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Stochastic Phonological Knowledge: The Case of Hungarian Vowel Harmony

1. Acknowledgments

- This talk is based on a research project done in collaboration with **Zsuzsa Londe**, a graduate student in the UCLA Department of Applied Linguistics.
- We would like to thank our Hungarian-speaking consultants and experimental subjects for their enthusiastic help in providing data.

2. Theme

- Linguists commonly focus on clean, systematic areas of the grammar.
- Not all areas of the grammar are clean and systematic—others show lexical variation: *sing ~ sang*, *cling ~ clung*, *ding ~ dinged*
- What should linguistic theory say about these areas?

3. "Exceptions" are Often Patterns Themselves (Pinker and Prince 1988)

- English past tense: *cling ~ clung*, *fling ~ flung*, *sling ~ slung*
  - This is productive (tests by Bybee and Moder 1983, Prasada and Pinker 1993, Albright and Hayes 2003)
- Hungarian: sometimes two patterns compete so closely we can't tell which one is the dominant one—see later on

4. A Commonly-Adopted Analytic Approach

- Designate one pattern as "regular", and somehow deal with the rest:
  - Assign diacritics so words will undergo minor rules (Halle and Mohanan 1985)

    thus *sat* [sæt] is: /sɪt/$_{\text{[+past, +Lowering Ablaut]}}$
    Lowering Ablaut: V → [+low]

  - Lexically list them, relegating the productivity of their pattern to an analogical mechanism such as a connectionist network (Pinker and Prince 1988).

    thus: *sat* is simply: /sæt/$_{\text{[+past]}}$

5. Claims

- Neither of the above approaches does justice to what the native speaker knows.
- Language learners do their work *effectively*, learning
  - the various rival patterns
  - their relative representation in the lexicon (i.e., numbers of forms)
- In novel situations, when required to inflect a novel stem, speakers behave stochastically, producing outputs in numbers that *match the lexical frequencies*.

6. Plan

- Describe a gradient, semi-systematic area of Hungarian vowel harmony
- Demonstrate, using data from a nonce-probe ("wug" test) experiment, that speakers do indeed project lexical variation into stochastic knowledge, which guides their behavior.
- Propose an analysis using stochastic Optimality Theory, following the general approach of Zuraw (2001).

HUNGARIAN VOWEL HARMONY: BACKGROUND

7. Some of the research literature on Hungarian vowel harmony

- Esztergár (1971), Arlotto (1972), Kiparsky (1973), Ringen (1975), Vago (1976, 1980), Kontra and Ringen (1986), Hare (1990), Ringen and Vago (1998), Dienes (1997), Siptár and Törkenczy (2000)

8. Hungarian vowels

IPA			**Orthography (used here)**		
Front Unrounded	Front Rounded	Back	Front Unrounded	Front Rounded	Back
i, iː	y, yː	u, uː	i, í	ü, ű	u, ú
eː	ø, øː	o, oː	é	ö, ő	o, ó
ɛ		ɔ, aː	e		a, á

Remember: "e" is a lower vowel than "é".

9. Nomenclature

N = front unrounded; mnemonic for "neutral"
F = front rounded; mnemonic for "pure front"
B = back

10. Our Illustrative Suffix

- We focus on a common and representative suffix, the dative:
  - ***-nak*/*-nek***, depending on vowel harmony

11. Vowel Harmony: The Simple Generalizations

- If the last vowel of the stem is B, the stem takes back suffixes:

BB	abl**a**k-nak	'window-dat.'	
NB	bír**ó**-nak	'judge-dat'	(despite preceding /í/)
BFB	amőb**á**-nak	'amoeba-dat.'	(despite preceding /ő/)

- If the last vowel of the stem is F, the stem takes front suffixes:

F	**ü**st-nek	'cauldron-dat.'	
BF	koszt**ű**m-nek	'woman's suit-dat.'	(despite preceding /o/)

12. Slightly More Complicated Generalizations

- If the stem consists entirely of N-type (front unrounded vowels), usually it takes front suffixes:

N	kert-nek	'garden-dat.'
N	cím-nek	'address-dat.'

- But there is a set of exceptional stems (about 25, in our data set) that take back suffixes even though they contain no back vowels at all; for example

N	híd-nak	'bridge-dat.'
N	síp-nak	'whistle-dat.'

  These are often called the *híd* stems, after a common one.
  Most *híd* stems are monosyllabic.

- All words of the form …FN, …FNN, …FNNN, etc. take front harmony:

FN	fűszer-nek	'spice-dat'
FNN	őrizet-nek	'custody-dat.'

13. Core Cases for This Paper: …BN and …BNN

- Here, lexical idiosyncrasy is greatest.
- Individual words can require back suffixes, or require front suffixes, or allow both ("doublets"; Vago 1976).

- For example, here are three words whose last two vowels are /… a é/:

BBN	mutagén-nek	ONLY		'mutagen-dative'
BN	farmer-nak	OR	farmer-nek	'jeans-dative'
BN	arzén-nak	OR	arzén-nek	'arsenic-dative'
BN	pallér-nak	ONLY		'foreman-dative'

- A learner of Hungarian would be well advised to memorize the behavior of each word—though there are good ways to guess; see below.

14. Terminology

mutagén	is a	*front-inducing stem*
farmer, arzén	are	*doublets*
pallér	is a	*back-inducing stem*

(Many stems are inherently front- or back-inducing due to the vowels they contain.)

15. Statistical Patterning

Idea: look at the Hungarian lexicon and count the front-inducing, doublet, and back-inducing stems for each vowel pattern.

Earlier work:

- Kontra and Ringen (1986)—a study of harmony in loan words
- Siptár and Törkenczy (2000)

16. Two Crucial Statistical Generalizations

- **Height Effect**: In […BN], e (= [ɛ]) takes front suffixes more often than é (=[eː]), which takes front suffixes more often than i, í. (= [i, iː]).
- **Count Effect**: BNN words take front suffixes more often than comparable BN words do.

These generalizations have hitherto been collected by hand—can we do better with a systematic search?

17. How We Searched the Hungarian Lexicon

- Assess the harmony behavior of the Hungarian language community by **Googling** large numbers of Hungarian words.
- Validate: Locate all the crucial cases (BN, BNN) and have three native speakers rate them all.

A GOOGLE SURVEY OF HUNGARIAN VOWEL HARMONY

18. Basic Method (Zuraw 2001)

- Example. Recall earlier data (coauthor's native speaker intuition):

mutagén-nek	'mutagen-dative'
arzén-nak OR arzén-nek	'arsenic-dative'
pallér-nak	'foreman-dative'

- We Google both possibilities and count hits:

Word	**Hits**	**Percent**
mutagénnak	0	0%
mutagénnek	31	100%
arzénnak	12	67%
arzénnek	6	33%
pallérnak	10	91%
pallérnek	1	9%

- A caution: this counts *pages that contain* the target word, not *tokens* of the target word. For relative estimates of words that are not too common, this probably is not a large distortion.
- Googling facilitated by a computer program, "Query Google," which Googles about 2000 words/minute.[1]
- We undertook a number of controls, mostly not reported here, to minimize random garbage in the Google data.

19. Sorting the Data: A Noise-Averting Criterion

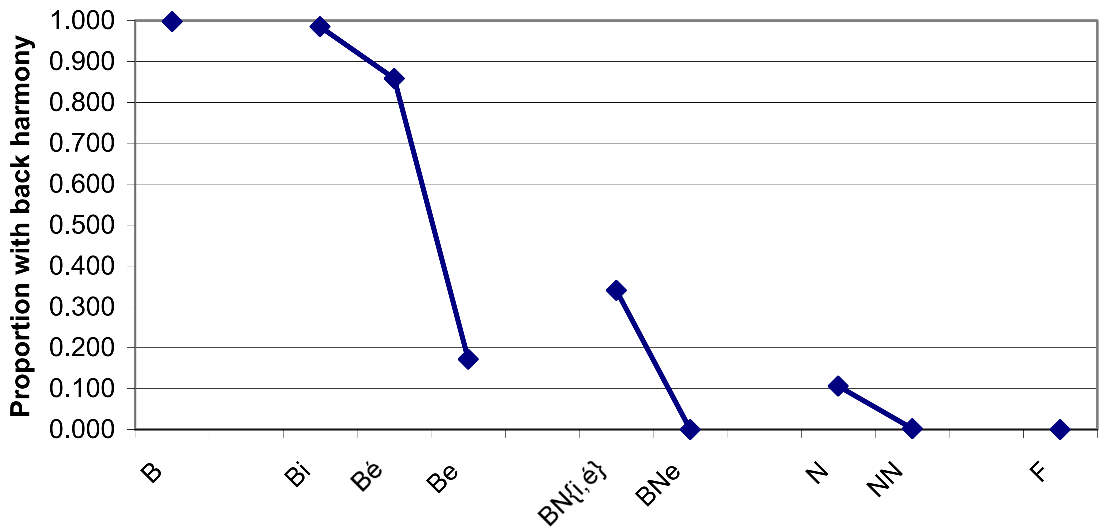
More than 97% back:	counted as all back
Less than 3% back:	counted as all front
Otherwise:	counted as a "doublet"

Then, for simplicity, all values were reduced to a number (all back = 1, all front = 0):

$$\frac{\text{total back} + .5 \times \text{total doublet}}{\text{total front} + \text{total doublet} + \text{total back}}$$

[1] "Query Google" is implemented as a Web applet at www.linguistics.ucla.edu/people/hayes/QueryGoogle/.

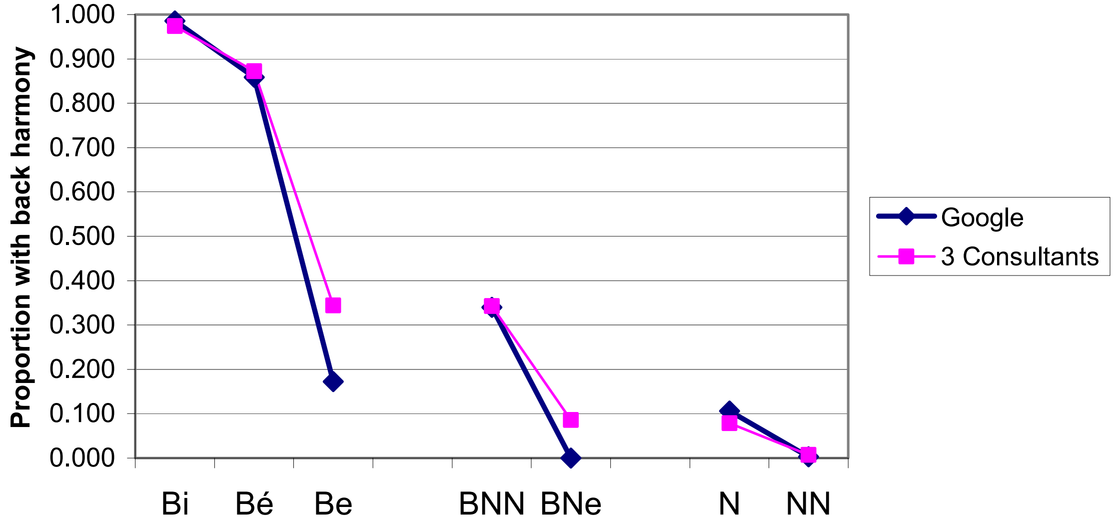
20. Results (11,000 stems)



- Straightforward cases:
  - Words ending in F take front harmony (.000 back in Google data)
  - Words ending in B take back harmony (.997 back)
- Words with all N: just a few are of the *híd* type described in (12) (.018).
  - A monosyllable is more likely to be a *híd* stem than a disyllable (N = .106; NN = .003).
- Words ending with […BN]: there is indeed a **Height Effect**, of the type described in (16). The lower the vowel, the less transparent it is.
  - Be (.172) < Bé (.858) < Bi,í (.985)
- BN vs. BNN: as noted above in (16), there is indeed a **Count Effect**:
  - BN (.842) > (.239).
- The Height effect is present in BNN words to a limited extent:
  - BNe (.000) < $\text{BNN}_{[-\text{low}]}$ (.340).[2]

[2] Chi square tests: for BNe vs. BN(other), $\chi^2 = 8.98$, p = .003; for all others $\chi^2 > 40$ and my software returns zero as the p-value.

21. Checkup: Elicit 1129 Words from Three Native Speakers



THE PRODUCTIVITY OF THE PATTERN: A WUG TEST

22. To Test

- Are these generalizations just random accidents of the lexicon, or are they actively apprehended and extended by Hungarian speakers?
- Test productivity by asking them to add -*nak* or -*nek* to made-up stems ("wug" test; Berko 1958)

23. Wug Words: Two Sets of 15 Forms

Basis of selection: test the generalizations noted above.

Type	**Set 1**	**Set 2**
Bé	hádél, kolén	vuszék, vánél
Be	órel, bontel, kázen	ranyel, unyeg, csúltek
Bi	monyil, csádik	kánit, pozin
BNN	poribit, lányitég	lolivit, ányivél
BNe	fányedeg, luteker	álendel, móleter
F	gyülüt	hösög
N	híny	nyís
NN	zefét	petlér
B	szandat	bortog

- Each subject saw one set or the other.
- Words were chosen to be phonologically ordinary but not to evoke any particular existing word.

24. Frames

- Our wug-sentence frames gave consultants the nominative (no ending) and asked them to provide the dative (*-nak*/*-nek*).

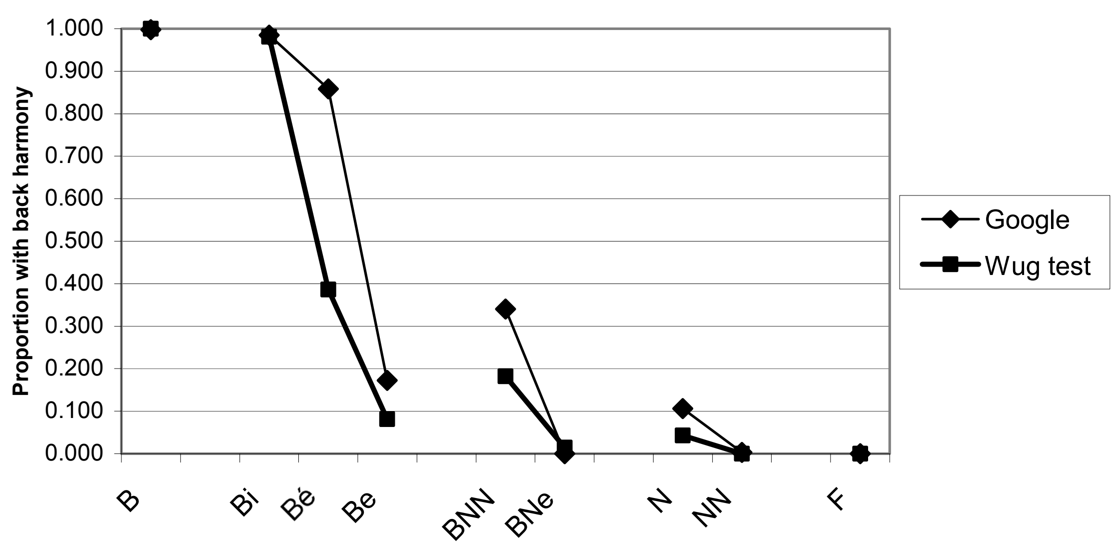
25. Sample Frame (translated into English)

> **hádél**
>
> Women in the Middle Ages used hádél to wash clothing. Back then, ___*(hádél)*________ grew abundantly in the fields. It is very hard to find nowadays, but it is said that __*(hádélnek or hádélnek)*___ had a wonderful fragrance.

- Various controls used to avoid effects of test order or frame sentence.
- Test was a simple written questionnaire, distributed to 171 (fairly well educated) Hungarians in Budapest and Tiszafüred, Hungary, mostly friends and relatives of my coauthor.

RESULTS OF THE WUG TEST

26. Matchup with the Lexicon as Measured by Google



27. Reviewing the Earlier Qualitative Findings—Do They Match with Wug Test Data?

- Words ending in F take front harmony (backness score 0).
- Words ending in B take back harmony (1).
- Words with all neutrals: they were occasionally treated as being of the *híd* type (.021), but normally given front suffixes. A monosyllable is far more likely to be a *híd* word than a disyllable (N = .043; NN = 0).

- Words ending with BN: **Height Effect**—the lower the vowel, the fewer the back suffixes: Be (.081) < Bé (.386) < Bi (.981).
- BN vs. BNN: **Count Effect**—number of neutrals matters.
    - BNi (.306) < (.981); BNe (.014) < Be (.182).[3]
- There is an overall **frontness bias**. Likely explanation:
    - Rarer words take front harmony more often (stem log frequency-backness correlation in Google data: r = .15), and wug words are felt to be rare.
- See Zuraw (2001) for a similar match-up in Tagalog.

28. Theoretical Conclusions

- Hungarian speakers are good stochastic learners.
- When given a wug word, Hungarians vacillate, following the pattern of their lexicon as a whole.
- Wug-testing behavior: they like to make a **representative** and **suitable** range of guess—rather than guessing the "best choice" every time.

A THEORETICAL MODEL OF VARIATION IN HUNGARIAN VOWEL HARMONY

29. What Should a Model Accomplish?

- Permit the speaker to **list** lexical entries that indicate the form that is actually used for a particular BN or BNN stem (most such stems are *not* doublets).
- Model the speaker's **expectations** about what harmony a novel stem will take (thus accounting for our Wug test data).
- Characterize the native speaker's knowledge of **what could in principle be listed**.
    - Example: "bortog-nek", from our Wug test, is considered by native speakers to be impossible no matter what; yet "nyís-nak" seems imaginable but unlikely.

30. Theories Employed

- **Optimality theory** (Prince and Smolensky 1993), with
- **Variation due to free ranking of constraints** (Anttila 1997a, 1997b)
- **Match quantitative effect with stochastic rankings** (Boersma 1997, Boersma and Hayes 2001)
    - Every constraint pair (A, B) associated with a probability (0-1), specifying how likely A >> B on any given speaking occasion.
- The **dual listing/generation model** of Zuraw (2001):
    - Certain inflectional forms are listed.

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[3] For the comparisons just noted, results of a chi-square test are as follows: N vs. NN: $\chi^2 = 6.664$, $p < .01$; Be vs. Bé: $\chi^2 = 104$, $p \cong 0$; Bé vs. Bi: $\chi^2 = 245$, $p \cong 0$; BNi vs. Bi: $\chi^2 = 247$, $p \cong 0$; BNe vs. Be: $\chi^2 = 15.75$, $p = .00007$.

- Faithfulness constraints force the use of a particular listed form even if it violates other constraints.
- A “subterranean grammar” of lower-ranked, normally-inactive constraints governs behavior in novel situations.

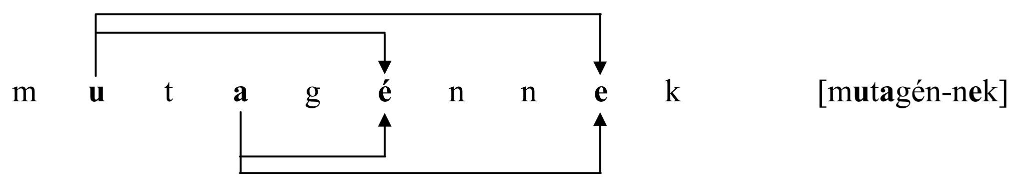
31. GEN

- GEN provides allomorphic variants ([ablaknak], [ablaknek]), based on the fact that the dative suffix has a dual lexical entry /{nak, nek}/.[4]

32. Markedness Constraints Governing Harmony

These are versions of the AGREE family (Lombardi 1999), relativized to distance.

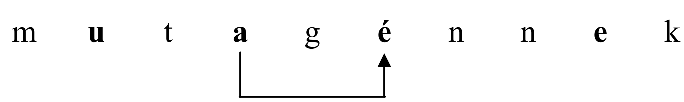
- DISTAL B incurs a violation in every instance in which a front vowel is preceded by a back vowel anywhere in the word, e.g.



incurs four violations.

- Similarly DISTAL F.

- LOCAL B incurs a violation in every instance in which the closest vowel preceding a front vowel is back, e.g. just one violation for



- Similarly LOCAL i; LOCAL é; LOCAL e
- LOCAL í will be ignored, since we have no Wug test data on this vowel.

- One constraint with a “double trigger”, analyzed in depth by Walker (2001), but just stipulated here: “LOCAL NN”, violated when NN is followed by B.

33. The Height Effect in BN Words

- Claim: in [...BN], both B and N are influencing harmony, and lower front vowels are stronger triggers.
- See Kaun (1995) for the general approach: harmony is triggered preferentially by perceptually-inferior vowels, lacking the extreme phonetic realization of their category.

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[4] Many suffixes have just one allomorph (e.g. -*nék* ‘1 sg. conditional’); these have only one entry.

- Lower front vowels have lower F2, and are thus inferior perceptually.
- They need more help, and get it by spreading.
- Posited universal ranking:

  LOCAL e >> LOCAL é >> LOCAL i

34. Constraint Rankings: Strict

- LOCAL B strictly dominates DISTAL F (probability = 1), to obtain [amőbá-nak], not *[amőbá-nek]:

/amőbá {-nak, -nek}/	LOCAL B	DISTAL F
☞ amőbá-nak		*
*amőbá-nek	*!	

- LOCAL F strictly dominates DISTAL B, to obtain [ʃofőr-nek], not *[ʃofőr-nak]:

/ʃofőr { -nek, -nak }/	LOCAL F	DISTAL B
☞ ʃofőr-nek		*
*ʃofőr-nak	*!	

35. Stems are Frequently and Stably Disharmonic

- Reason: IDENT-IO([back]) IN STEMS is undominated.
- For the frequent specially faithful character of stem material, see e.g. Casali (1997).

/farmer/	IDENT-IO([back]) IN STEMS	LOCAL B
☞ farmer		*
*farmar	*!	

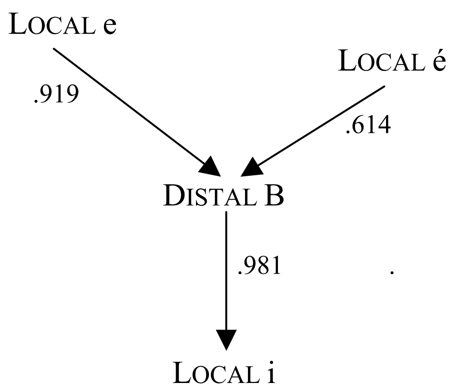
36. About Stochastic Rankings

- The stochastic rankings to follow are hand-created (hypothesized by the authors);[5] see later for the possibility of learning them by algorithm.
- In the formalism of stochastic OT, ranking is represented Gaussian probability distributions arrayed along a linear scale. I will simplify the presentation by just giving pairwise ranking probabilities.

[5] However, the predictions of each proposed hand-ranked grammar were checked by machine, using OTSoft (Hayes, Tesar and Zuraw, 2003).

37. Stochastic Rankings Needed

- DISTAL B is in gradient ranking relations with its local neutral-vowel competitors, producing free variation for Be, Bé, and Bi in appropriate proportions.



- This achieves a ideally-perfect frequency match to the varying BN forms. Here, we attempt to model the proportion of *-nak* forms in the Wug test data:

	Wug test	Model[6]
/Bi/	.981	.981
/Bé/	.614	.613
/Be/	.081	.081

- The perfect match is unsurprising we're specifying 3 relative rankings (only 3 cases of constraint conflict) to model 3 frequency values; tiny deviations result because grammar-testing is stochastic.

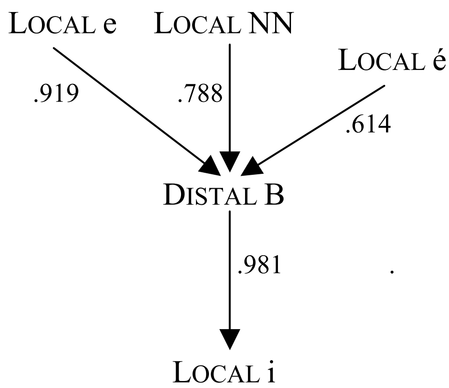
38. Adding in the Effect of LOCAL NN

- Comparing each case of BN_i with $B\mathbf{N}N_i$: (proportion with *-nak*):

	Wug test		Wug test
/Bi/	.981	/BNi/	.306
/Bé/	.614	/BNé/	.059
/Be/	.081	/BNe/	.014

  In the analysis here, this is because the forms on the right violate LOCAL NN, which penalizes *-nak*.
- This will increase the fraction of *-nek* for each $B\mathbf{N}N_i$ relative to BN_i.
- We're now generating 6 frequencies with only 4 conflicting constraint pairs, so a perfect data match is unobtainable.
- Reasonably good results can be obtained as follows:

[6] Grammar was tested by running it for 100,000 trials. Multiple runs yielded very similar results.



39. Results

Numbers are the proportion of back *-nak* generated:

	Wug test	Model		Wug test	Model
/Bi/	.981	.981	/BNi/	.306	.212
/Bé/	.614	.613	/BNé/	.059	.142
/Be/	.081	.081	/BNe/	.014	.045

- Results are quantitatively imperfect, but qualitatively correct in capturing relative comparisons:

  Bi > Bé > Be
  BNi > BNé > BNi
  Bi > BNi, Bé > BNé, Be > BNe

40. Letting Individual Lexical Items Have their Say

- The Hungarian variation is primarily word-by-word variation, and not token-by-token (the latter only in the doublets).
- Most suffixed words have an *invariant* suffix, not a statistical blend of the suffix choice predicted by the grammar given so far.
- Hence, evidence for memorization: the mature Hungarian speaker has internalized many lexical entries that specify for BN, BNN word types which suffixes a stem must take.

41. Zuraw's Theory (Zuraw 2001)

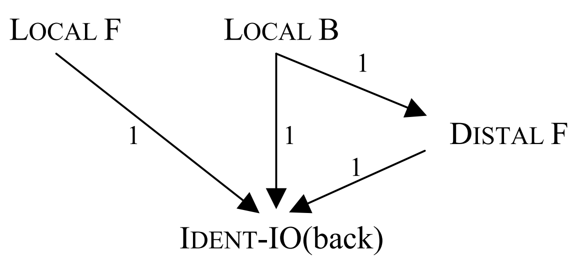
- Faithfulness constraints requiring that the phonological form of the listed entry be faithfully reflected in surface form.
- We assume here a strict ranking: IDENT-IO([back]) >> { LOCAL i, LOCAL é, LOCAL e, LOCAL NN, DISTAL B }.
- Here is how the form *matek-nak* 'math-dative' wins, despite having the less statistically likely suffix choice:

/matek-nak/	IDENT-IO([back])[7]	LOCAL e	DISTAL B
☞ matek-nak		*	
*matek-nek	*!		*

- **Wug forms** have no lexical entry for their datives—hence the inventory of stochastically-ranked "subterranean" constraints { LOCAL i, LOCAL é, LOCAL e, LOCAL NN, DISTAL B } have their say when a speaker takes a wug test (which, for a child, is every day).

42. *Not* Letting Individual Lexical Items Have their Say—Where Appropriate

- We don't want IDENT-IO([back]) to protect monstrosities.
- Hungarian has absolutely no:
  - ➢ F stems that take back suffixes (**hűd-nak*)
  - ➢ B stems that take front suffixes (**hud-nek*)
  - ➢ F(N)* stems that take back suffixes (**ühid-nak*)
- If LOCAL B, LOCAL F, and DISTAL F strictly dominate IDENT-IO(back), then *even if the speaker tried to internalize exceptional entries for such words*, the grammar would not permit her to utter them as disharmonic.[8]



- No **hűd-nak*, even if the lexicon asks for one

/hűd-nak/	LOCAL F	IDENT-IO(back)
☞ hűd-nek		*
* hűd-nak	*!	

- No **hud-nek*, even if the lexicon asks for one

/hud-nek/	LOCAL B	IDENT-IO(back)
☞ hud-nak		*
* hud-nek	*!	

[7] Note: this is *general* IDENT-IO(back), not IDENT-IO([back]) IN STEMS. Suffixes must harmonize with preceding B and F, but stem vowels need not do so.

[8] This is the Richness of the Base idea (Prince and Smolensky 1993), applied to alternations.

- No **hű̋di-nak*, even if the lexicon asks for one

/hű̋di-nak/	DISTAL F	IDENT-IO(back)
☞ hű̋di-nek		*
* hű̋di-nak	*!	

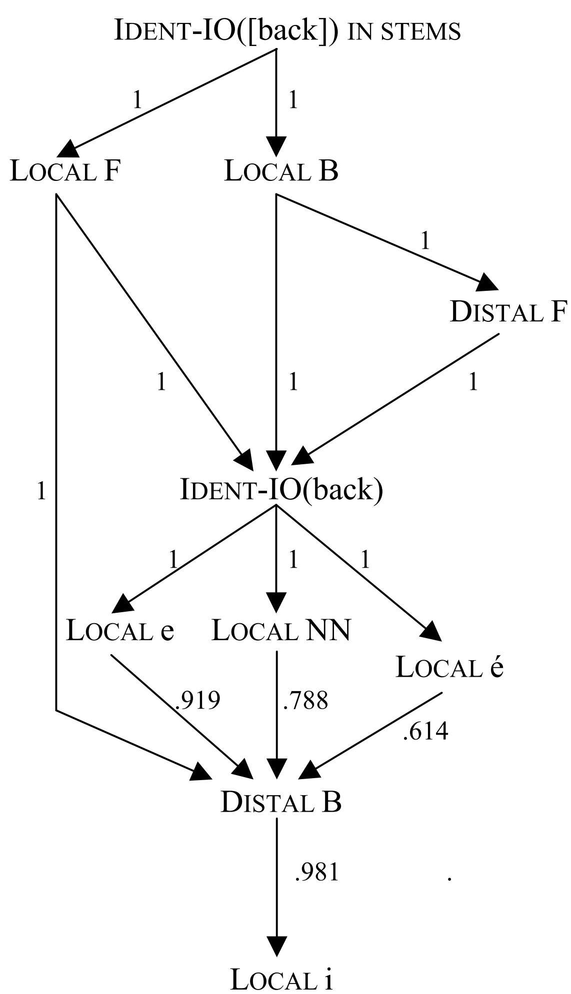
- However, for all Markedness constraints ranked below IDENT-IO(back) (cf. (41)), an invariant listed form violating that constraint *can* assert itself in the output.

43. Summary

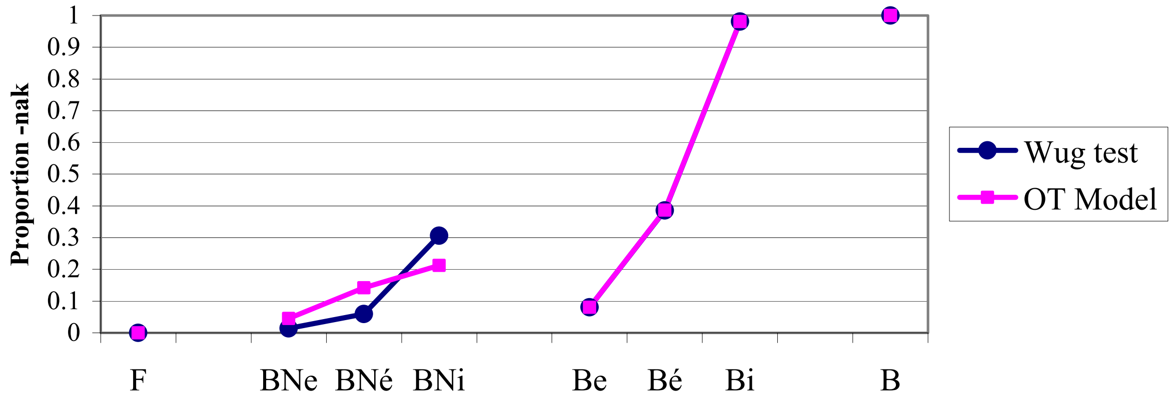
The analysis has:

- Ruled out monstrosities like **hű̋d-nak*.
- Accounted for stochastic behavior when it is observed, e.g. our wug test data.
- Permitted the lexicon to dictate an outcome, where no monstrosity would arise.

44. Full Hasse Diagram



45. Comparison: Model against Wug Test Data



L

LEARNING THE GRAMMAR

46. Higher Aspirations for Linguistic Theory?

- The ultimate test for a theory of UG: couple it with a learning algorithm and representative data, and see if the right grammar is learned.

47. Using Current Ranking Algorithms as a First-Pass Effort

- **Step I**: use Low Faithfulness Constraint Demotion (Hayes 2004) to determine what is a *possible* harmony pattern.[9] This is done by ranking Faithfulness appropriately:

  Local F, Local B >>
  Distal F >>
  Ident-IO(back) >>
  Local e, Local NN, Local é, Local B, Local i

- **Step II**: Ignore Faithfulness, and determine the *statistical details* by using the Gradual Learning Algorithm (GLA; Boersma 1998, Boersma and Hayes 2001), constrained to respect the rankings already discovered

48. Result

- This learns a grammar rather like (44), differing only slightly in the details. Here are its predictions,[10] together with the learning data and the Wug test data:

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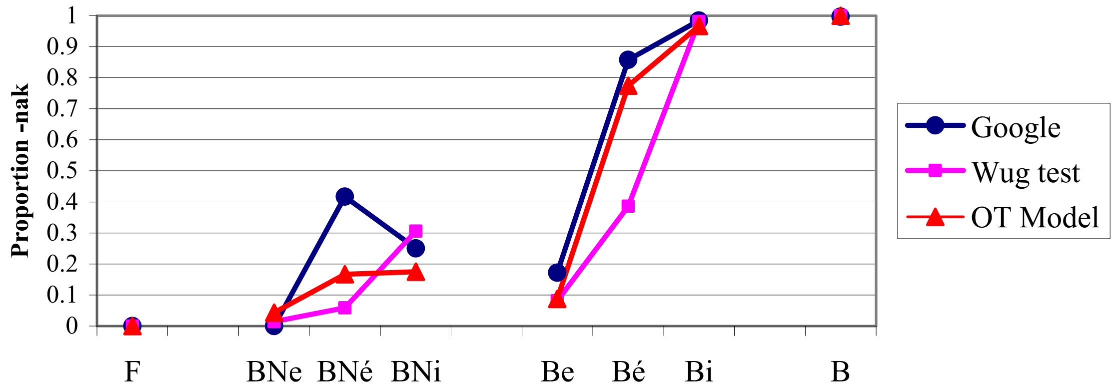
[9] Biased Constraint Demotion (Prince and Tesar 2004) works just as well.

[10] Average of ten runs; standard deviation across runs is moderate.



49. How to Learn Patterns That are Nicer than the Input Data

- Note the odd glitch in the Google data: too many *-nak* for BNé.
- This was almost certainly accidental, due to there being so few stems of this type in the corpus (4 *-nak*, 2 doublet, 6 *-nek*).
- GLA learning "smooths" this out a bit, by making use of information from the Bé forms.
- Native speakers smooth it out even more—how?

TWO ISSUES FOR FURTHER STUDY

50. Intersuffix Agreement

- If a stem takes *-nek* instead of *-nak*, then for the inessive singular it probably takes *-ben* instead of *-ban*. What explains this? (Quick answer: extension of OO-correspondence; but more data needed before proceeding.)

51. Further Refinement of the Trigger Distance Constraint System

- BFN vs. FBN — not treated under our mere "local-distal" distinction.
- Needed: a replacement for the (now widely doubted[11]) autosegmental theory of long-distance assimilation effects, which will do equally well at characterizing the notion "closest trigger".
- Families like AGREE B___ >> AGREE BX___ >> AGREE BXX___ … seem a possibility but need further working out…

[11] See Frisch, Broe, and Pierrehumbert (1997), Hansson (2001, Rose and Walker (2001).

CONCLUSION

52. What have we learned?

- Lexical variation (word-by-word) is accurately projected by Hungarian speakers into behavioral variation (guessing the pattern of new words).
- Stochastic Optimality Theory offers a model that can describe this ability on the part of speakers, while retaining the essence of earlier phonological analyses.
- Current learning algorithms support a first-pass effort at learning the rankings from data.
- Many issues, particularly involving learning, remain…

References

Albright, Adam and Bruce Hayes (2003)"Rules vs. analogy in English past tenses: a computational/experimental study," *Cognition* 90: 119-161.

Anttila, Arto. 1997a. *Variation in Finnish phonology and morphology*. Doctoral dissertation, Stanford University, Stanford, Calif.

Anttila, Arto. 1997b. Deriving variation from grammar: A study of Finnish genitives. In *Variation, change and phonological theory*, ed. Frans Hinskens, Roeland van Hout, and Leo Wetzels. Amsterdam: John Benjamins. Rutgers Optimality Archive ROA-63, http://ruccs.rutgers.edu/roa.html.

Baayen, H., Schreuder, R., de Jong, N., & Krott, A. (2002). Dutch inflection: The rules that prove the exception. In S. Nooteboom, F. Weerman, and F. Wijnen (Eds.), *Storage and computation in the language faculty*. Dordrecht: Kluwer, 61-92.

Berko, Jean (1958). The child's learning of English morphology. *Word* **14**: 150-177.

Boersma, Paul (1997) "How we learn variation, optionality, and probability," *Proceedings of the Institute of Phonetic Sciences of the University of Amsterdam* 21:43–58. http://www.fon.hum.uva.nl/paul/

Boersma, Paul and Bruce Hayes (2001) Empirical tests of the Gradual Learning Algorithm. Linguistic Inquiry 32: 45-86.

Bybee, Joan and Moder, Carol L. (1983). Morphological classes as natural categories. *Language*, *59*, 251–270.

Casali, Roderic (1997). "Vowel elision in hiatus contexts: which vowel goes? Language 73: 493-533

Dienes, Péter (1997) Hungarian neutral vowels. In: *The Odd Yearbook*, 151-180, on-line, budling.nytud.hu/~cash/odd/odd97/dp.pdf

Frisch, Stefan, Janet Pierrehumbert, and Michael Broe (1997) Similarity and phonotactics in Arabic. ROA 223.

Esztergár, Marianne (1971) *A generative phonology of nouns and vowel harmony in Hungarian*. Ph.D. dissertation, University of California, San Diego.

Halle, Morris and K. P. Mohanan (1985) Segmental phonology of modern English. *Linguistic Inquiry* 16: 57-116.

Hansson, Gunnar (2001) *Theoretical and Typological Issues in Consonant Harmony*. Ph.D. dissertation, UC Berkeley.

Hare, Mary (1990) The role of similarity in Hungarian vowel harmony: A connectionist account. *Connection Science*, 2:123-150.

Hayes, Bruce (2004). Phonological acquisition in Optimality Theory: the early stages. In R. Kager, J. Pater, & W. Zonneveld (Eds.), *Fixing priorities: constraints in phonological acquisition*. Cambridge University Press. http://www.linguistics.ucla.edu/people/hayes/Acquisition/.

Hayes, Bruce, Bruce Tesar, and Kie Zuraw (2003) "OTSoft 2.1," software package, http://www.linguistics.ucla.edu/people/hayes/otsoft/.

Kaun, Abigail (1995) *The Typology of Rounding Harmony: An Optimality Theoretic Approach*. Ph.D. dissertation, UCLA. Rutgers Optimality Archive 239, [http://roa.rutgers.edu/view.php3?id=239].

Kontra, Miklós and Catherine Ringen (1986) Hungarian vowel harmony: the evidence from loanwords. *Ural-Altaische Jahrbücher* 58:1-14

Lombardi, Linda (1999). Positional faithfulness and voicing assimilation in optimality theory. *Natural Language and Linguistic Theory* 17, 267-302.

Olsson, Magnus, 1992; *Hungarian Phonology and Morphology*, Lund University Press, Sweden

Pinker, Steven and Alan S. Prince (1988). On language and connectionism: Analysis of a parallel distributed processing model of language acquisition. *Cognition* 28: 73–193.

Prasada, Sandeep and Steven Pinker (1993). Generalization of regular and irregular morphological patterns. *Language and Cognitive Processes*, *8*, 1–56.

Prince, Alan and Paul Smolensky. 1993. *Optimality Theory: Constraint Interaction in Generatire Grammar*. Technical Report TR-2, Rutgers University Cognitive Science Center, New Brunswick, NJ. To appear, MIT Press.

Prince, Alan and Bruce Tesar (2004). Learning phonotactic distributions. In R. Kager, J. Pater, & W. Zonneveld (Eds.), *Fixing priorities: constraints in phonological acquisition*. Cambridge University Press.

Ringen, Catherine (1975) *Vowel Harmony: Theoretical Implications*. Ph.D. dissertation, Indiana University. Published 1988: New York: Garland.

Ringen, Catherine and Robert Vago (1998) Hungarian vowel harmony in Optimality Theory. *Phonology* 15:393-416.

Rose, Sharon and Rachel Walker. (2001) A typology of consonant agreement as correspondence. ROA 458.

Siptár, Peter and Miklos Törkency (2000) *The Phonology of Hungarian*. Oxford: Oxford University Press.

Vago, Robert (1976) Theoretical implications of Hungarian vowel harmony. *Linguistic Inquiry* 7:243-263.

Vago, Robert (1980) *The Sound Pattern of Hungarian*. Washington: Georgetown University Press.

Walker, Rachel (2001) Round licensing, harmony, and bisyllabic triggers in Altaic. *Natural Language and Linguistic Theory* 19:827-878.

Zuraw, Kie (2001) *Patterned Exceptions in Phonology*, Ph.D. dissertation, UCLA.