Extended indexation and the typology of opacity, unnaturalness, and exceptions

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Overview

- Opaque mappings in Optimality Theory (OT): problematic
  - Various proposals: OT-CC (McCarthy 2007), Serial Markedness Reduction (Jarosz 2014), Stratal OT (Bermúdez-Otero 1999), …
  - Novel proposal (Nazarov 2019): opacity, unnaturalness, exceptions all arise from **indexed constraints**
- Indexed constraints: powerful, difficult to track mechanism
  - What is the typological effect of the various types of indexed constraints needed for Nazarov's (2019) analysis?
  - What are the consequences of this for learning opaque and unnatural patterns?

Opacity (in OT)

Opaque mappings

- Opaque mapping: two separate subpatterns interact in such a way that one subpattern creates “exceptions” to the other
  - Example A: Canadian Raising (Chomsky 1964, Chambers 1973, Idsardi 2006)

Subpattern 1: Raising – aɪ, aʊ raise to ʌɪ, ʌʊ before Ç, NOT before Ç̬
/raɪt/ → [rʌɪt] ‘write’ /raɪd/ → [raɪd] ‘ride’

Subpattern 2: Flapping – t,d flap (and voice) to ɾ in (roughly) V́_V
/blit+iŋ/ → [bliɾiŋ] ‘bleating’ /blid+iŋ/ → [bliɾiŋ] ‘bleeding’

Opaque interaction: Application of Flapping leads to Raising before Ç̬!
/raɪt-ɚ/ → [rʌɪɾɚ] ‘writer’ /raɪd-ɚ/ → [raɪɾɚ] ‘rider’

Opaque mappings

- Opaque mapping: two separate subpatterns interact in such a way that one pattern creates “exceptions” to the other
  - Example B: Bedouin Arabic (McCarthy 2007)

Subpattern 1: Raising – a raises to i(/u) in nonfinal open syllable (_CV)
/samiʕt/ → [simiʕt] ‘I heard’

Subpattern 2: Epenthesis – i(/u) inserted in C + sonorant + # cluster
/libn/ → [libin] ‘clay’

Opaque interaction: Application of Epenthesis leads to lack of Raising _CV!
/gabl/ → [gabil] ‘before’

Opaque mappings in OT

- In Optimality Theory (OT), opaque mappings are (usually!; see Baković 2011) problematic
  - Overapplication opacity (process applies in superset of predicted cases): desired output candidate has unmotivated Faithfulness violations

    /raɪt-ə͡/: ✓[rʌɪrə͡]/*[raɪrə͡] - same relevant M violations, ✓[rʌɪrə͡] loses

  - Underapplication opacity (process applies in subset of predicted cases): desired output candidate has unmotivated high-ranked Markedness violations

    /gabl/: ✓[gabil]/*[gibil] - *a/_CV ranked above Ident(V), ✓[gabil] loses

Solutions

- Traditional:
  - Opaque mappings means that one constraint ranking is evaluated ‘before’ the other (OT-CC, McCarthy 2007: Precedence constraints; Serial Markedness Reduction, Jarosz 2014: Constraints on order of Markedness improvement; Stratal OT, Bermúdez-Otero 1999: rankings tied to morphosyntactic domains)
  - Exceptions (and unnaturalness) through other mechanisms (indexed constraints, Pater 2000; etc.)
- Novel proposal:
  - Opaque mappings, exceptions, unnaturalness come from the same source: locally indexed constraints (Nazarov 2019)
  - Which one is obtained depends on the particular indexed constraints and their ranking

Indexation proposal

Indexation

- Indexation: universal constraints may have variants specific to some inputs (morphemes/words) only (Kraska-Szlenk 1995, Pater 2000)

  *[+voice]: no voiced segments
  *[+voice]$_i$: no voiced segments in *i* words

- *Extended indexation*: indices are binary (cf. Becker 2009) and local to specific segments (Round 2017); basically same as SPE diacritics

  *[+voice]$_{[+i]}$: no voiced [+i] segments ✓[d]$_{[-i]}$ *[d]$_{[+i]}$

Canadian Raising with indexation

- Raising: *aJC$_{[+i]}$ >> Ident(low)

/ɹaɪt[+i]/	***aJC$_{[+i]}$**	**Id(low)**
[ɹaɪt$_{[+i]}$]	*!	
☞[ɹʌɪt$_{[+i]}$]		*

All underlying segments are [-i] unless specified otherwise

- Flapping: *VTV >> *[+voice]$_{[+i]}$, Ident(son), Ident(voi)

/bʌt[+i]ɚ/	***VTV**	***[+voice]$_{[+i]}$**	**Id(son)**	**Id(voi)**
[bʌt$_{[+i]}$ɚ]	*!			
☞[bʌr$_{[+i]}$ɚ]		*	*	*

Canadian Raising with indexation

- The surface voicing of a [+i] segment does not influence raising

/ɹaɪt[+i]-ə/	*VTV	*[+voice]$_{[+i]}$	*aJC$_{[+i]}$	Ident(low)	Ident(son)	Ident(voi)
ɹaɪt$_{[+i]}$ə	*!		*			
ɹʌɪt$_{[+i]}$ə	*!			*		
ɹaɪd$_{[+i]}$ə	*!	*	*			*
ɹʌɪd$_{[+i]}$ə	*!	*		*		*
ɹaɪɾ$_{[+i]}$ə		*	*!		*	*
☞ ɹʌɪɾ$_{[+i]}$ə		*		*	*	*

All segments are [-i]
unless specified otherwise

Richness of the Base

- Anything with [+i] always shows up as voiceless and triggers raising unless it's in the flapping context

/aɪd[+i]/	*VTV	*[+voice]$_{[+i]}$	*[-voice]$_{[-i]}$	*aJC$_{[+i]}$	Ident(low)	Ident(son)	Ident(voi)
aɪt				*!			*
☞ ʌɪt					*		*
aɪd		*!		*			
ʌɪd		*!			*		
aɪɾ		*!		*		*	
ʌɪɾ		*!			*	*	

All underlying segments are [-i]
unless specified otherwise

Richness of the Base

- Anything with [-i] always shows up as voiced and never triggers raising

/aɪt[-i]/	*VTV	*[+voice]$_{[+i]}$	*[-voice]$_{[-i]}$	*aJC$_{[+i]}$	Ident(low)	Ident(son)	Ident(voi)
aɪt			*!				
ʌɪt			*!		*		
☞ aɪd							*
ʌɪd					*!		*
aɪɾ						*!	*
ʌɪɾ					*!	*	*

All underlying segments are [-i] unless specified otherwise

Representing exceptionality

- Difference between opacity and exceptionality:
  - Opacity: conditioning by another process or by surface context (systematic)

*VTV >> *aJC$_{[+i]}$, *[+voice]$_{[+i]}$, *[-voice]$_{[-i]}$ >> Faith

[+i] consonants can be voiced only if they undergo Flapping

Otherwise, [+i] consonants are always voiceless

  - Exceptionality: a mapping is conditioned by specific morphemes (asystematic)

(*VTV >>) *aJC$_{[+i]}$ >> Faith >> *[+voice]$_{[+i]}$, *[-voice]$_{[-i]}$

[+i] consonants may surface as any type of consonant (voiced or voiceless)

Representing unnaturalness

- *[+voice] and *[-voice] can be indexed in any way possible:
  $*[+voice]_{[-i]}$, $*[+voice]_{[+i]}$, $*[-voice]_{[-i]}$, $*[-voice]_{[+i]}$
  - This allows us to represent unnatural Raising: exclusively before voiced C

$*aJC_{[+i]}$, $*[+voice]_{[-i]}$, $*[-voice]_{[+i]}$ >> Faith, $*[+voice]_{[+i]}$, $*[-voice]_{[-i]}$

[-i] (non-Raising) consonants are always voiceless
[+i] (Raising) consonants are always voiced

Indexation analysis: summary

- Crucial elements:
  1. Local binary indexation (*extended indexation*); Becker (2009) ∪ Round (2017)
  2. Constraint(s) that make(s) the mapping of the opaque process (Raising) dependent upon indices
     e.g., *aJC$_{[+i]}$
  3. Constraint(s) that make(s) the context of the opaque process dependent upon indices
     e.g., *[+voice]$_{[+i]}$, *[-voice]$_{[-i]}$
  4. Ranking these constraints w.r.t. Markedness constraint that triggers the interacting process and well as faithfulness
     e.g., ***VTV** >> *aJC$_{[+i]}$, *[+voice]$_{[+i]}$, *[-voice]$_{[-i]}$ >> **Faith**

Questions + methodology

Questions

- The extended indexation analysis presumes that the right indexed constraints exist
  - Factorial typology: all rankings of these indexed constraints and the universal constraints are a predicted language
    - What is the range of languages predicted for the Canadian Raising setup?
    - What predictions does the presence of context-sensitive (e.g., *aJC$_{[+i]}$) vs. context-free indexed Markedness (e.g., *[+voice]$_{[+i]}$) constraint make?
  - Indexed constraints (e.g., *aJC$_{[+i]}$) must be induced from universal constraints (e.g., *aJC)
    - What does this mean for the acquisition path of opaque generalizations?

Simulations

- Using OT-Help 2.0 (Staubs et al. 2010), find factorial typology (unique languages only) for Canadian Raising candidate space and four sets of constraints:
  1. Only universal constraints (see next slide)
  2. Universal constraints + context-free indexed constraints
     *[+voice]$_{[-i]}$, *[+voice]$_{[+i]}$, *[-voice]$_{[-i]}$, *[-voice]$_{[+i]}$
  3. Universal constraints + context-sensitive indexed constraints
     *aJC$_{[+i]}$, *aJC$_{[-i]}$
  4. Universal constraints + context-free/sensitive indexed constraints
     All of the above

Constraint set

- Universal constraints

  *ɾ̥

  *VTV (no [t/d] between vowels)

  *aJC (no unraised diphthong [aɪ/aʊ] before consonants)

  *aJC̥ (no unraised diphthong [aɪ/aʊ] before voiceless consonants)

  *[+voice], *[-voice]

  Ident(voice), Ident(sonorant), Ident(low)

Constraint set

- Universal constraints (bolded constraints get indexed versions)

  *ɾ̥

  *VTV (no [t/d] between vowels)

  ***aJC** (no unraised diphthong [aɪ/aʊ] before consonants)

  *aJÇ (no unraised diphthong [aɪ/aʊ] before voiceless consonants)

  ***[+voice], *[-voice]**

  Ident(voice), Ident(sonorant), Ident(low)

Inputs + candidate space

- Inputs:

Wug input

/glaɪt$_{[-i]}$/ /raɪt$_{[+i]}$/ /raɪd$_{[-i]}$/ /vlaɪd$_{[+i]}$/

/ glaɪt$_{[-i]}$-ə/ /raɪt$_{[+i]}$-ə/ /raɪd$_{[-i]}$-ə/ /vlaɪd$_{[+i]}$-ə/

Wug input

- Candidate space: 16 candidates for each input
  - Voicing of initial consonant: voiced/voiceless [g/k] [r/r̥] [v/f]
  - Height of diphthong: unraised/raised [aɪ/ʌɪ]
  - Voicing and sonorancy of stem-final /t,d/ [d/t/ɾ/r̥]

Processing

- OT-Help 2.0 deterministically finds all unique languages in the factorial typology
  - One run for each of the 4 constraint sets
  - Only OT-compatible languages considered

- Unique languages for each constraint set further summarized into unique sets of alternations (e.g.{[ʇʌɪt~ ʇʌɪɾə], [ʇaɪt~ʇaɪɾə], [ʇaɪd~ʇaɪɾə])
- Manually classified by the apparent status of the Raising process:
  - Opaque (if Raising before voiceless unless Flapping applies)
  - Unnatural (if Raising only before voiced C)
  - Exceptionful (if context for application of a process cannot be recovered from alternation)
  - Unmarked (all other cases)

Results

Alternations: no indexed constraints

- 25 unique alternation patterns (1-2 alternations per language)
- All are Unmarked:
  - Voicing neutralization patterns:
    - Consonant voicing neutralized (8) — ç̥Vt (~ ç̥V̥ɾə) — ç̬Vd (~ ç̬Vɾə)
    - Voiceless unless Flapping applies (3) — ç̥Vt ~ ç̥Vɾə — (avoids violation of *r̥)
    - Voiceless, unless after diphthong (2) — ç̥Vd ~ ç̥Vɾə — (avoids violation of *aJç̥)
    - No neutralization (12) — Vt (~ V̥/ɾə) & Vd (~ Vɾə)
  - Pathologies:
    - *[-voice] >> *[+voice], Faith leads to lack of voiceless C (sol: universal *[+v] >> *[-v])
    - *aJç̥, Id(low) >> Id(voice) leads to consonant voicing after diphthong (sol: Harmonic Serialism?)

Alternations: no indexed constraints

- 25 unique alternation patterns (1-2 alternations per language)
- All are Unmarked:
  - Application of Raising:
    - No Raising (11)
    - Raising everywhere (9)
    - Raising before voiceless C (5)

Alternations: no indexed constraints

- 25 unique alternation patterns (1-2 alternations per language)
- All are Unmarked:
  - Application of Flapping:
    - No Flapping (7)
    - Flapping everywhere in V_V (12)
    - Flapping only alternating with voiced segments (6) Vt~Vtɚ & Vd~Vrɚ

Alternations: context-free indexed constraints

- 52 unique alternation patterns (1-3 alternations per language)
  - 25 Unmarked (see before)
- + 27 Exceptionful alternation patterns
  - Voicing neutralization patterns:
    - Voiceless unless Flapping applies (3)
    - Voiceless, unless in indexed segments in certain words (20)
      - (2 also have exceptional Flapping)
    - Voiceless only in indexed segments in certain words (2)
    - No neutralization (2)

Alternations: context-free indexed constraints

- 52 unique alternation patterns (1-3 alternations per language)
  - 25 Unmarked (see before)
- + 27 Exceptionful alternation patterns
  - Raising patterns:
    - No Raising (9)
    - Raising everywhere (9)
    - Raising before voiceless C (9)

Alternations: context-free indexed constraints

- 52 unique alternation patterns (1-3 alternations per language)
  - 25 Unmarked (see before)
- + 27 Exceptionful alternation patterns
  - Flapping patterns:
    - No Flapping (3)
    - Flapping everywhere in V_V (14)
    - Flapping only alternating with voiced segments (3) Vt~Vtɚ & Vd~Vrɚ
    - Flapping conditioned by word (7)

Alternations: context-sensitive ICs

- 44 unique alternation patterns (1-3 alternations per language)
  - 25 Unmarked (see before)
- + 19 Exceptionful alternation patterns
  - Voicing neutralization patterns
    - Consonant voicing neutralized (6)
    - Voiceless unless Flapping applies (1)
    - Voiceless, unless in indexed segments in certain words (3) *overlap with context-free ICs*
    - No neutralization (9)
  - Exceptionful voicing neutralization arises from interaction between *aJC$_{[+i]}$ and (pathological) post-diphthong voicing

Alternations: context-sensitive ICs

- 44 unique alternation patterns (1-3 alternations per language)
  - 25 Unmarked (see before)
- + 19 Exceptionful alternation patterns
  - Raising patterns:
    - No Raising (0)
    - Raising everywhere (0)
    - Raising conditioned by specific indexed segments (16)
    - Raising before voiceless C (3)

Alternations: context-sensitive lCs

- 44 unique alternation patterns (1-3 alternations per language)
  - 25 Unmarked (see before)
- + 19 Exceptionful alternation patterns
  - Flapping patterns:
    - No Flapping (7)
    - Flapping everywhere in V_V (12)
    - Flapping only alternating with voiced segments (2) Vt~Vtɚ & Vd~Vrɚ

Alternations: full constraint set

- 122 unique alternation patterns (1-3 alternations per language)
  - 25 Unmarked (see before)
  - 43 Exceptional patterns (see before; 27 for context-free, 19 for context-sensitive – 3 overlapping patterns)
- 54 remaining patterns that require context-free+sensitive indexation
  - Voicing neutralization patterns: Exceptionality
    - Voiceless unless Flapping applies (4)
    - Voiceless, unless in indexed segments in certain words (25)
      - (all overlap with exceptional or unnatural Raising)
    - No neutralization (25)

Alternations: full constraint set

- 122 unique alternation patterns (1-3 alternations per language)
  - 25 Unmarked (see before)
  - 43 Exceptional patterns (see before; 27 for context-free, 19 for context-sensitive – 3 overlapping patterns)
- 54 remaining patterns that require context-free+sensitive indexation
  - Raising patterns: Opacity, Exceptionality, and Unnaturalness
    - Raising everywhere (1)
    - Raising before whatever alternates with a voiceless consonant (1) ʌɪt~ʌɪɾɚ
    - Raising conditioned by specific indexed segments (44)
      - *(include opacity+exceptionality)* *e.g.* ʌɪt~ʌɪɾɚ & aɪd~aɪɾɚ & ʌɪd~ʌɪɾɚ
    - Raising before voiced C (8) aɪt & ʌɪd

Alternations: full constraint set

- 122 unique alternation patterns (1-3 alternations per language)
  - 25 Unmarked (see before)
  - 43 Exceptional patterns (see before; 27 for context-free, 19 for context-sensitive – 3 overlapping patterns)
- 54 remaining patterns that require context-free+sensitive indexation
  - Flapping patterns: Exceptionality
    - No Flapping (8)
    - Flapping everywhere in V_V (32)
    - Flapping only alternating with voiced segments (9) Vt~Vtɚ & Vd~Vrɚ
    - Flapping conditioned by word (5)
      - Includes cases of opaque application of Raising, e.g., aɪt~aɪtɚ & ʌɪt~ʌɪrɚ & ʌɪd~ʌɪrɚ

Results summary

- Unindexed constraints only: 25 Unmarked patterns
- Context-free indexed constraints (*$[+vce]_{[+i]}$): + 27 Exceptional patterns
  - Voicing neutralization (3 overlap with context-sensitive indexed constraints)
  - Flapping
- Context-sensitive ind. constraints (*$aJC_{[+i]}$): + 19 Exceptional patterns
  - Raising
- All constraints: + 54 Opaque, Exceptional, or Unnatural patterns
  - Opaque, Exceptional (+Opaque), or Unnatural Raising
  - Flapping (with opaque Raising)

Discussion

Experiment

- Factorial typology based on indexed analysis for Canadian Raising:
  - Universal constraints:
    - no opacity/exceptionality/unnaturalness*
  - Adding only context-free indexed constraints or only context-sensitive indexed constraints:
    - adds exceptionality only
  - Adding both types of indexed constraints:
    - also adds opacity and unnaturalness as options
- Opacity and unnaturalness needs two types of indexed constraint!
- What does this mean for learning opacity and unnaturalness?

Learning indexed constraints

- Indexed constraints:
  - All potential indexed constraints included universally?
    - Difficult to maintain because indices bound to language-specific morphemes
  - Induced whenever needed by learner? Becker (2009), Coetzee (2009), Pater (2010), Round (2017)
- Pater (2010): indexed constraints induced whenever ranking inconsistency detected
  - One input needs A >> B, another input needs B >> A → induce A_i or B_i
  - Defines what evidence is needed for an indexed constraint

Opaque Canadian Raising

- Coming back to actual Canadian Raising:

  /raɪt/ → [rʌ̲ɪ̲t] ‘write’ /raɪd/ → [raɪd] ‘ride’
  /raɪt-ɚ/ → [rʌ̲ɪ̲ɾɚ] ‘writer’ /raɪd-ɚ/ → [raɪɾɚ] ‘rider’

- There is evidence for an indexed version of *aJC
  - /raɪt-ɚ/ → [rʌ̲ɪ̲ɾɚ] needs *aJC >> Ident(low) not motivated by *aJC̣
  - /raɪd-ɚ/ → [raɪɾɚ] needs Ident(low) >> *aJC
- However, without the presence of $*aJC_{[+i]}$, there is no evidence for $*[+voice]_{[+i]}$ or $*[-voice]_{[-i]}$
  - No morpheme-specific voicing neutralization present

Unnatural Canadian Raising

- Unnatural (counterfactual) version of Canadian Raising:

/raɪt/ → [rʌɪt]
/raɪt-ɚ/ → [raɪrɚ]

/raɪd/ → [rʌɪd]
/raɪd-ɚ/ → [rʌɪrɚ]

- There is evidence for an indexed version of *aJC
  - /raɪd-ɚ/ → [rʌɪrɚ] needs *aJC >> Ident(low) not motivated by *aJ̰
  - /raɪt-ɚ/ → [raɪrɚ] needs Ident(low) >> *aJC, *aJ̰
- Again, without the presence of $*aJC_{[+i]}$, there is no evidence for $*[+voice]_{[+i]}$ or $*[-voice]_{[-i]}$
  - No morpheme-specific voicing neutralization present

Implications for acquisition

- Context-sensitive indexed constraints will be induced first
  - On their own, just yield a pattern of Exceptionality
- Context-free indexed constraints will be induced second
  - Both CF and CF indexed constraints necessary for opacity/unnaturalness!

- Implication: there will be an intermediate stage of exceptionality

Stage 0	Universal constraints only	
Stage 1	Universal constraints + *aJC[+i]	*Exceptionality*
		(Raising allowed before any consonant)

Implications for acquisition

- Context-sensitive indexed constraints will be induced first
  - On their own, just yield a pattern of Exceptionality
- Context-free indexed constraints will be induced second
  - Both CF and CF indexed constraints necessary for opacity/unnaturalness!

- Implication: there will be an intermediate stage of exceptionality

  Stage 1 Universal constraints + *aJC[+i]
  Stage 2 Universal constraints + *aJC[+i] + *[+/-voice][+i]
  Unnaturalness (Raising before voiced) or Opacity (Raising before /t/)

Implications for typology

- Exceptions require 1 stage of indexed constraint induction + ranking
- Opacity/Unnaturalness require 2 stages of indexed constraint induction + ranking
  - Context-sensitive first
  - Then, context-free

- Implies:
  - Opacity/unnaturalness more fragile in transmission to other generations
  - Therefore, opacity/unnaturalness will be typologically rarer than exceptions

Generalizability

- Here, effects shown just for Canadian Raising case
- However, mechanism behind this is shared with opacity *on environment* (Baković 2011) and unnaturalness in general:
  - Context-sensitive indexed constraints necessary to define the position of the environment w.r.t. the focus of the process

    aɪ → ʌɪ / __$C_{[+i]}$ *aJ$C_{[+i]}$

  - Context-free indexed constraints necessary to define default realization of the environment

    $C_{[+i]}$ is voiceless unless Flapping applies *VTV >> *$[+voice]_{[+i]}$

Generalizability

- Future work:
  - How does this mechanism interact with specific properties of other cases of opacity?
  - Are there any particular properties of opacity *on environment* cases that can annul this prediction?
- Prediction:
  - Given the environment location/environment specification dichotomy, opacity *on environment* (and unnaturalness) will:
    - Go through a phase of exceptionality while they are learned (and possibly when they are learned incorrectly)
    - Be rarer typologically than exceptionality

Learning (simulations)

- More questions for future work:
  - Test these claims with implemented learning algorithms
    - Especially, incremental learning algorithms
    - Some work with non-incremental learning algorithms (BCD + locally indexed constraint induction, Round 2017) done already
  - Human acquisition
    - Do we see misanalyses of opacity as exceptionality in the course of acquisition? (requires testing on nonsense words)
  - Typology
    - How can we quantify the prevalence of opacity *on environment* and exceptionality, respectively?

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References

- **Baković,** E. 2011. Opacity and ordering. In J.A. Goldsmith, J. Riggle, and A.C.L. Yu (eds.), The Handbook of Phonological Theory, 2nd ed., 40–67. Wiley-Blackwell.
- **Becker**, M. 2009. Phonological trends in the lexicon: the role of constraints. U of Massachusetts Amherst dissertation.
- **Bermúdez-Otero**, R. 2003. The acquisition of phonological opacity. In J. Spenader, A. Eriksson & Ö. Dahl (eds), *Variation within Optimality Theory*, 25-36. Stockholm University.
- **Boersma**, P. 2007. Some listener-oriented accounts of h-aspiré in French. *Lingua* 117(12): 1989–2054.
- **Chambers**, J. 1973. Canadian raising. *Canadian Journal of Linguistics* 18: 113-35.
- **Chomsky**, N, & M. Halle. 1968. *The Sound Pattern of English*. New York: Evanston. **Lin**, Y. 2005. Learning features and segments from waveforms: a statistical model of early phonological acquisition. UCLA dissertation.
- **Goldrick**, M. 2001. Turbid Output Representations and the Unity of Opacity. In *Proceedings of the Northeast Linguistic Society 30*, Rutgers University, edited by Masako Hirotani, Andries Coetzee, Nancy Hall, and Ji-Yung Kim, 231–45. Amherst, MA: GLSA.
- **Idsardi**, W. 2000. Clarifying opacity. *The Linguistic Review* 17: 337–350.
- **Jarosz**, G. 2014. Serial Markedness Reduction. In Proceedings of the 2013 Annual Meeting on Phonology, ed. John Kingston, Claire Moore-Cantwell, Joe Pater, and Robert D. Staubs. Washington, DC: Linguistic Society of America.
- **Joos**, M. 1942. A phonological dilemma in Canadian English. *Language* 18: 141–144.
- **Kisseberth,** C.W. 1970. The treatment of exceptions. *Papers in Linguistics* 2: 44–58.
- **Łubowicz**, A. 2003. Contrast preservation in phonological mappings. U of Massachusetts Amherst dissertation.
- **Mayer**, C. 2018. An algorithm for learning phonological classes from distributional similarity. MA thesis, UCLA.
- **McCarthy**, J.J. 1999. Sympathy and Phonological Opacity. *Phonology* 16(3): 331-399.

References

- **McCarthy**, J.J. 2007. *Hidden generalizations: phonological opacity in Optimality Theory*. London: Equinox.
- **McCarthy**, J.J. 2008. The Gradual Path to Cluster Simplification. *Phonology* 25: 271–319.
- **Mielke**, J., M. Armstrong & E. Hume. 2003. Looking through opacity. *Theoretical linguistics*, 29(1-2):123-139.
- **Mullin**, K. 2011. The Necessity of Diacritics for Descriptive Adequacy. Talk given at RUMMIT 2011.
- **Van Oostendorp**, M. 2008. Incomplete Devoicing in Formal Phonology. *Lingua* 118: 1362–74.
- **Osadcha**, I. 2019. Lexical stress in East Slavic: variation in space and time. U of Toronto dissertation.
- **Pater**, J. 2000. Non-uniformity in English secondary stress: the role of ranked and lexically specific constraints. *Phonology* 17(2): 237–74.
- **Pater**, J. 2010. Morpheme-Specific Phonology: Constraint Indexation and Inconsistency Resolution. In Phonological Argumentation: Essays on Evidence and Motivation, edited by Steve Parker, 123–54. London: Equinox Press.
- **Pater**, J. 2014. Canadian raising with language-specific weighted constraints. *Language* 90(1): 230-240.
- **Sanders,** N. 2006. *Strong lexicon optimization*. Talk given at Umass Phonology Group. Available at http://sanders.phonologist.org/Papers/sanders-umass.pdf.
- **Staubs**, R., M. Becker, C. Potts, P. Pratt, J.J. McCarthy & J. Pater. 2010. OT-Help 2.0. Software package. U of Massachusetts Amherst.
- **Temkin-Martínez**, M. 2010. *Sources of non-conformity in pshonology: Variation and Exceptionality in Modern Hebrew Spirantization*. USC dissertation.
- **Tesar**, B.B., and P. Smolensky. 2000. *Learnability in Optimality Theory*. Cambridge, Massachusetts: MIT Press.
- **Zuraw**, K. 2000. *Patterned exceptions in phonology*. UCLA dissertation.

Appendix

Unnaturalness

- Anything with [+i] always shows up as voiceless and triggers raising unless it's in the flapping context

/aɪd[+i]/	*VTV	*[-voice]$_{[+i]}$	*aJC$_{[+i]}$	Ident(low)	Ident(son)	Ident(voi)	*[+voice]$_{[+i]}$
aɪt		*!	*!			*	
ʌɪt		*!		*		*!	
aɪd			*!				*
☞ ʌɪd				*			*
aɪɾ			*!		*		*
ʌɪɾ				*	*!		*

All underlying segments are [-i] unless specified otherwise

Exceptionality

- If *[+voice, -i] below Faithfulness: raising occurs in lexically specific environments

/ɹaɪm[-i]/	*VTV	*aJC$_{[-i]}$	Ident(low)	Ident(son)	Ident(voi)	*[+voice, -i]	*[-voice, +i]
ɹaɪm		*!				*	
☞ ɹʌɪm			*			*	
ɹaɪb		*!		*		*	
ɹʌɪb			*	*!		*	
ɹaɪp		*!		*			
ɹʌɪp			*	*!	*		

All underlying segments are [+i] unless specified otherwise