Stochastic constraint-based grammars for Hausa verse and song

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1. Singing is complicated; it comes in layers …

- Three layers in Hausa (Chadic, W.Africa):
    - Words are arranged as poetry, to fit a **meter**.
    - The poetry is *re*-arranged in a **musical rhythm**, related to but not identical with the meter.
    - The sung rhythm is **realized in time**, in ways that are orderly but more than just mechanical reflections of musical rhythm.

2. Interest for phonologists here

- Extensive **variation** (even within a single poem), necessitating a formal model that can treat it.
- A new pattern of **harmonic bounding** — the implicational, maxent version.
- A bit of the renascent research program of **generative phonetics** — grammars of sound that go all the way to the physical surface.

HAUSA POETRY AND SONG

3. Source of my knowledge

- The publications, data collection, and vast personal knowledge of my research collaborator, Prof. **Russell Schuh** of UCLA.

4. Hausa poetry is based on light and heavy syllables

- A syllable is **light** if it ends in a short vowel. Symbol: ⏑ "breve" [ta]
- Else it is **heavy**. Symbol: – "macron" [tan, taa]

5. Hausa meters

- A characteristic pattern of heavies and lights, defining a form of verse.
- For instance, here is the "catalectic mutadarik" meter, often used in Hausa:

$$\left\{\begin{matrix}\smile\smile\\ -\end{matrix}\right\} - \left\{\begin{matrix}\smile\smile\\ -\end{matrix}\right\} - \left\{\begin{matrix}\smile\smile\\ -\end{matrix}\right\} - \smile -$$

6. The importance of moras for Hausa verse

- Heavy syllables assumed to have two moras, lights one.
- We'll assume some sort of traditional moraic representation (e.g. Hyman 1985, Hayes 1989).
- Mutadarik above is a simple case of bimoraic equivalence; free substitution of bimoraic sequences.

7. There are quite a few meters in Hausa

- See Schuh's work in References; here we cover just one.

THE RAJAZ METER

8. Basics of rajaz [ˈɹʌdʒʌz] structure

- Unit of composition is a **stanza** containing **five lines**.
  - ➢ Line 5 is special — see below.
- A **line** is composed of two[1] **metra** (sg. **metron**)
- A **metron** is normally composed of **six moras**.

9. The taxonomy of metron types

- There are **five major types** of metron, of which one hardly ever occurs initially, one hardly ever occurs finally.
- Combined counts of an 11 poem, 2476 line corpus:

Type	*As Metron 1*		*As Metron 2*		*Both metra together*	
	count	*fraction*	*count*	*fraction*	*count*	*fraction*
⏑ – ⏑ –	1146	0.463	521	0.210	1667	0.337
– – –	173	0.070	864	0.349	1037	0.209
– ⏑ ⏑ –	336	0.136	494	0.200	830	0.168
– – ⏑ –	688	0.278	47	0.019	735	0.148
⏑ ⏑ – –	25	0.010	487	0.197	512	0.103

10. A rajaz stanza that has all five metron types

- Stanza 32 of "Tutocin Shehu" ("The Banners of the Sheikh") by Mu'azu Had'eja (1955)

⏑ – ⏑	– /	– ⏑	⏑ –
Wà.kíi.là	náa	mân.cè	wá.níi
Maybe	I-PERF	forget	somebody

⏑	–	⏑ – /	⏑	⏑ – –
Káa	sán	há.líi	dà	tù.nàa.níi
you-PERF	know	manner	with	memory

[1] Three, in trimeter rajaz.

```
  –  –            ᴗ   –  /  –  –  –
Bàl.lée           kà.már  mìs.kíi.nìi
how-much-less     as-with poor-person

  ᴗ  –  ᴗ  –      /   ᴗ    ᴗ  –  –
Wà.kíi.là  bàa        shí  à.níi.níi
maybe      give-IMP   him  tenth-of-penny

ᴗ              –       ᴗ          –     /   ᴗ  –   ᴗ  –
Ă              sán     dà         yái       tù.nán.ní.yáa
one-SBJNCT     know    whether    he-does   memory
```

"Maybe I've forgotten somebody,
You know how thing are with memory.
How much less for a poor person,
Maybe give him a tenthpenny coin,
And know whether he remembers."

11. 7-mora metra (– – ᴗ –) can be "explained away"

- General convention of Hausa meter: *you may count initial heavy as light*.
- Let's take this at face value — now all metra are hexamoraic at the analytic level.
  - ➢ This will produce an intriguing result when we get to the phonetics.

12. Generalizations from (9) we want the analysis to cover

- Hexamoraicity of metra
- All metra end with heavy
- Iambic preference (iamb = ᴗ –, half a metron)
  - ➢ ᴗ – ᴗ – and its partner – – ᴗ – are 48.5% of all metra.

ANALYSIS OF THE METER

13. Metrical grids (Liberman 1975, Lerdahl and Jackendoff 1983)

```
                x                 x         Superstrong
     x          x          x      x         Strong
x    x   x  x   x   x   x  x   x  x   x  x  Weak
|    |\__/  |   |\__/   |  |\__/  |   |\__/
ᴗ    –      ᴗ   –       ᴗ  –      ᴗ   –
a    san    da  yai     tu nan    ni  yaa   (sample syllables)
```

- Columns define beat strength.
- Rows define levels of periodicity
- Grids serve as a "measuring stick" for candidate lines.
- For concreteness I've aligned a fully iambic line with the grid — reciting it, you can hear the rhythm.

14. Maxent metrics

- Sources:
  - **Maxent grammars**: Smolensky (1986), Goldwater and Johnson (2003); Hayes and Wilson (2008)
  - **As applied to metrics**: Hayes, Wilson and Shisko (2012)

15. Background on the maxent grammars to be developed here

- Maxent is one type of **Harmonic Grammar** (Smolensky 1986; Smolensky et al. 1992)
- It uses a variant of the **GEN** + **EVAL** architecture, as in Optimality Theory
- EVAL contains **constraints**, assigns **probabilities** to the candidates in GEN:
  - (very close to) **zero** for ungrammatical candidates
  - **positive probability** to acceptable candidates
  - The grammar **matches frequency** among multiple acceptable candidates.
- N.B.: no inputs or outputs, just GEN
- EVAL works like this:
  - Constraints are not ranked but **weighted**.
  - A mathematical formula (((24) below) translates violations and weights into predicted probabilities.
- How things work out in practice:
  - High-weighted constraints essentially **rule structures out**.
  - Weaker constraints determine **preferred** structures; they **match frequency** among the existing forms.

16. Our GEN

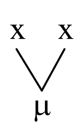
- In principle, all strings of ᴗ and – (infinite)
  - In practice: it is safe to use a finite set of 64 candidates for each metron.[2]
- We treat initial and final metra of the line separately, each with its own GEN.
  - This is safe: their patterning is statistically independent.
- We provide a separate GEN for stanza-final lines, which behave differently from non-final.
- Thus GEN = four lists of 64 candidates, each marked for a separate combination of 1st/2nd mora, stanza-final/non-final.

17. Constraints that (with the grid) enforce hexamoraicity

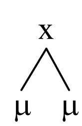
*STRETCH: For every grid column greater than one to which a mora is associated, assess a penalty.

*SQUEEZE: For every mora greater than one sharing a grid column, assess a penalty.

*Violation of *STRETCH*



*Violation of *SQUEEZE*



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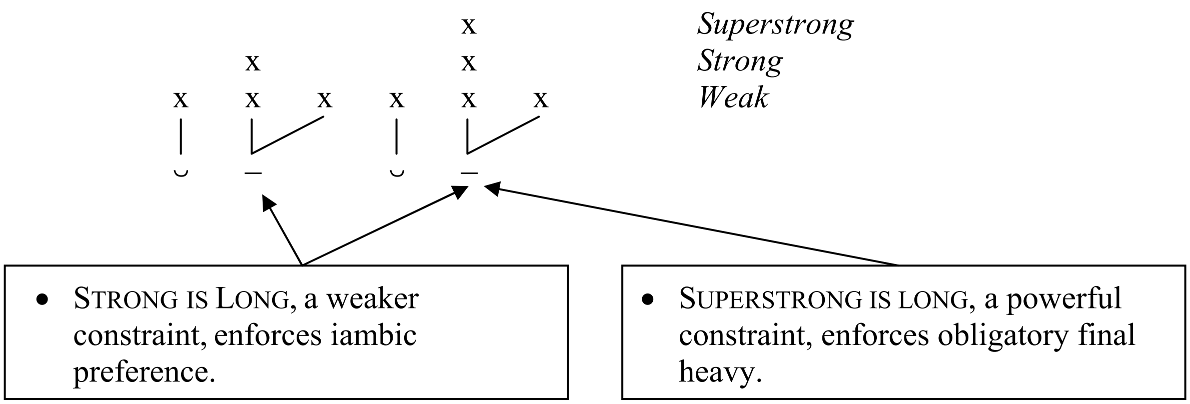
[2] We follow the method of Daland (in press), who establishes the conditions under which an infinite candidate set will not wreck a maxent analysis.

18. Constraints that relate weight to grid column height (cf. (13))

- These are **prominence alignment** constraints (Prince and Smolensky 1993)
  - similar to the well-known WEIGHT TO STRESS,
- They relate **weight** to **grid column height**.

a. STRONG IS LONG	Assess a penalty for any Strong (or stronger) grid column that does not initiate a heavy syllable.
b. SUPERSTRONG IS LONG	Assess a penalty for any Superstrong grid column that does not initiate a heavy syllable.
c. LONG IS STRONG	Assess a penalty for any heavy syllable that is not initiated in a Strong (or stronger) grid column.

19. Effects of the constraints in (18)



- In a minute we'll see the role played by LONG IS STRONG, which is also weak.

20. Full analysis I: The really strong constraints

*STRETCH, *SQUEEZE, SUPERSTRONG IS LONG plus
*THREE LIGHTS IN A ROW (true in all Hausa meters, also active in Ancient Greek)
*DON'T START LINE WITH ◡ ◡ (a mystery from the viewpoint of theory, but certainly valid)

- Together, these limit common metra to:
  - First metron: ◡ – ◡ –   – – ◡ –   – ◡ ◡ –   – – –
  - Second metron: ◡ – ◡ –   ◡ ◡ – –   – ◡ ◡ –   – – –

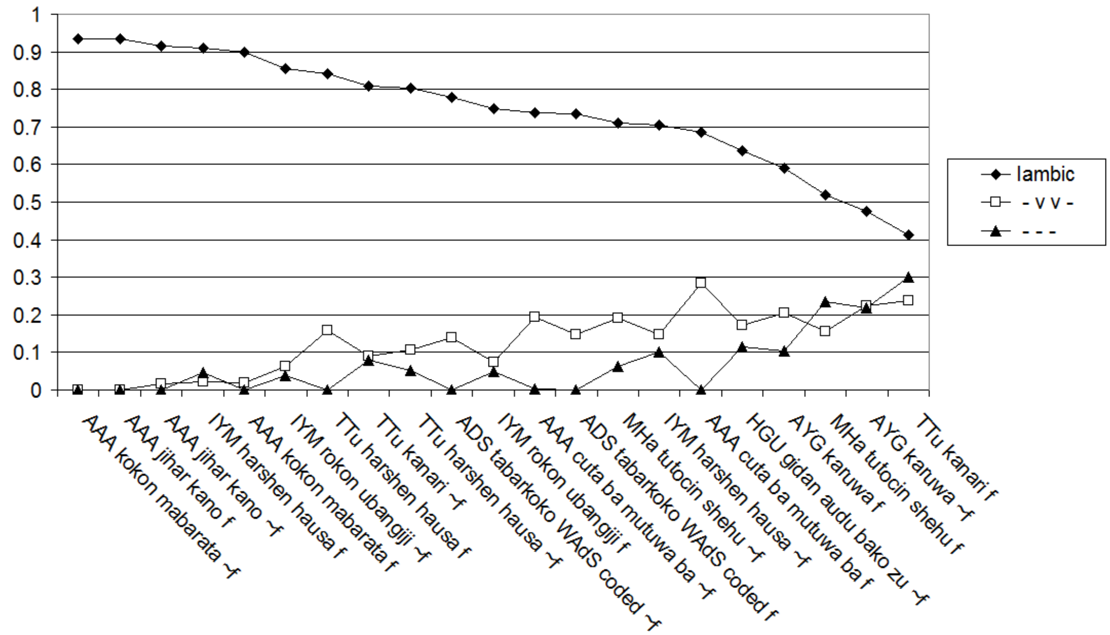
  These are the only candidates in GEN that obey all five constraints.
- Rest of the analysis: dealing with the **relative frequencies** of the five types.

21. Metron 1: A key pattern

- **First metra** vary by an orderly pattern:
  - Frequency of **iambic** ({[◡ – ◡ –],[– – ◡ –]}) > Freq. of [– ◡ ◡ –] > Freq. of [– – –].
  - True (with tiny exceptions) for every poem, both stanza-final and stanza-non-final.

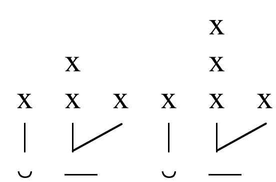
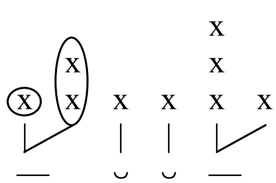
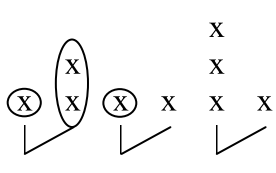
22. Graph: iambic > [– ◡ ◡ –] > [– – –] in the first metron

- f = final lines of stanzas, ~f = nonfinal lines



23. Can we derive this frequency relation from basic principles?

- Look at the violations of the constraints that discriminate these candidates:

	Violations of STRONG IS LONG	Violations of LONG IS STRONG
	**0**	**0**
	**1** from grid column 2	**1** from first heavy
	**1** from grid column 2	**2** from 1st and 2nd heavy

- This is **harmonic bounding** (subsets of constraint violations), matching frequency pattern.

24. Capturing the generalization (22) with the math of maxent

- Here is the formula by which maxent derives predicted **probabilities** from the **violations** of candidates and the **weights**:

$$p(\omega) = \frac{1}{Z} e^{-\Sigma_i \lambda_i \chi_i(\omega)}, \text{ where } Z = \Sigma_j \, e^{-\Sigma_i \lambda_i \chi_i(\omega_j)}$$

$p(\omega)$	predicted probability of metron type ω
Σ_i	summation across all constraints
λ_i	weight of the *i*th constraint
$\chi_i(\omega)$	the number of times ω violates the *i*th constraint
Σ_j	denotes summation across all possible metra

25. Deriving the implicational hierarchy just mentioned

- From the formula just given, it is easy to show that:
  - if Candidate A **harmonically bounds** Candidate B, then A necessarily gets **higher or equal probability** as B.
  - This is just what we observe in the frequencies of (22).
  - So poets can vary the weights of STRONG IS LONG and LONG IS STRONG as a part of their metrical style; but given harmonic bounding, they *must* reflect the *relative* frequency pattern.

26. Metron 2: much more is arbitrary

- Different poets favor different types for line-final metra
- … and they often like to use a different pattern for the final metron of the final line of the stanza.
- We can attribute *some* of this variation to patterns of singing (below), and the presence of refrains, but we think it is primarily stylistic.
- We therefore include a number of rather arbitrary constraints that govern possible line-final and stanza-final metra.

27. Analyzing the poems in full: procedure

- We use the core constraints already seen — enforcing adherence to the rhythmic template
- Plus constraints of
  - Requiring particular line endings (we invoke "quantitative clausulae", found in Slavic and Greek/Latin prose)
- Using software, we set the weights separately for every poem to match the data.[3]
- The "core constraints" virtually always get big weights.

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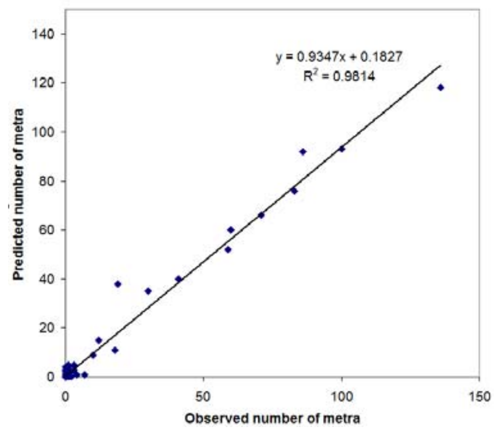
[3] Useful software: the "Solver" plug-in of Excel, or the Maxent Grammar Tool (www.linguistics.ucla.edu/people/hayes/MaxentGrammarTool/)

28. The weights for one poem, “Tutocin Shehu”

*SQUEEZE	4.2	*◡ ◡ ◡	1.4
*STRETCH	3.6	– – – CLAUSULA (LINE-FINAL)	0.8
SUPERSTRONG IS LONG	3.3	DON’T EMPLOY “INITIAL HEAVY AS LIGHT” CONVENTION	0.7
STRONG IS LONG — last metron of stanza	2.9	LONG IS STRONG	0.5
DON’T START LINE WITH ◡ ◡	2.4	STRONG IS LONG	0.4

29. Model fit

- Not bad; **scattergram** of predicted and observed frequencies is given at right.
- 256 data points: one GEN of 64 types for each of the four combinations of Metron 1/Metron 2, Stanza-final/Stanza-nonfinal.
- Most data points are near the origin.
- Other poems have very different metron patterns but similar accuracy of the grammar’s predictions.[4]



SINGING THE RAJAZ

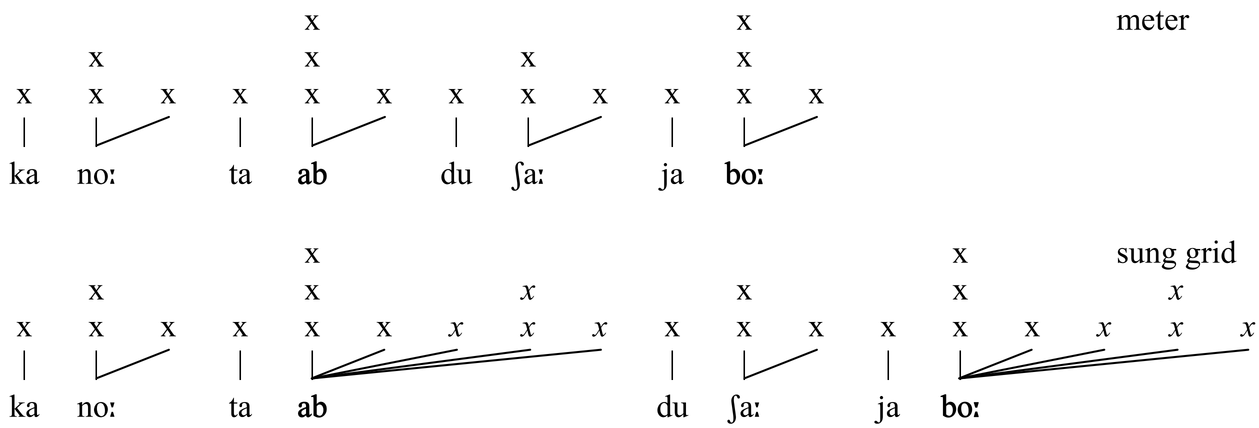
30. Data

- Schuh’s collection has recordings of five artists singing poetry in rajaz.
- **Not one** sings it “straight”, with the grid given above in (13).
- Every time, we see **remapping** of the basic pattern of the meter onto a new pattern for song.
  - ➢ This is also common in English and other European languages.
- Let’s look at two such remappings.

31. Remapping in “Tutocin Shehu” as sung by Abubakar Ladan

- The rhythm is what in Western music we would call 9/8 time.
- Grid is “augmented” with spliced-in material.

There are three other constraints are active for poems other than “Tutocin Shehu”: – – CLAUSULA (LINE-FINAL), ◡ ◡ – CLAUSULA (LINE-FINAL), and – – – CLAUSULA, STANZA FINAL.

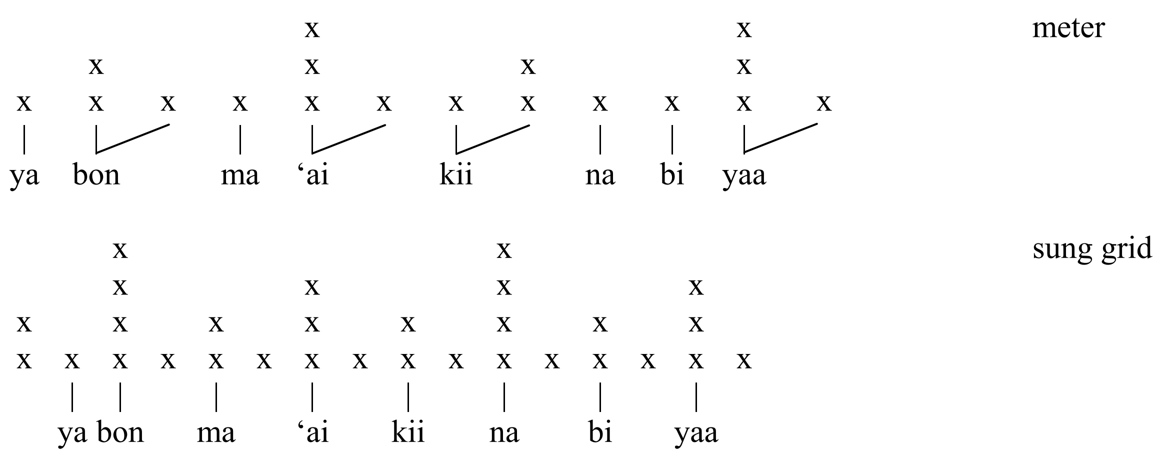


Káno̖o tá Ábdù sháa yàbóo (line 1a)
Kano of Abdu receive praise
'Kano of Abdu be praised'

[listen] Please ignore the quasi-disyllabic character of [ab].

32. Kokon mabarata,[5] by Ak'ilu Aliyu, sung by the poet

- Binary rhythm with short upbeat.
- Striking (but not total) disregard for syllable quantity — e.g. heavy syllables tend to fall in the stronger positions.



33. Analysis of "remapping"

- We have more questions than answers here!
- One very simple theory:
  - Poetry gets written as rajaz.
  - Meter is *thrown away*, leaving pure text.
  - Pure text is then sung to a new grid — no "grid-to-grid" connection[6]

[5] "Alms Seekers' Bowl"

- Yet — remapping is also found in improvised poetry (Schuh, forthcoming)
    - Can a poet *simultaneously* respect the requirements of two different grids?
    - These issues — "how many levels, how do they interact" — are cogently raised by Kiparsky (2006) for English folk verse, and explored in depth for Tashilhiyt Berber song by Dell and Elmedlaoui (2008).

MODELING THE PHONETICS OF RAJAZ SINGING

34. Generative phonetics

- Any theory that formally models the productive capacity of the native speaker to form novel phonetic representations and realize them physically in sound.

35. We are witnessing a revival of generative phonetics.[7]

- **Constraint-based models** (with GEN and EVAL) can directly express the functionally-sensible, conflicting teleologies we see in phonetics.
- **Harmonic grammar** is easily extended to treat the quantitative data.
- **Effective learning models** let us tune the phonetic grammars closely to language data — perhaps as children do when they acquire the phonetic pattern of their native language.
- Some standout work: Boersma (1998 et seq.), Flemming (2001), Flemming and Cho (2015), Windmann et al. (2015)

36. A fundamental principle of phonetic realization: *quantitative compromise* between conflicting targets

- **Example**: adding syllables to a word lengthens the word, but by less than the duration of the syllables added — since the original word shortens.
- Original reference is Lehiste (1972); see Fletcher (2012) for literature review.

sum	*summon*	*summoner*
longest [sʌm]	medium [sʌm]	shortest [sʌm]
546 ms.	348 ms.	273 ms.
shortest word	medium word	longest word
[sʌm]	[sʌmən]	[sʌmənər]
546 ms.	570 ms.	580 msec.

- Duration of [sʌm] is a compromise between its own inherent duration, and desire for words not to be too long.
- Phonetics of duration: stuffing **compressible sponges** into **stretchable sacks**.

[6] There are very clear examples of this; e.g. in the famous "Queen of the Night aria", Mozart utterly obliterates the iambic pentameter rhythm provided by his librettist Emanuel Schikaneder.

[7] Two outstanding works of rule-based generative phonetics: Allen et al. (1987), Beckman and Pierrehumbert (1988)

37. Implementing compromise in maxent grammars: Flemming (2001)

- His “maxent” is actually a non-stochastic version, generating one single output.
- Let linguistic categories each have a quantitative **target value**.
- Constraints penalize deviations from the value.
    - Actually: squared deviations, since otherwise you get many tied winners.

38. What Flemming accomplished with this model

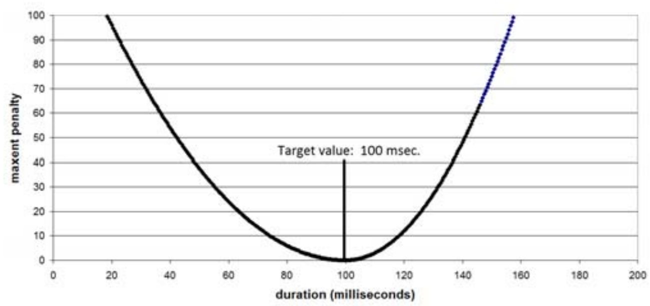
- Derived — as a theorem — the most famous of all compromise effects in phonetics: the **locus** effect in stop consonants (Sussman et al. 1991)
- Formant frequency at consonant release is a compromise between vowel target and consonant target.

39. “Sponges” and “sacks” for phonetic duration grammars

- *SQUEEZE: violations = square of [candidate value − target value] (in milliseconds)
- *STRETCH: violations = square of [target value − candidate value] (in milliseconds)
- We use both constraints for all targets, hence everything is both a sponge and a sack.

40. A schematic chart relating maxent penalty to deviation from target

- Weight of *SQUEEZE is 10; *STRETCH is 20.
- Since penalty is based on squared distance, we get two half-parabolas, steeper for *STRETCH.



41. Moving toward the rajaz analysis

- We set up **duration targets** for each of these categories:
    - syllable
    - mora
    - grid column
    - metron
- Each target is regulated by a *STRETCH and a *SQUEEZE constraint.
- We “**maxentify**” Flemming:
    - utilizing the maxent **learning procedure**
    - System outputs not a single value but a **probability distribution**.

42. The set of candidates (GEN)

- A three-syllable metron should have a GEN that specifies all combinations of three nonnegative real numbers, one for each syllable.
- But this is uncountably infinite …
- In practice, use **Boersma's idealization** (Boersma 1998)
  - all values on a fine-spaced grid (every 10 msec.) that are …
  - within a particular range covering all actual values (80 - 490 msec.)

43. The data we model

- Syllable durations of 100 lines of Tutocin Shehu
- Last syllable of metron hard to measure (often prepausal; "fades out") and we omitted these syllables from the modeling
  - Hence our "metron" target is really a "hemimetron" target.
  - Total syllables modeled = 562

44. Learning the grammar from data

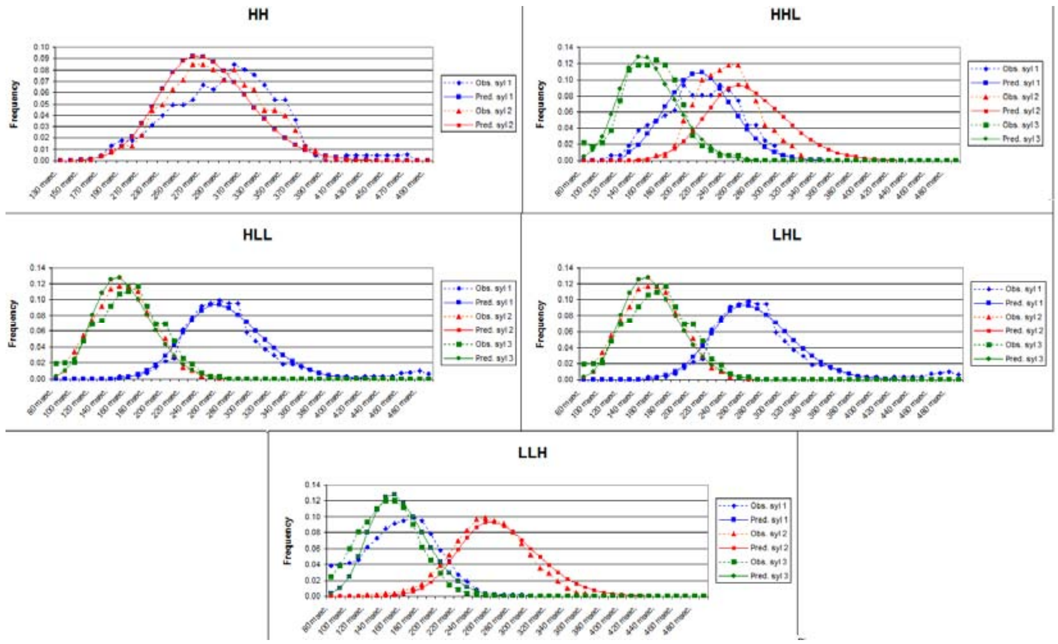
- To get the right weights, we use a machine search, following the method laid out in Flemming and Cho (2015).
- This is hard (local maxima of search space); please consider this work-in-progress.

45. The 12 parameters of our phonetic grammar

- Durational targets for four categories:
  - Mora: 110 msec.
  - Syllable: 187 msec.
  - Grid column: 129 msec.
  - Hemimetron: 573 msec.
- Weights for four *STRETCH constraints based on these targets:
  - *STRETCH MORA: 3.17
  - *STRETCH SYLLABLE: 2.07
  - *STRETCH GRID COLUMN: 4.87
  - *STRETCH HEMIMETRON: 0.88
- Weights for four *SQUEEZE constraints based on these targets:
  - *SQUEEZE MORA: 1.96
  - *SQUEEZE SYLLABLE: 0.03
  - *SQUEEZE GRID COLUMN: 0.63
  - *SQUEEZE HEMIMETRON: 0 (hence no effect)

46. This ends up working fairly well

- General fit is not bad, with predicted *distributions* (solid) matching *distributions* (dotted).

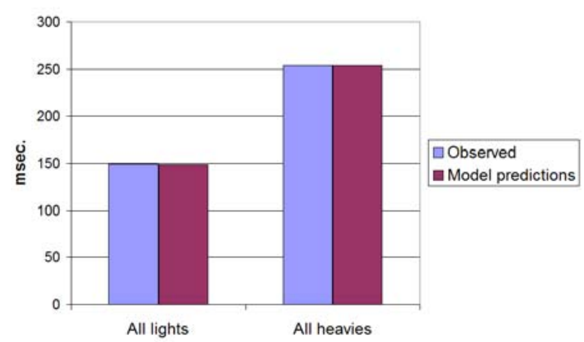


47. Reasoning through this qualitatively

- We will look at four compromises that get made and how the model captures them.

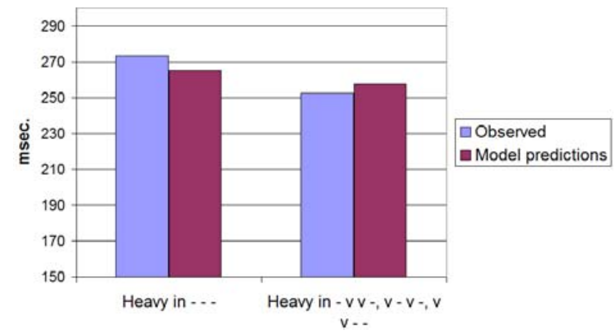
48. Heavy syllables are not twice as long as two lights

- Key idea: syllable target is lower than the doubled value of mora target. Maxent compromises.



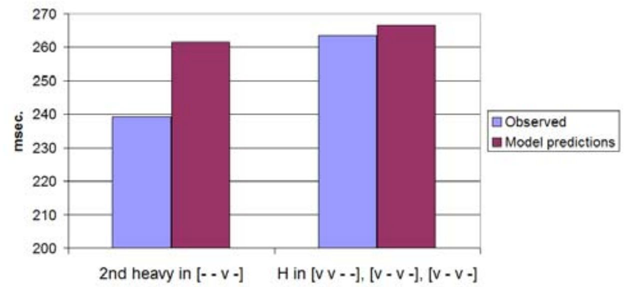
49. Heavies in [– – –] are longer than heavies in [◡ ◡ – –], [◡ – ◡ –], [– ◡ ◡ –]

- Key idea: The moras of light syllables are “fat” moras. Syllables of [– – –] do not have to share the metron with “fat” moras and have more room.
- Model predicts a difference in the right direction; a better model would predict a bigger difference.



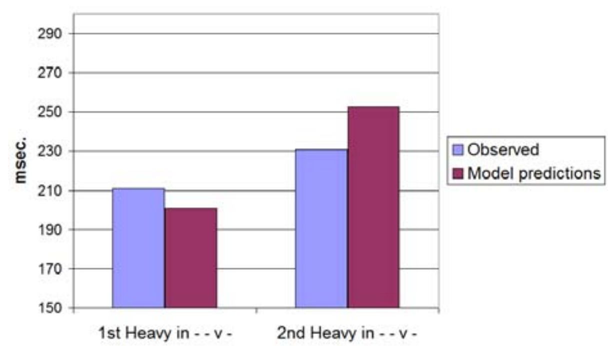
50. Heptamoraic [– – ◡ –] should have the shortest syllables of all

- Key idea: an extra mora must share the metron — one more “sponge in the sack”
- Model predicts a difference in the right direction; a better model would predict a bigger difference.



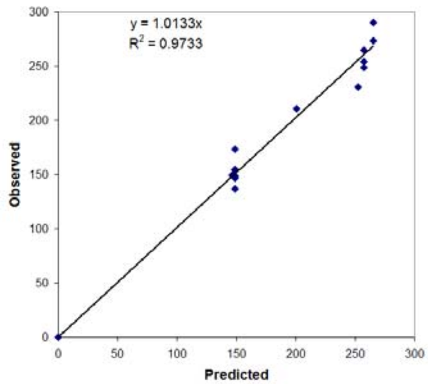
51. Of the first two heavies in [– – ◡ –], the first should be the shortest

- First heavy fills a single grid slot, due to the “count initial heavy as light” convention (11).
- Analysis: compromise between syllable and mora targets vs. grid column target.
- Model predicts the difference, but exaggerates it.



52. Overall model accuracy

- Scattergram of predicted vs. observed frequency for all 14 "types" of syllable (cases that the grammar treats distinctly).



53. Pondering the result

- Maxent **naturally derives the compromises** observed in phonetic patterning
- Here, the compromise involves **all** levels discussed. Initial syllable of heptamoraic metron is:
  - **longer** because it is **phonologically heavy**
  - **shorter** because the **metrics** assigns it to one grid column
  - **also shorter** because the sung-grid metron must accommodate seven moras
- The phonetic system is clearly **adaptable**, since the phonetic targets of the sung rhythm are superimposed on the phonological targets.

54. Overall conclusions

- We think we are doing pretty well modeling the metron frequencies of the 11 poems, using maxent and a mixture of natural and stylistic constraints.
- The remapping from verse rhythm to sung rhythm is at present a puzzle for theory — but at least we have some clear cases that could be used to help figure it out.
- Durational modeling is reasonably accurate and uses what seem to be sensible constraints.

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