Dispersion in OT: Color Contrast in Middle Polish Nasal Vowels

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1. Introduction

In this paper, I develop and motivate an extension of classic Optimality Theory (OT; Prince and Smolensky 1993) that is sensitive to the relative dispersion of phonetic contrasts between all words in a language. Using this framework, I provide an analysis of the color contrast seen in Middle Polish nasal vowels. In addition, this analysis demonstrates how the opaque color alternation in Polish nasal vowels can be accounted for in a framework with direct mapping between input and output, a notorious hurdle for analyzing opaque phonological generalizations. The use of a strong version of Lexicon Optimization to encode sound change directly into the lexicon simulates the effects of the intermediate representations needed for opacity.

2. The framework: Faithfulness, Dispersion, and Markedness in OT

The framework of *Faithfulness, Dispersion, and Markedness in OT* (FDM-OT) used in this paper is an OT framework consisting of the three constraint families used in its name (see also Sanders 2002 and to appear).

2.1. Faithfulness constraints

The family of $\mathcal{F}$-constraints (faithfulness constraints) ensure that the input and output have identical phonological properties. Constraints in this family are, in general concept, the same as faithfulness constraints from Correspondence Theory (McCarthy and Prince 1995), though note that properties of identity for FDM-OT's $\mathcal{F}$-constraints are scalar, not binary (cf. Flemming 1995, Padgett 1995, Gnanadesikan 1997, etc.):[1]

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1. I do not assume any specific set of properties; I use generalized properties that should be easily translatable to most feature theories (modulo binarity).

 WCCFL 21 Proceedings, ed. L. Mikkelsen and C. Potts, pp. 415–428. Somerville, MA: Cascadilla Press.

(1) *ℱ-P* (faithfulness to property *P*):
If *x* and *y* are segments in a correspondence relationship with each other, then their specifications for property *P* must be the same. Violations are counted gradiently along a well-defined and bounded scale for each *P*: the more different *x* and *y* are, the worse the violation.

2.2. Dispersion constraints

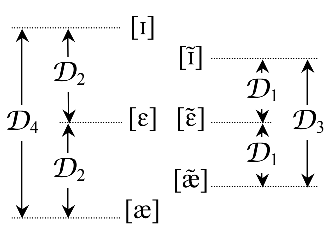
Perceptual distinctiveness between contrastive segments is known to play a role in phonology (de Saussure 1959, etc.). This insight has recently been translated into OT as Dispersion Theory (Flemming 1995, Padgett 1997, to appear, and Ní Chiosáin, and Padgett 2001), and in other forms (Boersma 1998, Steriade 1995, etc). I follow the general model put forth in Dispersion Theory, with a family of $\mathcal{D}$-constraints (dispersion constraints) which punish contrasts that are too perceptually close or indistinct:

(2) $\mathcal{D}_n$-*P* (dispersion of contrasts for property *P*):
Every pair of words *x* and *y* in the output which contrast for property *P* must be at least as far apart as the *n*th from smallest allowable perceptual distance for *P*.

This family also comes with universal rankings. Each ranking is a strict total order over the set of $\mathcal{D}_n$-*P* constraints for some property *P*:

(3) $\mathcal{D}_0\text{-}P \gg \mathcal{D}_1\text{-}P \gg \mathcal{D}_2\text{-}P \gg \ldots \gg \mathcal{D}_{n-1}\text{-}P \gg \mathcal{D}_n\text{-}P$

$\mathcal{D}$-constraints in this paper are somewhat abstract; I do not make any specific claims about exact absolute perceptual spacing, only relative spacing. An example is given below for vowel height, with $\mathcal{D}_1$-height banning the closest separation in a pair, as in [ĩ ɛ̃], and so on.

(4)


$\mathcal{D}_1$-height bans [ĩ ɛ̃] and [ɛ̃ æ̃]
$\mathcal{D}_2$-height bans [ɪ ɛ] and [ɛ æ]
$\mathcal{D}_3$-height bans [ĩ æ̃]
$\mathcal{D}_4$-height bans [ɪ æ]

In order for $\mathcal{D}$-constraints to function, they must have access to all the contrasts in the language at the same time. Thus, candidates (and by extension, inputs) must be *sets* of words. This is a radical departure from standard OT, in which candidates and inputs are only individual words. Matching inputs and outputs are indicated with identical subscript numbers.

2.3. Markedness constraints

FDM-OT, like OT, also has a notion of markedness. In FDM-OT, markedness refers *solely* to articulatory difficulty:

(5) <u>$\mathcal{M}$-*A* (markedness of articulation *A*)</u>:
No output word can contain the articulation *A*.

$\mathcal{M}$-constraints obey certain universal rankings, with the $\mathcal{M}$-constraints for more difficult articulations outranking those for easier articulations:

(6) $\mathcal{M}\text{-}A_1 \gg \mathcal{M}\text{-}A_2 \gg \mathcal{M}\text{-}A_3 \gg \ldots$, where A_1 is more difficult than A_2, etc.

2.4. Richness of the Base

The OT hypothesis of Richness of the Base is compatible with FDM-OT, though not required for the framework to function:

(7) <u>Richness of the Base (RotB)</u>:
Let □ be the set of every possible word, *W* □ □ be the set of all possible words in some language, and *G* be the grammar of the same language. Then *G*(□) = *W*.[2]

2.5. Lexicon Optimization[3]

Because RotB allows any possible word to act as an input, a mechanism is needed which selects a particular underlying representation (UR) from the pool of possible inputs to be used as the sole input:

(8) <u>Lexicon Optimization (LO; based upon Prince and Smolensky 1993)</u>:
Let *O* be an output in some language, *G* be the grammar of the same language, and *I* □ □ be the set of all inputs I_k □ □ such that $G(I_k) = O$. Then, the UR for *O* will be the input in *I* which is most faithful to *O*, as determined by the ranking of $\mathcal{F}$-constraints in the constraint hierarchy.

Thus, while multiple inputs (such as /kowt/, /kot/, /k^{h}ot/, etc.) can map to the English word [k^{h}owt] 'coat', LO will select the most faithful input /k^{h}owt/ as the single UR. Adhering only to LO, the UR for 'coat' in the past tense would then be selected as /k^{h}owɾ/, since the past tense is pronounced

2. In this paper, I use finite mini-languages for □ and *W*, with the understanding that the analysis is to be extended to the larger supersets.
3. The concepts in §2.5–2.6 have their genesis in Sanders 2001 and to appear.

[kʰowɾəd], with flapping. But LO is often combined with the hypothesis that each morpheme has only a single UR.

(9) Minimal Storage:
Every morpheme has exactly one underlying representation which can be used to derive all of its allomorphs.

(10) Weak LO:
Lexicon Optimization (8) combined with Minimal Storage (9).

Weak LO ensures that 'coat' is stored only as /kʰowt/, never as /kʰowɾ/. Some research on allomorphy argues that Minimal Storage need not be strictly adhered to (Aronoff 1976, Bybee 1988, Mester 1994, Burzio 1996, Kager 1996, etc.). If some amount of multiple storage is needed in the lexicon, do we need Minimal Storage at all? I propose that (9) be abandoned.

(11) Strong LO (SLO):
Lexicon Optimization by itself, without Minimal Storage.

SLO can be used to simulate opacity in FDM-OT by storing the necessary intermediate forms directly into the evolving lexicon.

2.6. Diachronic sound change

In FDM-OT, a diachronic sound change results from constraint reranking, with a 'late' grammar (G_l) different from the 'early' grammar (G_e), producing a new set of possible words for the language (W_l):[4]

(12) diachronic sound change (DSC):

early grammar		late grammar	
□	DSC	□	= the default, universal input
□ G_e	□ □ □ □ □	G_l □	assigned by RotB
W_e		$W_l \neq W_e$	

The ordering between a DSC and SLO is not fixed, with one ordering entailing a transparent mapping between the input □ and output W_l, and the other allowing an opaque mapping:

4. The analysis here oversimplifies both SLO and DSC as monolithic processes that apply in one step. Most likely, they are more gradient in nature (SLO storing more frequent items first, etc.).

(13) <u>DSC preceding SLO □ transparent mapping in late grammar</u>:

```
early grammar                late grammar
        □            DSC          □   =  the default, universal input
        □  Ge    □ □ □ □ □   Gl   □      assigned by RotB
        We                        Wl  ≠  We
                            SLO   □
                                  Wl  =  lexicon
```

(14) <u>SLO preceding DSC □ potentially opaque mapping in late grammar</u>:

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early grammar                late grammar
        □            DSC    ───►  We  =  lexicon, overrides RotB
        □  Ge    □ □ □ □ □   Gl   □
        We                        Wl  ≠  We
        □  SLO
        We  =  lexicon ──┘
```

Because I am interested in opacity in this paper, I only consider the case of SLO ordered before a DSC (14), since the reverse ordering can only result in a transparent mapping (due to direct mapping between the input and output, which can only be transparent).

3. The data: The Polish nasal vowels

3.1. Opacity in Modern Polish

The underlying front nasal vowel /ɛ̃/ backs and rounds to [ɔ̃] before underlyingly word-final voiced obstruents. When the triggering consonant is not word-final, /ɛ̃/ surfaces faithfully. Since word-final obstruents must be voiceless on the surface, the nasal vowel alternation in the singular is opaque.

(15)

stem UR	*[ɔ̃]*	*[ɛ̃]*	*gloss*
/zɛ̃mb/	zɔ̃mp	zɛ̃mbɪ	‘tooth/teeth’
/zɛ̃nd/	zɔ̃nt	zɛ̃ndɪ	‘row(s)’
/vɛ̃w̃z/	vɔ̃w̃ʂ	vɛ̃w̃zɛ	‘snake(s)’
/krɛ̃ŋg/	krɔ̃ŋk	krɛ̃ŋʲgʲi	‘circle(s)’

In a serial framework, such cases of opacity are accounted for by ordered rules and intermediate representations, as below:

(16)

UR	/zɛ̃mb/
ɛ̃-Backing	zɔ̃mb
Devoicing	zɔ̃mp
output	[zɔ̃mp]

Frameworks with direct mapping between input and output, such as OT, have difficulty reproducing this type of opacity (as argued by McCarthy and Prince (1993), among many others).

Various extensions to OT have been put forth to allow opacity to be given an OT analysis, as in Benua 1995, Inkelas and Orgun 1995, Kirchner 1996, McCarthy 1997, 1999, Kiparsky 1998, etc. However, these proposals either do not account for this particular class of opacity or deviate from one of the strongest and most interesting tenets of OT: direct mapping between the input and the output.[5] I propose that direct mapping should be adhered to and that its predictions concerning the inability of certain types of opacity to be synchronically productive should be taken seriously.

3.2. Lexical exceptions

In fact, this case of opacity turns out *not* to be synchronically productive (Westfal 1956).[6] Many lexical exceptions can be found (in comparison, word–final devoicing, which is always transparent, is exceptionless). The following representative words have transparent [ɛ̃] in the singular, where we expect opaque [ɔ̃] (cf. (15)):

	stem UR	*[ɛ̃]*	*[ɛ̃]*	*gloss*
(17)	/ʑɛ̃mb/	ʑɛ̃mp	ʑɛ̃mbɪ	‘finch (GEN PL/NOM SG)’
	/spɛ̃nd/	spɛ̃nt	spɛ̃ndɪ	‘round-up(s)’
	/vʲɛ̃j̃ʑ/	vʲɛ̃j̃ɕ	vʲɛ̃j̃ʑɛ	‘bond(s)’
	/prɛ̃ŋg/	prɛ̃ŋk	prɛ̃ŋʲgʲi	‘stripe (GEN PL/NOM SG)’

3.3. History

The nasal vowel alternation arose through a series of four DSCs. The word ‘tooth’ will be used as the model word for each DSC. Before about AD 1150, this word was pronounced [zɔ̃b] by speakers of West Slavic (the dialect of Slavic which eventually evolved into Polish, Czech, and Slovak). The following is the list of sound changes relevant to the case of opacity under discussion, in the order they applied:

5. For polymorphemic words, direct mapping can be supplemented with faithfulness between related outputs (Benua 1995, Burzio 1996, Kenstowicz 1996, Steraide 1996, etc.). Since I am concerned with opacity that can occur within monomorphemic words, output-based faithfulness is not sufficiently powerful to account for these data.

6. Pace Gussman (1980), who argues that those forms which show backing of /ɛ̃/ should still be derived rather than listed lexically, though he admits to a general lack of productivity.

(18)		West Slavic	<1150	zɔ̃b	zɔ̃bɪ	
	Step Ia	Lechitic	1150–1350	zɔ̃**ː**b	zɔ̃bɪ	vowel lengthening
	Step Ib	Lechitic	ca. 1300	z**ɜ̃**ːb	z**ɜ̃**bɪ	nasal decolorization
	Step II	Old Polish	1350–1500	zɜ̃ː**p**	zɜ̃bɪ	word-final devoicing
	Step III	Middle Polish	1500–1750	z**ɔ̃w̃**b	z**ɛ̃**bɪ	nasal colorization

In Lechitic, the ancestral version of Polish attested in court and church records circa AD 1150–1350, two DSCs occurred. There is some evidence that vowel lengthening happened first, but since they interact transparently, an ordering does not really matter. Due to space limitations, I skip the analysis of Step Ia, vowel lengthening before word-final voiced consonants, and I begin with Step Ib, decolorization of the nasal vowels.

4. Step Ib: Lechitic nasal vowel decolorization

Color contrasts in vowels are known to be better for high vowels than for low vowels. In FDM-OT, this means that the higher ranked $\mathcal{D}$-color constraints ban low vowel color contrasts. I assign the following $\mathcal{D}$-constraints to the displayed perceptual distances in the vowel color space:

(19)

⋮		$\mathcal{D}_8$		⋮
[i]	$\mathcal{D}_4$	[ɨ]	$\mathcal{D}_4$	[u]
⋮		$\mathcal{D}_6$		⋮
[ɛ]	$\mathcal{D}_2$	[ɜ]	$\mathcal{D}_2$	[ɔ]
⋮		$\mathcal{D}_4$		⋮
[æ]	$\mathcal{D}_0$	[a]	$\mathcal{D}_0$	[ɒ]

In addition, nasal vowels have somewhat poorer color contrasts than oral vowels do (Beddor 1993 and references therein). Within FDM-OT, this fact is represented formally by having the constraint $\mathcal{D}_{(n-1)}$-color punish color contrasts in a pair of nasal vowels if $\mathcal{D}_n$-color rules out the corresponding oral pair (cf. Padgett 1997). For example, the oral pair [i ɨ] is ruled out by $\mathcal{D}_4$-color, so the nasal pair [ĩ ɨ̃] is ruled out by $\mathcal{D}_3$-color.

4.1. Step Ib.1: Early Lechitic

Early Lechitic had a standard five vowel system for the oral vowels [i ɛ a ɔ u], plus the two nasal vowel [ɛ̃] and [ɔ̃]. The following FDM-OT constraint ranking derives the correct output (see Sanders 2002 for this and other pieces of the overall analysis that must be skipped or glossed over for space reasons):

(20) $\mathcal{D}_4$-color ≫ $\mathcal{F}$-color ≫ $\mathcal{D}_5$-color ≫ $\mathcal{D}_6$-color

By SLO, only these seven vowels will be stored in the lexicon, and they thus act as inputs to the next DSC in Late Lechitic, nasal decolorization.

4.2. Step Ib.2: Late Lechitic

Based on spelling changes of the time, it is assumed that the two nasal vowels merged to a single central vowel color (Stieber 1968, de Bray 1980), given here as mid central [ɜ̃]. In order to force the two nasal vowels to merge into one in the output, $\mathcal{D}_5$-color, the constraint that that punishes the [ɛ̃ ɔ̃] pair, must be promoted, and $\mathcal{F}$-color must be demoted:

(21) Step Ib.2: Late Lechitic nasal vowel decolorization

		prom	*dem*	
i u ɛ ɔ ɛ̃ ɔ̃ a	$\mathcal{D}_4$ color	$\mathcal{D}_5$ color	$\mathcal{F}$ color	$\mathcal{D}_6$ color
a. i u ɛ ɔ ɛ̃ ɔ̃ a		×!		×²
✓ b. i u ɛ ɔ ɜ̃ a			×²	×
c. i u ɜ ɜ̃ a			×⁴!	

The fully faithful candidate (21a) violates the newly-promoted $\mathcal{D}_5$-color, because the pair [ɛ̃ ɔ̃] is too perceptually close. The remaining candidates (21b–c) satisfy $\mathcal{D}_5$-color, but at the expense of $\mathcal{F}$-color. The nasal decolorization candidate (21b) incurs fewer violations, because it only involves a merger of two vowels, compared to four for mid vowel decolorization (21c).

5. Step II: Old Polish devoicing

5.1. Step II.1: Early Old Polish

The Early Old Polish grammar must be able to derive the Late Lechitic contrasts in obstruent voicing and in vowel duration, with the caveat that before word-final voiced consonants, only long vowels are allowed (due to the DSC of lengthening before word-final voiced consonants). By RotB, every possible input word must be considered, so the input is the set □ of all possible words (represented here by the mini-language showing both a vowel length contrast and a word-final voicing contrast).

(22) Step II.1: Early Old Polish (before word-final devoicing)

zɜ̃p$_1$ **zɜ̃b**$_3$ zɜ̃ːp$_2$ zɜ̃ːb$_4$	𝓕 voi	𝓜 V̌Ç#	𝓕 dur	𝓜 Ç#	𝓜 Vː
a. zɜ̃p$_1$ **zɜ̃b**$_3$ zɜ̃ːp$_2$ zɜ̃ːb$_4$		×!		$\times^2$	$\times^2$
✓ b. zɜ̃p$_1$ zɜ̃ːp$_2$ **zɜ̃ːb**$_{3,4}$			×	×	$\times^2$
c. **zɜ̃p**$_{1,3}$ zɜ̃ːp$_{2,4}$	$\times^2$!				×

The fully faithful candidate (22a) violates the high-ranking 𝓜-constraint banning short vowels before word-final voiced consonants. The candidate with word-final devoicing (22c) satisfies this constraint, but at the expense of high-ranking 𝓕-voicing. The candidate with vowel lengthening before word-final voiced consonants (22b) wins, despite violating the (lower-ranked) 𝓕-duration constraint. This candidate represents Early Old Polish.

By SLO, (22b) is stored in the lexicon, with /zɜ̃ːb/ stored as the UR for 'tooth', serving as the input for late Old Polish sound changes. This is a crucial step, because an intermediate representation showing the effects of voicing-induced lengthening is needed to allow opacity.

5.2. Step II.2: Late Old Polish

Late 14th-century misspellings suggest that word-final obstruents devoiced in Old Polish (Stieber 1968). Because Lechitic vowel length had been triggered by word-final voicing, devoicing of word-final obstruents opaquely masked vowel lengthening. Devoicing is achieved in Late Old Polish by promoting 𝓜-Ç# and demoting 𝓕-voicing. Recall that by SLO, the input is no longer ▯, the set of all possible words (given by RotB), but is rather the set of outputs from Early Old Polish, stored via SLO:

(23) Step II.2: Late Old Polish word-final devoicing

	prom	*dem*			
zɜ̃p$_1$ zɜ̃ːp$_2$ **zɜ̃ːb**$_{3,4}$	𝓜 Ç#	𝓕 voi	𝓜 V̌Ç#	𝓕 dur	𝓜 Vː
a. zɜ̃p$_1$ zɜ̃ːp$_2$ **zɜ̃ːb**$_{3,4}$	×!			×	$\times^2$
✓ b. zɜ̃p$_1$ **zɜ̃ːp**$_{2,3,4}$		$\times^2$!			×

Thus, the word for ‘tooth’, which was pronounced [zɜ̃ːb] in Early Old Polish, came to be pronounced as opaque [zɜ̃ːp], with lengthening apparently triggered opaquely by underlying word-final voicing that does not surface. In fact, this lengthening was triggered by surface voicing, in Late Lechitic, and has merely been ‘memorized’. If /zɜ̃b/ were borrowed as a new word at this stage, it would be pronounced transparently as [zɜ̃p], with no evidence of lengthening, since it is too new to contain lexicalized vowel length preserved by SLO at the end of Early Old Polish.

6. Step III: Middle Polish colorization

6.1. Step III.1: Early Middle Polish

Early Middle Polish had the five oral vowels [i ɛ a ɔ u] and a single nasal vowel [ɜ̃]. As seen in Late Lechitic (§4.2), the constraint ranking $\mathcal{D}_4$-color ≫ $\mathcal{D}_5$-color ≫ $\mathcal{F}$-color ≫ $\mathcal{D}_6$-color can derive this vowel system. In addition, Early Middle Polish had contrastive vowel length, so $\mathcal{F}$-duration must be ranked higher than all of the $\mathcal{D}$-duration constraints to allow short and long vowels in the input to emerge faithfully.

6.2. Step III.2: Late Middle Polish

During Middle Polish, the two nasal vowels colorized, with short [ɜ̃] fronting to [ɛ̃], and long [ɜ̃ː] backing and rounding to [ɔ̃], resulting in a new color contrast in place of an old length contrast (Stieber 1968, de Bray 1980). I argue that the new back-round nasal vowel was in fact a diphthong [ɔ̃w̃], contrary to the standard analysis which posits a pure nasal vowel [ɔ̃].

This departure from the traditional analysis is based on two reasonable assumptions: (i) duration contrasts are not as good for nasal vowels as they are for oral vowels; and (ii) the duration contrast between a short vowel and a diphthong is better than that between a short vowel and a long vowel. Thus, in order to enhance the relatively poor duration distinction between [ɜ̃] and [ɜ̃ː], diphthongization of the long nasal vowel occurred, while the oral vowels remained unchanged. Diphthongization arises if a constraint such as $\mathcal{F}$-nucleic is demoted below $\mathcal{D}_1$-duration, which punishes vowel length contrasts in nasal vowels (but not in oral vowels).

(24) Step III.1: Late Middle Polish colorization (diphthongization)

		prom	*dem*	
ɛ ɔ ɜ̃ ɛː ɔː ɜ̃ː	$\mathcal{F}$ dur	$\mathcal{D}_1$ dur	$\mathcal{F}$ nucl	$\mathcal{D}_2$ dur
a. ɛ ɔ ɜ̃ ɛː ɔː ɜ̃ː		×!		×3
✓ b. ɛ ɔ ɛ̃ ɛː ɔː ɔ̃w̃			×	×2
c. ɛ ɔ ɜ̃ ɛː ɔː	×!		×	×2

Fully faithful (24a) contains a poor duration contrast in the pair [ɜ̃ ɜ̃ː], violating high-ranking $\mathcal{D}_1$-duration. Candidate (24c) circumvents this problem by merging the two nasal vowels into one, with no length contrast at all. But $\mathcal{F}$-duration is also ranked highly, so this leaves candidate (24b), which preserves the duration contrast but enhances it by diphthongizing the long vowel. But where does the colorization come from?

The best nasal off-glides are back [w̃] and [ɯ̯̃], rather than front [j̃] or central [ɯ̵̯̃].[7] Ohala and Ohala (1993) cite evidence showing that back nasal consonants are more vowel-like than front nasal consonants are due to diminished perceptual cues to consonantality. Articulatory concerns also seem to play a role: nasal sounds are produced with a lowered velum, and back glides target the velum. With the velum lowered, it is easier to achieve the target, making back nasal glides easier to make than front nasal glides. Thus, the best nasal off-glide would seem to be a velar one, such as [w̃] or [ɯ̯̃]. This is represented in FDM-OT by a universal ranking of $\mathcal{M}$-j̃,ɯ̵̯̃ over $\mathcal{M}$-w̃,ɯ̯̃. With an undominated $\mathcal{M}$-constraint banning diphthongs with color contours, the diphthongized nasal vowel is ensured to be back [ɔ̃w̃] or [ʌ̃ɯ̯̃]. For space considerations, I omit the relevant tableau with the required ranking $\mathcal{M}$-j̃,ɯ̵̯̃ ≫ $\mathcal{D}_1$-duration ≫ $\mathcal{M}$-w̃,ɯ̯̃,$\mathcal{F}$-nucleic,$\mathcal{F}$-color.

Finally, the unchanged constraint ranking for Early Middle Polish for color contrast allows [ɛ ɔ] but not [ɛ̃ ɔ̃]. Thus, the back nasal vowel cannot be [ʌ̃ɯ̯̃], and the central nasal vowel cannot remain central. To sufficiently enhance the color contrast, the back nasal vowel must round to [ɔ̃w̃], while the central nasal vowel fronts to [ɛ̃]. In order to allow this color distinction to exist for nasal vowels (when it normally cannot with this ranking), I assume that the duration of the diphthong enhances the color contrast due to the extra time given to the listener to hear the cues to color contrast. Thus, the pair [ɛ̃ ɔ̃w̃] is allowed even though [ɛ̃ ɔ̃] is not.

7. The IPA does not have a symbol for a central glide, so I adopt the symbol [ɯ̵] on analogy with the use of the crossbar in the central vowels [ɨ] and [ʉ].

7. Comparison with standard OT

The Lechitic merger and Middle Polish split of the nasal vowels provides an interesting problem for standard OT, because OT is limited to just faithfulness and markedness constraints. Recall that [ɔ̃] and [ɛ̃] merged to central [ɜ̃] in Late Lechitic (§4.2). This requires a change in vowel color, so IDENT-[color] must be outranked by a markedness constraint which prefers central [ɜ̃] to front [ɛ̃] (and back [ɔ̃] as well). Thus, ✖ɛ̃ must outrank IDENT-[color] in Late Lechitic. In addition, ✖ɛ̃ must outrank ✖ɜ̃, since central [ɜ̃] is preferred over front [ɛ̃]. However, this is problematic, as it suggests that front [ɛ̃] (a fairly common vowel in languages with nasal vowels) is more marked than central [ɜ̃] (a significantly rarer vowel). Thus, in order for this ranking to hold, OT markedness constraints cannot be grounded in cross-linguistic inventories.

The problem is much worse once we consider the nasal vowel split in Late Middle Polish (§6.2). Short [ɜ̃] fronted to [ɛ̃], incurring the same violation of IDENT-[color] as the reverse change in Late Lechitic. Since central [ɜ̃] is the segment being lost, ✖ɜ̃ must outrank IDENT-[color]. It changes to front [ɛ̃], so we must also have ✖ɜ̃ outranking ✖ɛ̃. But this is exactly the opposite ranking of markedness constraints needed for Late Lechitic! This means that whatever OT markedness represents, it cannot be universal; otherwise, two contradictory rankings would not be allowed.

What is OT markedness if it does not match cross-linguistic inventories and cannot be universal? This question need not be asked in FDM-OT, because markedness, in the guise of universally ranked $\mathcal{M}$-constraints, is clearly defined by articulatory difficulty (which can have implications for cross-linguistic inventories through interaction with other constraints). The ranking paradox for the Lechitic merger and Middle Polish split of the nasal vowels does not arise in FDM-OT because $\mathcal{D}$-constraints, which are unavailable in standard OT, are a key part of the FDM-OT analysis, driving the relevant sound changes without requiring the relevant $\mathcal{M}$-constraints to be reranked with respect to each other.

8. Conclusion

I have constructed an analysis of the opaque nasal vowel alternation in Polish based on its historical origins within the framework of FDM-OT. A novel piece of my analysis is *Strong Lexicon Optimization*, which selects URs that are phonologically identical to their outputs. By having SLO interspersed with ordered diachronic sound changes, the analysis maintains the serialism and intermediate representations required to account for opacity without sacrificing direct mapping between the input and the output in the synchronic grammar. A consequence of SLO is that certain types of opacity cannot be synchronically productive, though they may still pervade the lexicon. This prediction is borne out for Polish, in which the nasal vowel alternation is not synchronically productive, yet is plentiful in the extant vocabulary.

In addition, FDM-OT's $\mathcal{D}$-constraints and set-based inputs and candidates provide an explanation for why the nasal vowels evolved the way they did, due to considerations of *contrast dispersion*. This type of analysis is unavailable in frameworks which treat inputs and candidates as individual words whose perceptual distinctiveness from other (unrelated) words cannot be measured. Such frameworks cannot adequately account for both the merger and the split of the Polish nasal vowels, as done in this paper with FDM-OT. In addition, this analysis adds to the general understanding of the history of nasal vowels in Polish, providing phonetic motivation for the relevant sound changes.

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