal closure characteristic of [k]: [k̹].
- Persistence of lip-rounding through the dorsal closure may lead to the perception of a labialized velar.
- But certain other consonants may just as readily be produced with perseverative labiality as may [k].
- We might thus predict little-to-no asymmetry in the diachronic comportment of *uka and, say, *uta. Yet Trique clearly has not treated these two patterns in a parallel fashion: *uta -/-> [ut^wa].
- Instead, the spreading asymmetry may serve to enhance the *acoustic* distinction between the velar and alveolar places of articulation.
- Accompanying trans-alveolar spreading, by contrast, would serve to *diminish* the velar-alveolar acoustic distinction.

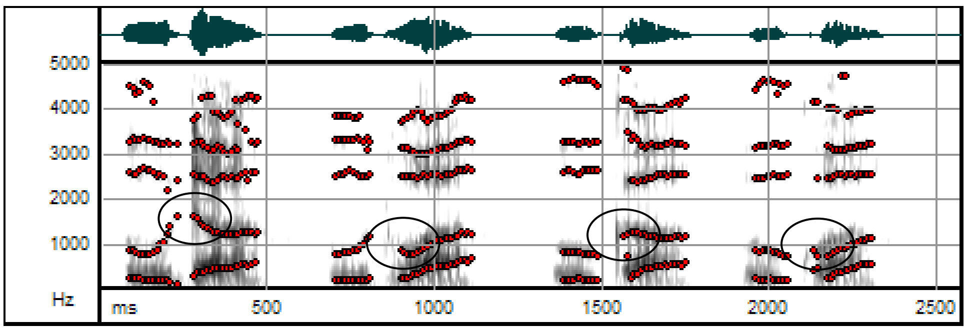
15. Waveforms, spectrograms, and formant tracks for the four sequences.

a. New York



[uda] [udʷa] [uga] [ugʷa]

b. Ohio



[uda] [udʷa] [uga] [ugʷa]

16.

		New York:		Ohio:
[uda]:	a.	**1700 Hz**	b.	**1700 Hz**
[udʷa]:		1200 Hz		1000 Hz
[uga]:		1500 Hz		1300 Hz
[ugʷa]:		**1000 Hz**		**900 Hz**

17. F2 onset values of New York English, and the proposed Trique diachrony:

proto-form: ↓							*uka		*uta ↓	
current form:		[ukʷa]		([utʷa])					[uta]	
F2 (Hz):	900	1000	1100	1200	1300	1400	1500	1600	1700	1800

- By considering the acoustic and consequent functional benefit of spreading labiality across velars—a pattern which might be present due to the variation inherent in speech production—and the counter-functionality of spreading labiality across alveolars, we might motivate the Trique sound change.

4. Experiment

- A laboratory condition may serve to recapitulate elements of the hypothesized historical scenario in "sped-up" form by introducing various amplitudes of white noise into the speech signal, and having listeners report on their perception. Although only the author's speech was employed, subsequent investigation of three other native speakers of English revealed largely comparable F2 onset values. (See 5b for one example.)

Subjects and methods

- 10 University of Illinois students in linguistics, all native English speakers.
- Sound files: [uda], [udʷa], [uɡa], [uɡʷa].
- Durations, pitch tracks and intensity contours were comparable across stimuli.
- Each file was overlaid with four levels of white noise, with each noise level increased in amplitude from the previous level. Including a no-noise level, this resulted in a total of four continua with five noise levels each, for a total of twenty sound files.
- Using PsyScope, subjects listened with headphones in a quiet room to 1000 trials—50 of each of the 20 sound files—in randomly generated blocks of 100, with a 2 second inter-trial interval, and untimed rests between blocks. Using the keyboard, subjects reported which sound sequence they heard ([uda], [udʷa], [uɡa], or [uɡʷa]). Subjects were encouraged to guess if they were undecided.

Results

18. Pooled errors

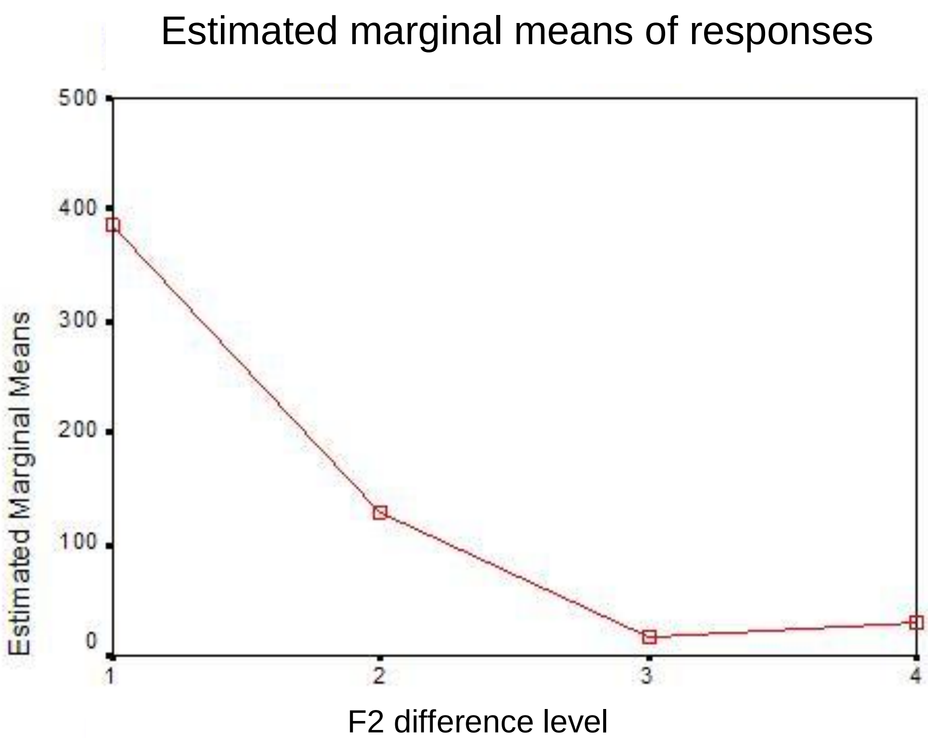
	uda	udʷa	uɡa
udʷa	263 (500 Hz)		
uɡa	500 (200 Hz)	118 (300 Hz)	
uɡʷa	32 (700 Hz)	792 (200 Hz)	57 (500 Hz)

19. F2-based confusion matrix

perceived↘ presented↓	Level 1	Level 2 (Nearest F2)	Level 3 (Mid F2)	Level 4 (Furthest F2)
uda	uda 1208	uɡa (200 Hz) 145	udʷa (500 Hz) 40	uɡʷa (700 Hz) 17
udʷa	udʷa 812	uɡʷa (200 Hz) 291	uɡa (300Hz) 71	uda (500 Hz) 223
uɡa	uɡa 964	uda (200 Hz) 355	udʷa (300 Hz) 43	uɡʷa (500 Hz) 47
uɡʷa	uɡʷa 879	udʷa (200 Hz) 501	uɡa (500 Hz) 14	uda (700 Hz) 15

- A repeated measures ANOVA confirmed a main effect for F2 similarity, $F(3, 27)=158.6$, $p<.001$. Pairwise comparisons with Bonferroni adjustment revealed a significant difference between Levels 1 and 2, and between Levels 2 and 3 ($p<.001$). The difference between Levels 3 and 4 was not significant ($p>.05$), even when including the idiosyncratic responses of the two aforementioned subjects, suggesting that when F2 differences surpassed a certain value, the rate of misperception leveled off. Mean responses for each level are graphically displayed in (11).

20.



5. Discussion and speculation

- Martinet (1975:25), "Only those who know that linguistic identity does not imply physical sameness, can accept the notion that discreteness does not rule out infinite variety and be thus prepared to perceive the gradualness of phonological shifts."

Consider how probability matching may play a role in sound changes of the Trique sort:

21. Conceivable diachronic scenario:

[uga......ug̦a......ug^{w}a]		[uda......ud̦a......ud^{w}a]	
less distinct from [uda]	more distinct from [uda]	more distinct from [ug$^{(w)}$a]	less distinct from [ug$^{(w)}$a]
less likely perceived unambiguously	more likely perceived unambiguously	more likely perceived unambiguously	less likely perceived unambiguously
less likely produced	more likely produced	more likely produced	less likely produced
∴ gradual move towards [ug^{w}a]		∴ stability of [uda]	

- A primary locus of imperfect reproduction of speech patterns may reside in listeners' misunderstanding speakers' *semantic* intentions, rather than their misunderstanding speakers' *phonetic* intentions.
- This scenario demonstrates how very minor phonetic tendencies, coupled with the sporadic lexical semantic ambiguities they might induce or eschew, may eventually have far-reaching consequences for the phonological system.
- The variability inherent in speech production may be the fodder for these sorts of sounds changes: the more distinct the variant from an acoustically similar contrastive value, the more likely the system will wend towards this variant.

- The exquisite articulatory control that speakers display in their productions is best evidenced by the fact that they are able to largely match the variability present in the ambient pattern. The probability matching itself, no doubt, betrays an extremely sophisticated statistical analytic ability on the part of learners. Moreover, their actual productions betray evidence that they are able to implement their calculated probabilities in their own speech.
- Language evolution is unguided and passive, just as in the evolution of species. experiments of the present sort probably tell us more about cognitive representations from the perspective of language change, rather than from the perspective of language processing.
- The gradience and variation inherent in speech production may be the fodder for these sorts of sounds changes: the more distinct the variant from an acoustically similar word, the more likely the system will wend towards this value. In the present experiment, the least confusable forms ([uda] and [ug^{w}a]) are exactly those which actually seem to have evolved in Trique from more confusable forms ([uda] and [uga]).

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