# Opacity in parallel models of phonology: Insights from Uyghur backness harmony

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# Goals of this talk

- To make a claim about how we should think about (at least some) **phonological opacity**

- To introduce you to a few **phonological frameworks** used in the field
  - I'll assume everyone is familiar with phonological rules
  - We'll also talk about a couple flavors of Optimality Theory

- To provide an example of how **quantitative methods** can inform theoretical considerations!

# Roadmap

1. What is phonological opacity and why is it interesting?
2. Opacity in Uyghur backness harmony
3. Challenges of opacity for Optimality Theory
4. A corpus study of variable rates of opacity in Uyghur
5. Opacity as conflict between lexical and phonological knowledge

# Phonological opacity

Phonological theory deals with **generalizations** about sound patterns

- Rule-based serialism[1] expresses these as **rewrite rules**
- Optimality theory[2] expresses these as **constraints**

Generalizations can **interact** with one another

Sometimes this interaction leads to a generalization being **obscured**

This is **phonological opacity**[3]

[1] Chomsky & Halle 1968
[2] Prince & Smolensky 1993/2004
[3] Kiparsky 1971, 1973; McCarthy 2007; Baković 2007, 2011; Baković and Blumenfeld 2019; a.o.

# Kiparsky's definition of opacity[4]

Assume a rule of the form *A* → *B* / *C*_*D*. This rule is **opaque** if there are surface forms with either:

- *A* in environment *C*_*D* (***underapplication***)
- *A* → *B* in environments other than *C*_*D* (***overapplication***)

**Underapplication**: A process doesn't apply when it should

**Overapplication**: A process applies when it shouldn't

[4] Kiparsky 1971, 1973

# Example: Canadian raising

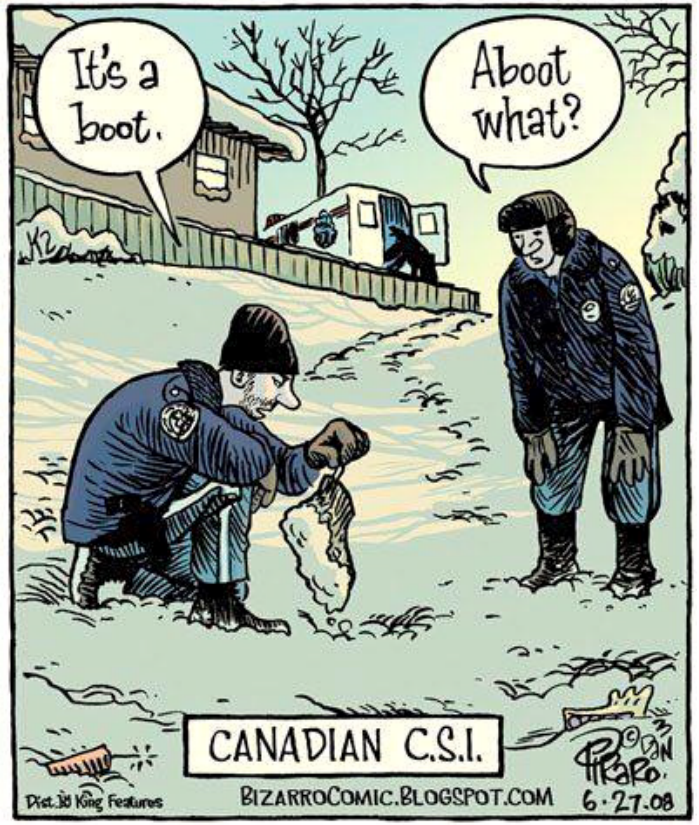
Many dialects of English **raise** the diphthongs /aɪ/ and /aʊ/ to [ʌɪ] and [ʌʊ] before voiceless sounds

| | | | |
|---|---|---|---|
| ‘knife’ | [n**ʌɪ**f] | ‘knives’ | [n**aɪ**vz] |
| ‘house’ | [h**ʌʊ**s] | ‘houses’ | [h**aʊ**zəz] |

This has come to be called **Canadian Raising**

**Rule 1(a)**: /aɪ/ → [ʌɪ] / __ [–voice]

**Rule 1(b)**: /aʊ/ → [ʌʊ] / __ [–voice]

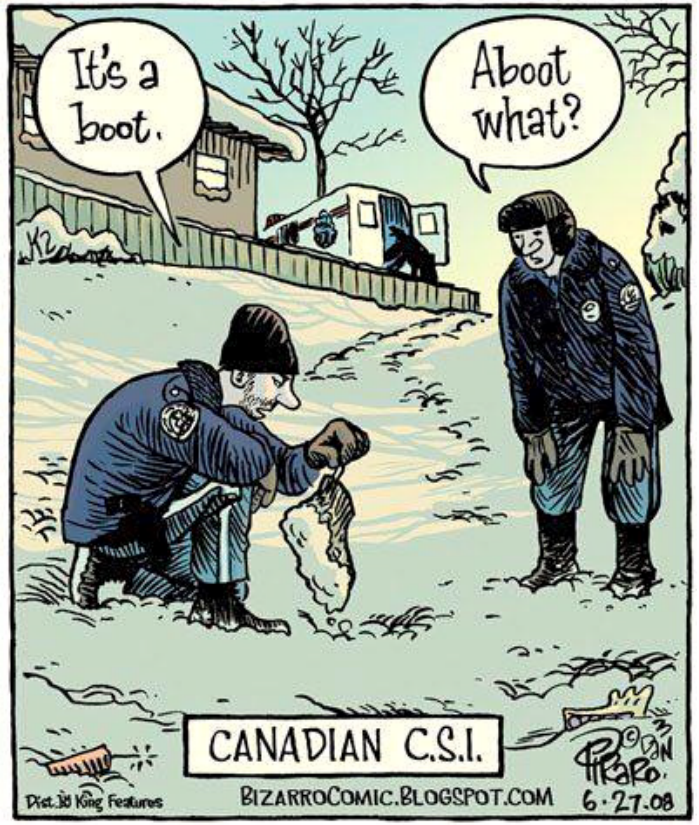


# Example: Canadian raising

North American English also has the familiar **tapping rule**, where /t d/ become [ɾ] following a stressed syllable.

| | | | |
|---|---|---|---|
| ‘eater’ | /i**t**-ɹ/ | → | [ˈi**ɾ**ɻ̩] |
| ‘reader’ | /ri**d**-ɹ/ | → | [ˈri**ɾ**ɻ̩] |

**Rule 2**: /t d/ → [ɾ] after stressed syllable

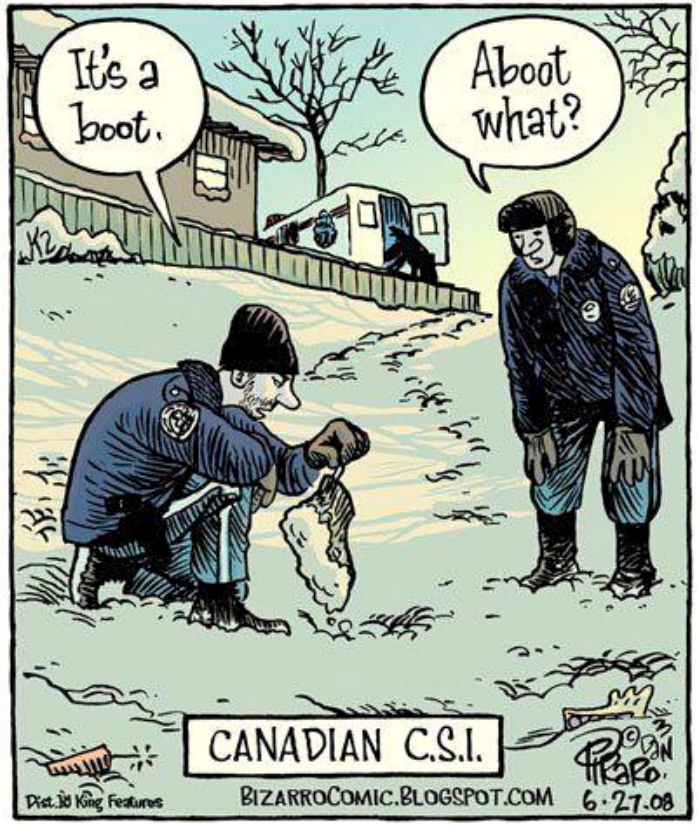



This rule **eliminates the voicing distinction** between /t/ and /d/

# Example: Canadian raising

These rules interact to produce opacity

| | ‘rider’ | ‘writer’ |
|---|---|---|
| **Input** | /ˈɹaɪd-ɻ/ | /ˈɹaɪt-ɻ/ |
| **Raising** | – | ʌɪ |
| **Tapping** | ɾ | ɾ |
| **Output** | [ˈɹaɪɾɻ] | **[ˈɹʌɪɾɻ]** |




Tapping **eliminates** the environment that caused raising

Looks like raising has applied when it shouldn’t have!

- This is **overapplication opacity** (or **counterbleeding**)

Joos 1942; Chambers 1973; Vance 1987; Bermúdez-Otero 2003; Idsardi 2006; Pater 2014; a.o.

# Why is opacity interesting?

**Challenges for learnability**

- Obscures generalizations
- Must learn a relationship between generalizations
- Studies have found both productive[5] and non-productive[6] opacity

**Challenges for theory**

- Theories represent generalizations differently (e.g., rules vs. constraints)
- Different representations predict different kinds of interactions
- Opacity is often used to argue in favor of one formalism vs. another

[5] e.g., Donegan & Stampe 1979, Al-Mozainy 1981, Vaux 2011
[6] e.g., Hooper/Bybee 1976, Mielke et al. 2003, Sanders 2003

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# The Uyghur Language

Uyghur [ʔʊjˈʁʊr] is a Southeastern Turkic language

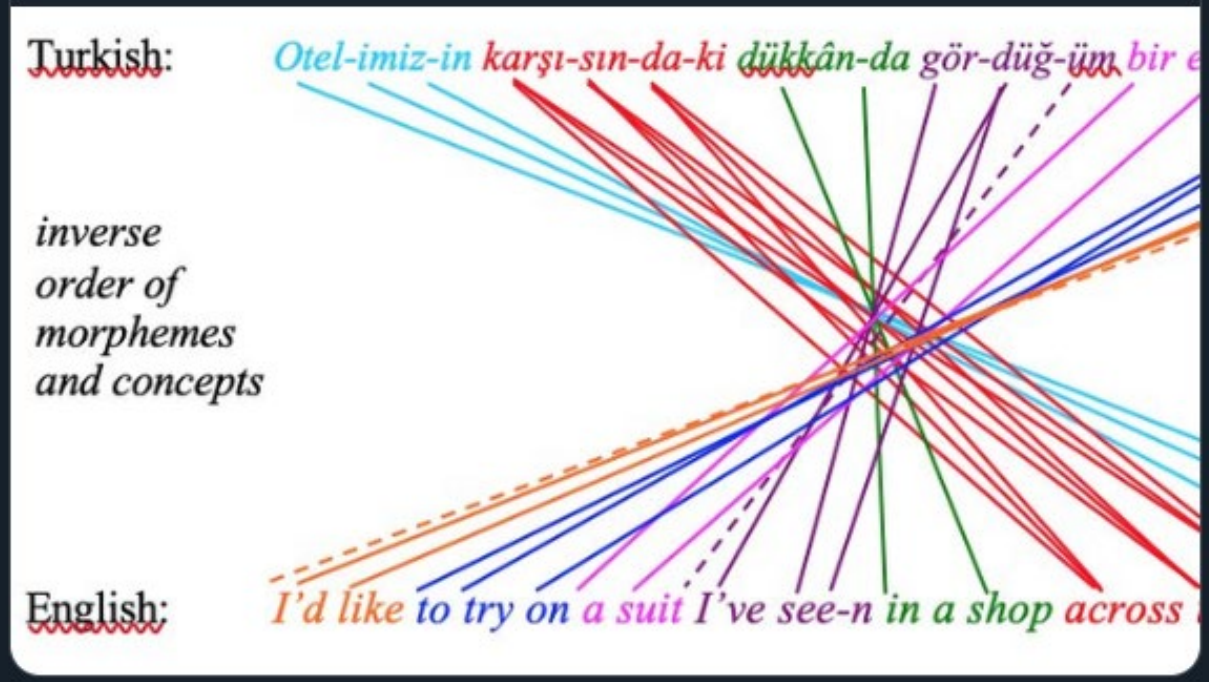
- Spoken by 10+ million people in Central Asia, mostly in northwestern China
- SOV word order, highly agglutinative, almost exclusively suffixing
- Opacity results from the interaction of **backness harmony** and **vowel reduction**


# Building words in Uyghur

**Elise Anderson**
@AndersonEliseM

Ittipaqlashturalmaywatqanliqimizdinmikin-tangey!

> **Bakhti Nishanov** @b_nishanov · Jul 16
> God help non-Turkic speakers who are trying to learn a Turkic language




7:39 AM · Jul 16, 2020 · Twitter for iPhone

**Rian Thum** @RianThum · Jul 16
Replying to @RianThum
Unscientific breakdown, minimizing grammatical terminology:

ittipaq ("unity")
+lash (mutual)
+tur (causative)
+al (ability)
+may (negative)
+wat (continuous)
+qan (>participle)
+liq (>noun)
+imiz ("our")
+din ("from")
+mi (>question)
+kin (sense of wondering)

1 1 14

**uyghurcollective** @uyghurkollektip · Jul 16
Replying to @RianThum
Maybe because we still haven't been able to unite them?- who knows!

1 1 2

# Relevant segments for backness harmony

| | Front | | Back | |
|---|---|---|---|---|
| | **Unrounded** | **Round** | **Unrounded** | **Round** |
| **High** | i | y | | u |
| **Mid** | e | ø | | o |
| **Low** | æ | | ɑ | |

| | Front | Back |
|---|---|---|
| **Voiceless** | k | q χ |
| **Voiced** | g | ʁ |

- The front vowels /i/ and /e/ are **transparent** to harmony[7]
- I won't talk much about consonants here[8]

[7] See Mayer, Major & Yakup 2022, Mayer, McCollum, & Eziz 2022

[8] See Mayer & Major, 2018; Mayer, Major & Yakup 2019, 2020; Mayer 2021

# Uyghur backness harmony

Broadly speaking, Uyghur backness harmony requires suffix forms to agree in backness with the **final harmonizing vowel** in the root[9]

| | **Front** | | **Back** | |
|---|---|---|---|---|
| 1 | pæn-lær | “science-PL” | top-lɑr | “ball-PL” |
| 2 | hɑlæt-lær | “situation-PL” | ætrɑp-lɑr | “area-PL” |
| 3 | ymid-lær | “hope-PL” | uniwersitet-lɑr | “university-PL” |

[9] e.g., Lindblad 1990; Hahn 1991a; Engsaeth et al. 2010, Abdulla et al. 2010

# Uyghur vowel reduction

/æ ɑ/ raise to [i] in **medial, open syllables**

| | | | |
|---|---|---|---|
| bɑlɑ | ‘child’ | bɑli-lɑr | ‘child-PL’ |
| qɑrɑ-ʃ | ‘look-GER’ | qɑri-di | ‘look-3.SG.PAST’ |
| mewæ | ‘fruit’ | mewi-si | ‘fruit-3.POS’ |
| søzlæ-ʃ | ‘talk-GER’ | søzli-di | ‘talk-3.SG.PAST’ |

This is related to an interaction between syllable weight and stress[10]

Not all stems undergo raising: [hɑwɑ-si] ‘weather-3.POS’ *[hɑwi-si]

[10] McCollum 2020, Mayer 2021

# Backness harmony + vowel reduction = opacity?

Vowel raising neutralizes /æ/ and /ɑ/to [i]

Consider a form like /ɑpæt-i-GA/ ‘custom-3.POS-DAT’

Two possible realizations (in principle)

Surface harmony

| | |
|---|---|
| **UR** | /ɑpæt-i-GA/ |
| **Raising** | ɑpit-i-GA |
| **Harmony** | ɑpit-i-ʁɑ |
| **SR** | [ɑpit-i-ʁɑ] |

Opaque harmony

| | |
|---|---|
| **UR** | /ɑpæt-i-GA/ |
| **Harmony** | ɑpæt-i-gæ |
| **Raising** | ɑpit-i-gæ |
| **SR** | [ɑpit-i-gæ] |

# Backness harmony + vowel reduction = opacity?

**Opaque harmony** is the norm in Uyghur

- Previous literature has reported more complex patterns, but data is questionable (Vaux 2001)

| Surface harmony | |
|---|---|
| **UR** | /ɑpæt-i-GA/ |
| **Raising** | ɑpit-i-GA |
| **Harmony** | ɑpit-i-ʁɑ |
| **SR** | [ɑpit-i-ʁɑ] |

| Opaque harmony | |
|---|---|
| **UR** | /ɑpæt-i-GA/ |
| **Harmony** | ɑpæt-i-gæ |
| **Raising** | ɑpit-i-gæ |
| **SR** | [ɑpit-i-gæ] |

# Rule-based approaches to opacity

Rule-based phonological models predict that both surface-true and opaque phonological patterns should exist across languages

✓ Surface harmony

| | |
|---|---|
| **UR** | /ɑpæt-i-GA/ |
| **Raising** | ɑpit-i-GA |
| **Harmony** | ɑpit-i-ʁɑ |
| **SR** | [ɑpit-i-ʁɑ] |

✓ Opaque harmony

| | |
|---|---|
| **UR** | /ɑpæt-i-GA/ |
| **Harmony** | ɑpæt-i-gæ |
| **Raising** | ɑpit-i-gæ |
| **SR** | [ɑpit-i-gæ] |

# OT approaches to opacity

Classical Optimality Theory **fails to predict** the opacity in Uyghur

- Let's see why!

✓ Surface harmony

| | |
|---|---|
| **UR** | /ɑpæt-i-GA/ |
| **Raising** | ɑpit-i-GA |
| **Harmony** | ɑpit-i-ʁɑ |
| **SR** | [ɑpit-i-ʁɑ] |

✗ Opaque harmony

| | |
|---|---|
| **UR** | /ɑpæt-i-GA/ |
| **Harmony** | ɑpæt-i-gæ |
| **Raising** | ɑpit-i-gæ |
| **SR** | [ɑpit-i-gæ] |

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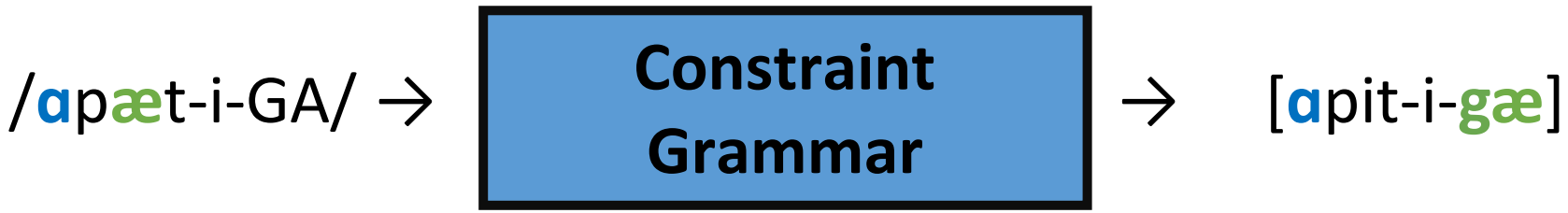
# Excursion on Optimality Theory

OT still models the mapping from underlying to surface form

- But mapping is mediated by **constraints** instead of rules




Constraints **penalize** certain aspects of this mapping process.

- We choose the ‘least bad’ output as the predicted surface form

Prince & Smolensky 1993/2004

# Constraints

**Markedness constraints** penalize configurations in the surface form

- “Don’t end a word with a voiced obstruent”
- “Don’t have an unstressed heavy syllable”
- “Adjacent vowels must agree in backness”

**Faithfulness constraints** penalize deviations from the underlying form

- “Don’t delete a segment in the UR”
- “Don’t insert a segment that wasn’t in the UR
- “Don’t change the height of a vowel”

# Simple example: Vowel reduction in Uyghur

We can model vowel reduction using a pair of (simplified) constraints

***UNRAISED**: Don’t have low vowels in medial open syllables

**ID**: Don’t change features ([high], [back], etc.) in the input

# Determining the output

Constraints are **ranked** with respect to one another

- Violations of higher ranked constraints are penalized more than violations of lower ranked constraints

Steps for choosing the output for a given input:

1. Consider **all possible output forms**
2. Choose the output that **minimizes** the most severe **constraint violations**

# Simple tableaux

If *Unraised >> ID, then we predict raising

| /bala-ni/ | ***Unraised** | **ID** |
|---|---|---|
| ☛ bali-ni | | * |
| bala-ni | *! | |

If ID >> *Unraised, then no raising

| /bala-ni/ | **ID** | ***Unraised** |
|---|---|---|
| bali-ni | *! | |
| ☛ bala-ni | | * |

Reading a tableau:

1. Move from left to right, keeping only candidates that have the lowest number of violations for each constraint
2. Stop when you're left with a single candidate

# Analyzing Uyghur opacity in classical OT

The following (simplified) constraints capture surface harmony and vowel reduction, but **fail to generate opacity**

**VAGREE**: Suffix vowels must agree with final harmonizing vowel in stem

***UNREDUCED**: Don't have low vowels in medial open syllables

**ID:** Don't change feature values of segments in the input

# Failure to predict opacity

| /bɑlɑ-lAr/ | *Unraised | VAgree | ID |
|---|---|---|---|
| bɑli-lær | | *! | * |
| ☛ bɑli-lɑr | | | * |
| bɑlɑ-lær | *! | * | |
| bɑlɑ-lɑr | *! | | |

| /ɑʔilæ-lAr/ | *Unraised | VAgree | ID |
|---|---|---|---|
| ☹ ɑʔili-lær | | *! | * |
| 💣 ɑʔili-lɑr | | | * |
| ɑʔilæ-lær | *! | | |
| ɑʔilæ-lɑr | *! | * | |

☛ : I should have won, and I did

☹: I should have won, but didn't

💣 : I shouldn't have won, but I did

# Two classes of solutions to the opacity problem in OT

**Smuggling in serialism**

- Constraint conjunction (Kirchner 1996)
- Sympathy (McCarthy 1999)
- Stratal OT (Kiparsky 2000, Bermúdez-Otero 2003)
- Candidate chain theory (McCarthy 2007)
- Serial markedness reduction (Jarosz 2014)

**Purely parallel mechanisms**

- Language-specific constraints (Pater 2014)
- Paradigm uniformity (Steriade 2000)
- Indexed constraints (Nazarov 2020)

Some see this proliferation of mechanisms as a point in favor of rule-based formalisms (e.g., Vaux 2008)

# Uyghur opacity in Stratal OT

**Stratum 1: Harmony**

| /ɑʔilæ-lAr/ | ID | VAgree | *Unraised |
|---|---|---|---|
| ɑʔili-lær | *! | * | |
| ɑʔili-lɑr | *! | | |
| ☛ ɑʔilæ-lær | | | * |
| ɑʔilæ-lɑr | | *! | * |

**Stratum 2: Raising**

| /ɑʔilæ-lær/ | *Unraised | VAgree | ID |
|---|---|---|---|
| ☛ ɑʔili-lær | | * | * |
| ɑʔilæ-lær | *! | | |

☛ : I should have won, and I did

# Recap

**Phonological opacity**: A phonological process appears to fail to apply where it should, or to apply where it shouldn't.

**Serial phonological models** like rules capture opacity by positing ordering relationships between processes.

**Parallel phonological models** can't do this because constraints are evaluated simultaneously

- No notion of intermediate stages in derivation

We can **extend** parallel models to deal with some opacity

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# An unexpected detail: variability

Some words in Uyghur **vary** in whether they show opaque or surface-true harmony

**Always opaque**

/ʃæjtɑn-i-GA/ → [ʃæjtin-i-ʁɑ] devil-3.POS-DAT

**Always surface-true**

/ærzɑn-i-GA/ → [ærzin-i-gæ] cheap-3.POS-DAT

**Either**

/æzɑn-i-GA/ → [æzin-i-ʁɑ]/[æzin-i-gæ] call to prayer-3.POS-DAT

# Corpus study

**Goal**: Use text corpora to explore opacity at scale

**Starting point**: three online Uyghur publications

- *Uyghur Awazi* (news)
  (Kazakhstan; ~4 million words)
- *Erkin Asiye radiosi* (news)
  (China; ~8 million words)
- *Uyghur akademiyisi* (culture)
  (China; ~2.5 million words)

# Building the corpus

I wrote **webscrapers** in collaboration with three undergraduate RAs[14]

- A program that traverses a site and 'scrapes' information from each page
- We scraped article titles, content, authors, and other metadata

Both harmony and raising are **represented orthographically**

[14] Thank you to Tyler Carson and Daniela Zokaiem (UCLA) and Rutvik Gandhasri (UCI)!

# Parsing the corpus

Started with an existing **morphological transducer**[15]

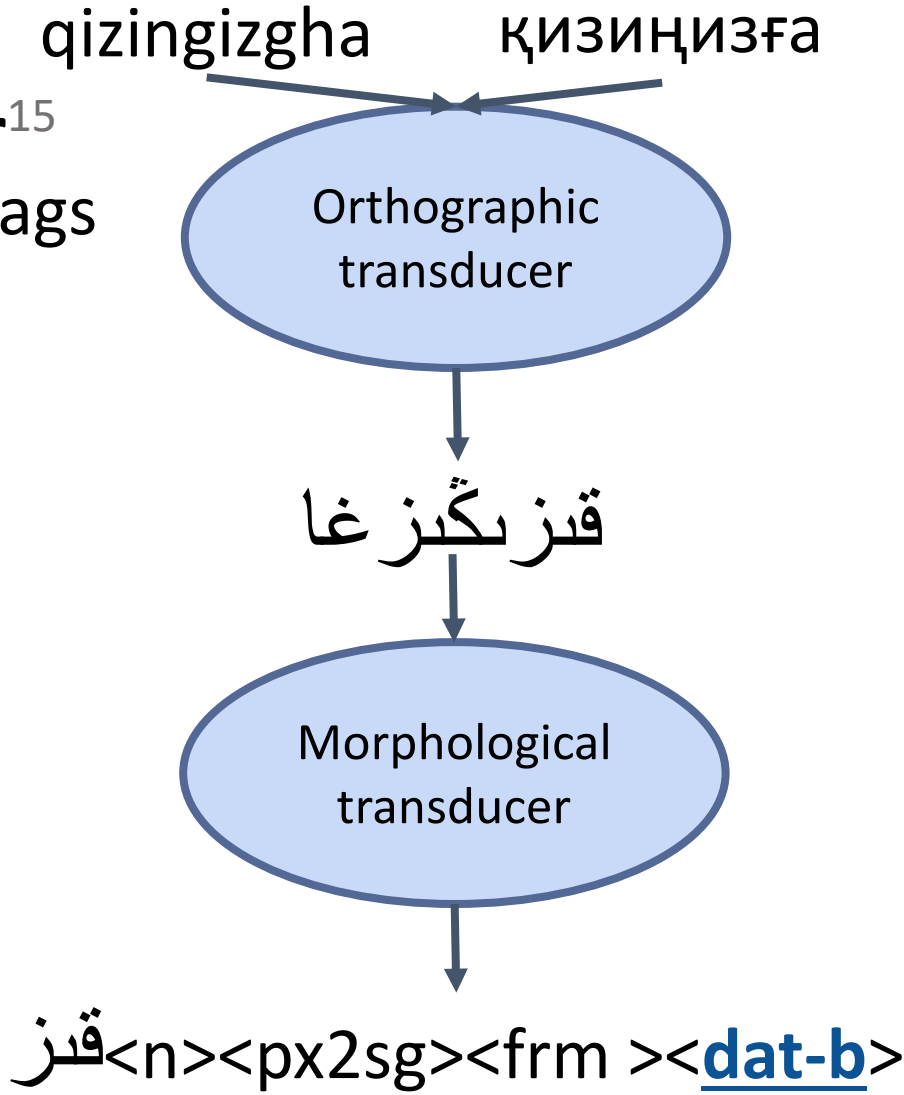
- Decomposes words into root + morphological tags

I modified this transducer to

- Accept Latin and Cyrillic orthography
- Detect the **harmonic quality of suffixes**

Lots of sanity-checking after the fact

- Excluding spurious parses, etc.




[15] Washington et al. 2019

# Corpus results

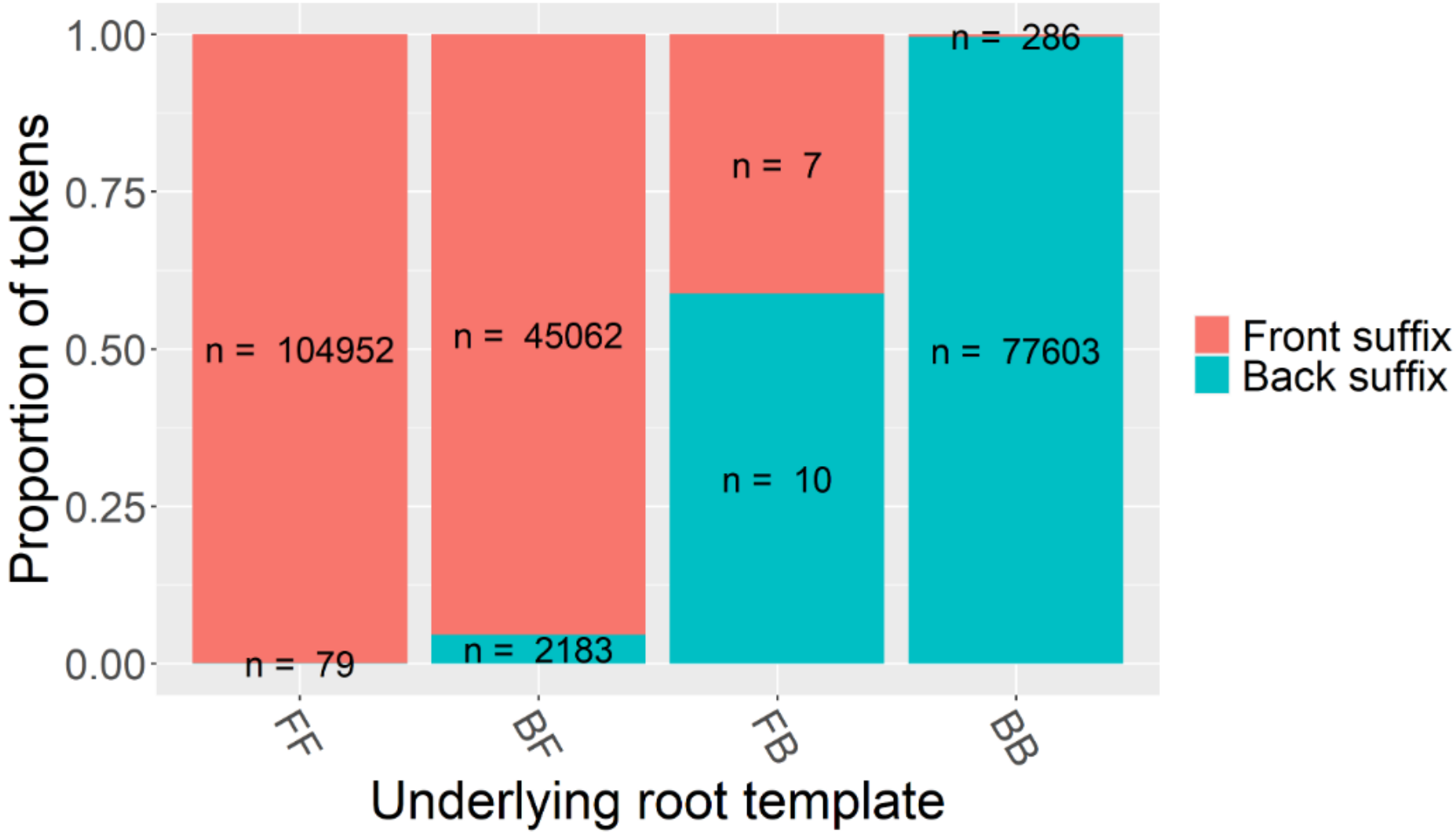
318 **roots** had the necessary structure for opacity AND underwent raising

- **BF** roots (*n=311*): e.g. /**ɑ**dæt/ ‘custom’, /sij**ɑ**sæt/ ‘politics’
- **FB** roots : (*n=7*): e.g. /ærz**ɑ**n/ ‘cheap’, /wætænd**ɑ**ʃ/ ‘compatriot’

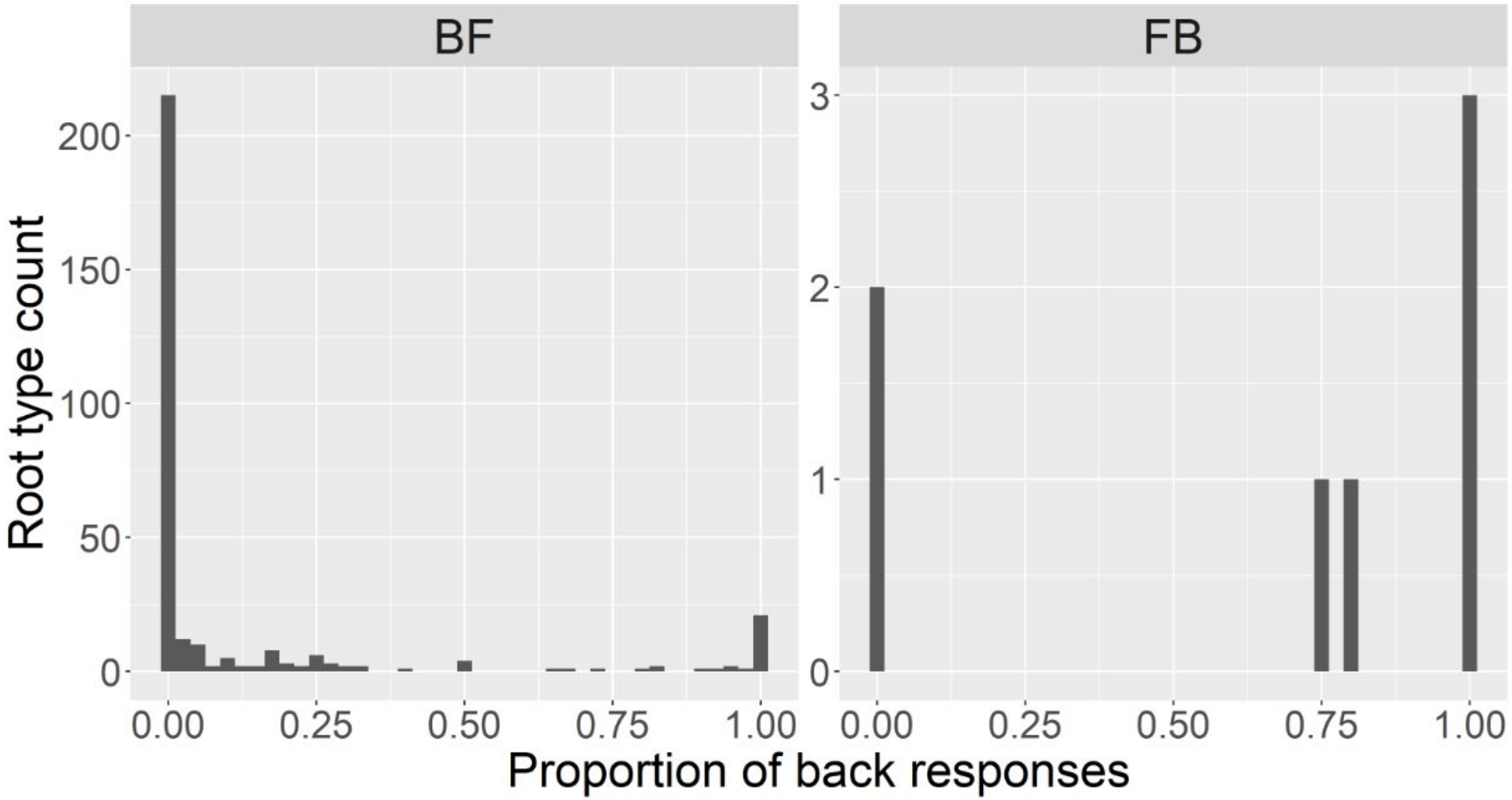
**Interim observation**: **FB** roots that raise are very uncommon

- Three of the seven involve the derivational suffix /-d**ɑ**ʃ/ ‘-mate’

# Corpus results (only raised tokens)



# Rates of opacity by root type



# An example: /idɑræ/

Example: /idɑræ/ “bureau, office, to rule (with auxiliary verb)”

- Surface-true harmony 11% of the time.

**Unsuffixed**

… *döletni qanun arqiliq **[idɑræ]** qilish…*
‘… the rule of law …’

**Opaque**

*1980-yillardin boyan merkiziy axbarat **[idɑrisidæ]** ishligen*
‘he has worked for the CIA since the 1980s’

**Surface-true**

*Gülnar xanim saqchi **[idɑrisidɑ]** qandaq mu’amilige uchridi?*
‘what kind of treatment did Gülnar receive at the police station?’

# What factors drive variability in opacity?

Fit a **mixed-effects logistic regression model** to identify significant predictors of variation

- Logistic regression: a model that tries to predict a binary outcome (here opaque vs. surface-true harmony) based on a set of predictor variables
- Mixed-effects: Extra machinery to account for non-independent samples
    - Here we sample repeatedly from the same authors and words

# Predictor variables

Included a range of different phonological and morphological predictors:

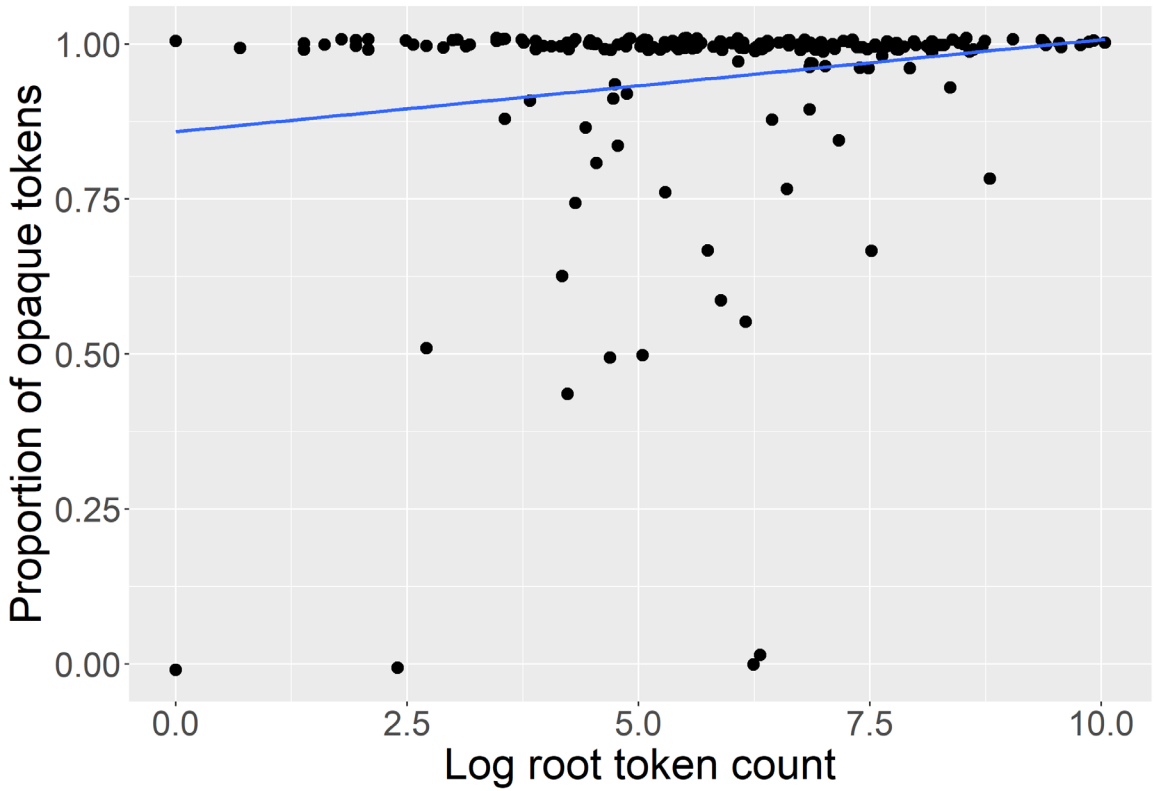
- **Log token frequency**: frequency is an important driver of phonological variability (Coetzee & Kawahara 2012)
- **Identity of final vowel:** suggested to be important by past work (Vaux 2001)
- **Proportion of raised tokens**: Hahn (1991b) suggests that raising obscures the harmonic class of a root.
- (A few others I'll omit for brevity)

# Sources of gradient opacity

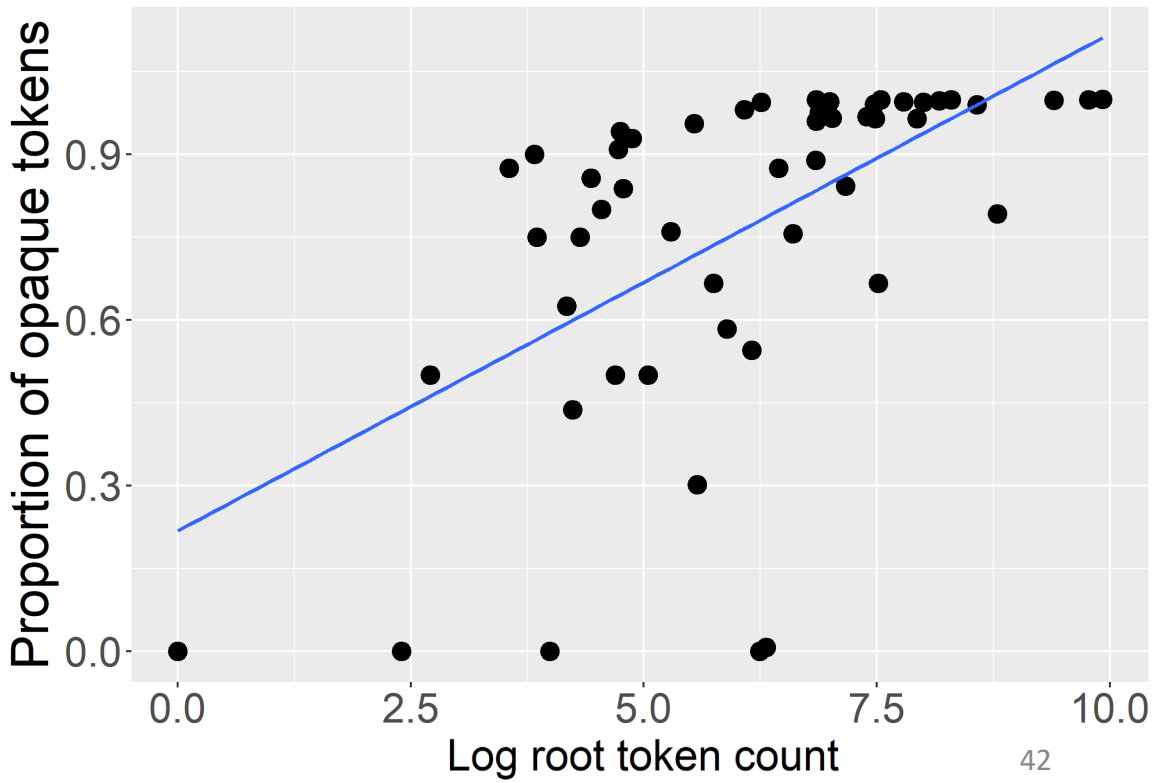
**Less frequent roots** tend to harmonize more transparently

(β=0.32, 95%-CI = [0.12, 0.51])

All roots

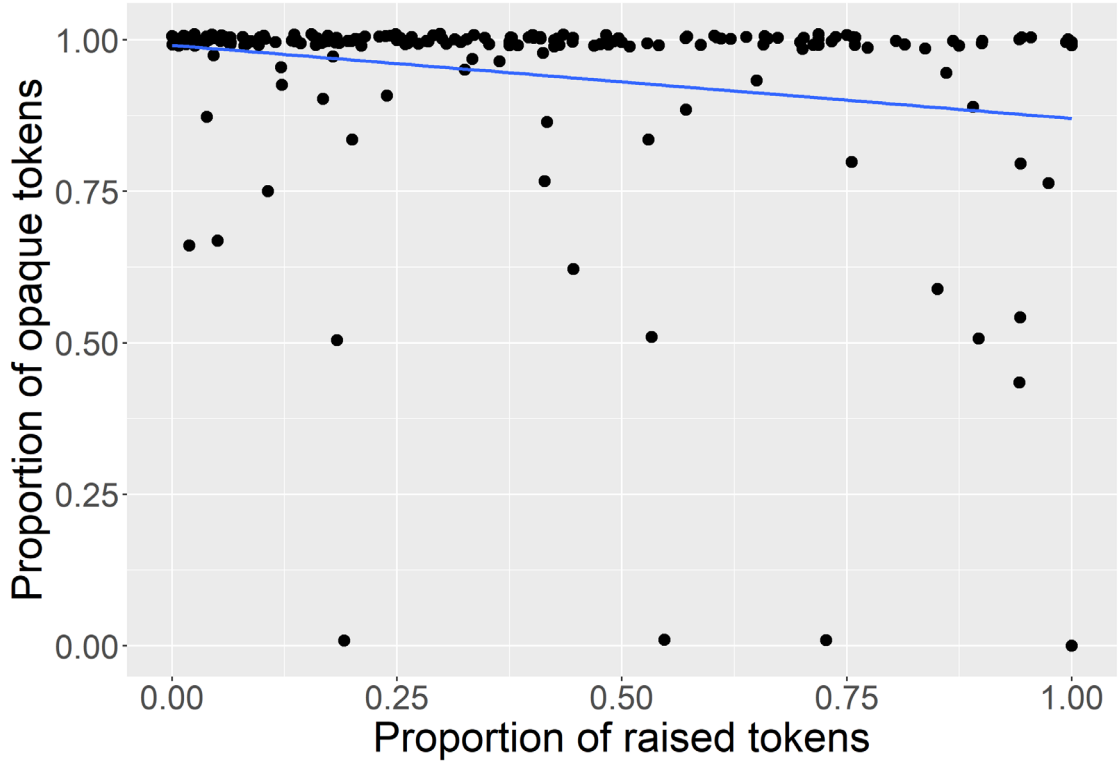



Varying roots



# Sources of gradient opacity

Opacity rates are also **negatively correlated** with **the proportion of tokens of a root that are raised** (β=–*2.21*, 95%-CI: [-3.72, -0.73])



# Summary so far

**Opacity is the norm** in Uyghur backness harmony

But **rates of opacity vary** across roots!

The **variation can be predicted** by phonological, morphological, and frequency-based factors.

# What does this mean for our theories?

Rules and expanded OT can model **categorical** surface-true/opaque harmony

- That *any* variability exists in rates of opacity is surprising!
- Requires variation in the order of rules/strata
- Rate of variation linked to specific lexical items

We could produce an ad hoc analyses that aligns with the data

- Probabilistic rule or stratum reordering

We'd like an explanation that **predicts** these properties

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# Proposal

We like to think of backness harmony as **phonological**, but it also has a strong **morphological** component.

- **Phonological:** Pressure to minimize surface disharmony
- **Morphological:** Lexical knowledge of which suffixes roots take

Morphological effects documented abundantly for Hungarian backness harmony (e.g. Rebrus, Szigetvári & Törkenczy 2023)

**Proposal:** Opacity, and the variation we see therein, is a case where these two sources of information **conflict**.

# Zones of variation (Hayes 2016)

Applied originally to cases in Hungarian backness harmony where **information in the root isn't sufficient to determine harmonizing behavior**

- Speakers rely on **lexical** (i.e. memorized) **information** about the root
- Roots in these zones exhibit **greater variability** in harmonic behavior

Uyghur has several zones of variation that highlight the role of lexical information in the harmony system.

# Zones of variation in Uyghur backness harmony

Diachronic change has introduced zones of variation into Uyghur harmony[17]

Historical */i/ and */ɯ/ → /i/

- Suffix backness for roots with no harmonizing sounds is arbitrary
- Not predictable from phonotactics or acoustics[18]
- Tendency towards back suffixes

| | |
|---|---|
| Front | bir-dæ “one-LOC” |
| | welisipit-lær “bicycle-PL” |
| Back | sir-lɑr “secret-PL” |
| | din-ʁɑ “religion-DAT” |
| | hejt-tɑ “festival-DAT” |

[17] e.g., Lindblad 1990, Hahn 1991b

[18] Mayer and Major 2018, Mayer et al. 2022

# Phonological & lexical learning (à la Zuraw 2000)

When we encounter a token of a root + harmonizing suffix like [ɑʔilæ-m-gæ] ‘to my family’ we learn two things:

**Something about the phonology**:

- front vowels are followed by front suffixes

**Something about the morphology**:

- The root /ɑʔilæ/ ‘family’ takes front suffixes

These observations often align, but in some cases they don’t!

- [ɑʔili-gæ] ‘to a family’ satisfies observation about root, but not about phonology

# Representing lexical knowledge

Lexically-specific behavior can be modeled using **indexed constraints**[19]

- Constraints that can only be violated by specific morphemes

Allow general phonological knowledge to be separated from lexically-specific knowledge

**Increased** exposure to lexical item→ **increased ranking** of indexed constraint

[19] Kraska-Szlenk 1997, 1999; Fukazawa 1999; Ito and Mester 1999; Pater 2009; Moore-Cantwell and Pater 2016; a.o.

# Indexed harmony constraints

Same constraints as before, plus two new indexed constraints[20]

**HARMONIZEBACK$_i$**: Suffixes attached to root *i* must be back
**HARMONIZEFRONT$_i$:** Suffixes attached to root *i* must be front

These constraints are **indexed to individual roots**

[20] Similar to the analysis of Nez Perce harmony in Chomsky & Halle 1968

# Sample (successful) tableaux

Root with low rate of opacity: /sɑhɑbæ/ ‘companion’

| /sɑhɑbæ-lAr/ | *Unraised | VAgree | HarmonizeFront$_{sahabe}$ | ID | HarmonizeBack$_{sahabe}$ |
|---|---|---|---|---|---|
| sɑhɑbi-lær | | *! | | * | * |
| ☛ sɑhɑbi-lɑr | | | * | * | |
| sɑhɑbæ-lær | *! | | | | * |
| sɑhɑbæ-lɑr | *! | * | * | | |

Root with high rate of opacity: /ɑʔilæ/ ‘family’

| /ɑʔilæ-lAr/ | *Unraised | HarmonizeFront$_{a'ile}$ | VAgree | ID | HarmonizeBack$_{a'ile}$ |
|---|---|---|---|---|---|
| ☛ ɑʔili-lær | | | * | * | * |
| ɑʔili-lɑr | | *! | | * | |
| ɑʔilæ-lær | *! | | | | * |
| ɑʔilæ-lɑr | *! | * | * | | |

# What about gradience?

I've been showing you classical OT tableaux, which predict a single winner

We can model variation using **maximum entropy optimality theory**[23]

- Constraints are numerically weighted
- Weights used to calculate a probability distribution over candidates
- Optimal weights can be learned from data

Probabilities can be used to calculate **likelihood of observed data**

- We can use this to facilitate numerical model comparison

[23] Smolensky 1986, Goldwater and Johnson 2003, Hayes and Wilson 2008

# Sample tableaux with optimal weights

| /ahalæ-lAr/ | **Obs. tokens** | **Pred. freq.** | **H** | **VAgree** *w=5* | **HarmonizeFront$_{ahale}$** *w=9.08* | **HarmonizeBack$_{ahale}$** *w=2.78* |
|---|---|---|---|---|---|---|
| ahali-lær | **1971** | **1969** | 7.78 | 1 | | 1 |
| ahali-lar | **537** | **535** | 9.08 | | 1 | |

| /aʔilæ-lAr/ | **Obs. tokens** | **Pred. freq.** | **H** | **VAgree** *w=5* | **HarmonizeFront$_{a'ile}$** *w=14.17* | **HarmonizeBack$_{a'ile}$** *w=0* |
|---|---|---|---|---|---|---|
| aʔili-lær | **2898** | **2898** | 5 | 1 | | 1 |
| aʔili-lar | **0** | **0** | 14.17 | | 1 | |

# Weighting indexed constraints

**HARMONIZEBACK** and **HARMONIZEFRONT** reflect **certainty of class membership**

- Natural to think of their weights probabilistically

We'll make the following proposal (HC = 'harmonic class')

$$w_{HarmonizeBack\_i} \propto P(\text{HC} = \text{BACK} \mid x_i)$$

$$w_{HarmonizeFront\_i} \propto P(\text{HC} = \text{FRONT} \mid x_i)$$

$$\propto 1 - P(\text{HC} = \text{BACK} \mid x_i)$$

<u>Weights of constraints are proportional to certainty in class membership</u>

# Validating the proposal

I test 6 different MaxEnt OT models

1. **Surface-true model**: Only VAGREE
2. **Opaque model**: VAGREE based on underlying vowel identity
3. **Lexical model**: Harmonize constraints only, scaled by P(HC|x)
4. **Opaque-surface model**: Combines 1&2
5. **Lexical-surface model**: Combines 1&3 – this is the proposed model
6. **Oracle model**: Perfectly predicts all rates

Constraints fit to dataset of raised tokens using the maxent.ot R library
(Mayer, Tan & Zuraw submitted)

# Calculating P(HC|*x*)

Approximate probability using a logistic regression model, parameterized according to (a) corpus results; (b) past work on noun class systems (e.g. Becker & Dow 2013, Becker & Gouskova 2016, Kupish et al. 2022)

Dependent variable: whether root takes a back suffix

Independent variables:

- Underlying final vowel identity
- Log token count
- Proportion of tokens that are raised
- (Some morphological details)
- (Some interaction terms)

# Fitting the models

Fit models to the **full set** of FF, BF, FB, BB forms

- Not just raised contexts

Weights for VAGREE and HARMONIZE constraints fit globally to data

- In 'lexical' models, HARMONIZE weights scaled by P(HC|*x*) for each root *x*

For each model, we can calculate the **likelihood** of the data

- The model assigns a probability to each word in the data set
- We take the product of all these probabilities to get the likelihood
- Lower likelihood == better fit by the model

# Results

| Model | Number of parameters | Log Likelihood | Bayesian Information Criterion |
|---|---|---|---|
| Surface-true | 1 | -114,333 | 228,679 |
| Opaque | 2 | -13,686 | 27,397 |
| Lexical | 10 | -12,039 | 27,520 |
| Opaque-surface | 3 | -11,378 | 22,794 |
| **Lexical-surface** | **13** | **-10,003** | **20,166** |
| Oracle | 1620 | -5,482 | 30,965 |

# Recap

1. Opacity is a proving ground for phonological theories
2. Serial theories like phonological rules predict opacity straightforwardly
3. Parallel theories like OT don’t unless supplemented with additional machinery
4. Variability in opacity in Uyghur poses problems for both models
5. We can reconcile this in a parallel model by modeling opacity as a case where phonological and morphological pressures conflict

# Takeaway points for theory

We don't understand opacity well enough

- Orderings that generate opacity tend to recapitulate the historical changes that led to the opaque pattern
- No guarantee that speakers' grammars are organized similarly

In this case, we get more insight into patterns in empirical data by considering opacity from a different perspective

Parallel models may give greater insight into (at least some) opacity

- Treat opacity in the same way as other exceptionality

# Limitations

Exploratory study, hypothesis needs confirmatory testing

Restricted genre of text

- Are rates similar in colloquial speech?

Unclear authorship due to political situation in China

# More general points

The internet provides richer data than we've ever had access to before!

- We can use computational tools to build and analyze corpora
- We can run behavioral experiments online

<u>We can bring quantitative data to bear on theoretical problems</u>

- Complements other perspectives
- Takes us towards a more complete picture of the language

# Collaborators on Uyghur

- Travis Major (USC)
- Mahire Yakup (Nazarbayev U.)
- Gulnar Eziz (Harvard)
- Adam McCollum (Rutgers)

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