Opacity and Sound Change in the Polish Lexicon*

Nathan Sanders, University of California, Santa Cruz dissertation defense, 19 March 2002

Goals

- develop the framework of FDM–OT, an extension of Optimality Theory which utilizes contrast dispersion and strong lexicon optimization
- analyze instances of opacity in Polish in FDM–OT; in particular, the color alternation in nasal vowels
- motivate the need for an analytical framework which is sensitive to contrast dispersion
- demonstrate how strong lexicon optimization without lexical minimization accounts for diachronic opacity

1 The Framework: Faithfulness, Dispersion, and Markedness in OT (FDM–OT)

Based upon Optimality Theory (OT; Prince and Smolensky 1993): language–specific ranking of universal violable constraints selects one output from a set of possible outputs for every possible input.

1.1 Faithfulness constraints

𝓕–constraints are essentially the same as faithfulness constraints from Prince and Smolensky 1993 and McCarthy and Prince 1995. They ensure that the input and output are the same.

(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: the more different *x* and *y* are, the worse the violation.

Properties are scalar (cf. Flemming 1995, Padgett 1995, Gnanadesikan 1997, Boersma 1998). For example, vowel height has at least three values:

(2)

/ɪ/	𝓕 height
a. ɪ	
b. ɛ	×
c. æ	×^{2}

In FDM–OT, inputs and outputs are *sets* of words, not just individual words as in OT (see §1.2). Words that are in a correspondence relationship with each other for the purposes of 𝓕–constraints are marked with matching subscript numerals. Corresponding segments within corresponding words are generally obvious and left unmarked.

(3)

pɪt$_1$ pĩn$_4$ pɛt$_2$ pɛ̃n$_5$ pæt$_3$ pæ̃n$_6$	𝓕 height	
a. pɪt$_1$ pĩn$_4$ pɛt$_2$ pɛ̃n$_5$ pæt$_3$ pæ̃n$_6$		Standard American English
b. pɪt$_1$ pĩn$_{4,5}$ pɛt$_2$ pæt$_3$ pæ̃n$_6$	×	southeastern dialects, with neutralization of [ĩ ɛ̃] to [ĩ]

𝓕–constraints have no universal rankings: languages may differ in how they are ranked with respect to each other.

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1.2 Dispersion constraints

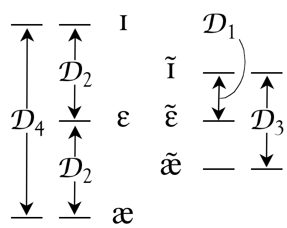
It has been known for some time that the perceptual distinctiveness between contrastive segments plays a role in phonology (de Saussure 1959, Martinet 1964, Lindblom 1986, 1990, etc.). This insight has recently been translated into OT in various implementations: Dispersion Theory (Flemming 1995, Padgett 1997, to appear, and Ní Chiosáin and Padgett 2001), Functional Phonology (Boersma 1998), and others (Steriade 1995, etc.). I follow the general model of Dispersion Theory, with constraints which punish contrasts that are too perceptually close/indistinct:

(4) **$\mathcal{D}$–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*.

(5) **universal hierarchy of $\mathcal{D}$–constraints** (strict, total order for each property; no order across properties)
$\mathcal{D}_0\text{–}P \gg \mathcal{D}_1\text{–}P \gg \mathcal{D}_2\text{–}P \gg \ldots \gg \mathcal{D}_{N-1}\text{–}P \gg \mathcal{D}_N\text{–}P \gg \mathcal{D}_{N+1}\text{–}P$

The scale of 'allowable perceptual distances' can be obtained directly through phonetic experimentation and indirectly by examining patterns of cross–linguistic dispersion.

(6) **simplified scale of vowel height dispersion**



(7)

pɪt₁ pɪ̃n₄ / pɛt₂ pɛ̃n₅ / pæt₃ pæ̃n₆	$\mathcal{F}$ hgt	$\mathcal{D}_1$ hgt	$\mathcal{F}$ hgt	$\mathcal{D}_2$ hgt	$\mathcal{D}_3$ hgt	$\mathcal{D}_4$ hgt	
a. pɪt₁ pɪ̃n₄ / pɛt₂ pɛ̃n₅ / pæt₃ pæ̃n₆		×2		×4	×5	×6	Standard American English ($\mathcal{F}$–height ≫ $\mathcal{D}_1$–height)
b. pɪt₁ pɪ̃n₄,₅ / pɛt₂ / pæt₃ pæ̃n₆	×		×	×2	×3	×4	southeastern dialects ($\mathcal{D}_1$–height ≫ $\mathcal{F}$–height)

1.3 Markedness constraints

FDM–OT, like standard OT, has a notion of markedness.

(8) **$\mathcal{M}$–A** (markedness of articulation A)
No output word can contain the articulation A.

(9) **universal hierarchy of $\mathcal{M}$–constraints** (not a strict or total order because some articulations are incomparable)
$\mathcal{M}\text{–A}_a \gg \mathcal{M}\text{–A}_b \gg \mathcal{M}\text{–A}_c \gg \ldots$, where A_a is more difficult than A_b, which is more difficult than A_c, ...

FDM–OT markedness hierarchies are defined *solely* in terms of articulatory difficulty, unlike in OT, in which markedness hierarchies can be based on articulatory difficulty, order of acquisition, cross–linguistic frequency, etc. OT–style markedness hierarchies cannot predict that neutralization and lack of contrast tend to result in articulatorily easier sounds (central vowels like [ɨ] are preferred in languages with only one vowel color; [ə] and [ʔ] are often default epenthetic segments, but are not as common as [i] and [t] in phonemic inventories; etc.).

1.4 Richness of the base

A basic tenet of OT is that the input is unconstrained. This is represented by requiring the constraint hierarchy to map every possible input to some possible output. In FDM–OT, which deals with sets of words rather than single words, richness of the base must be implemented slightly differently than in standard OT.

(10) **Richness of the Base (RotB) in FDM–OT**
Let Ω be the set of every possible word, $W \subseteq \Omega$ be the set of all possible words in some language, and G be the grammar of the same language. Then $G(\Omega) = W$.

Since Ω and W are unbounded sets, we cannot show their membership and the mapping between them directly. I use small, finite mini–languages to represent Ω and W, with the understanding that the analysis is to be extended to larger sets.

1.5 Strong lexicon optimization

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 eventually be used as the sole input.

(11) **Lexicon Optimization (LO)**
Let O be an output in some language, G be the grammar of the same language, and $I \subseteq \Omega$ be the set of all inputs $I_k \in \Omega$ such that $G(I_k) = O$. Then, the underlying representation for O will be the input in I which is most faithful to O, as determined by the ranking of faithfulness constraints in the constraint hierarchy.

Thus, while multiple inputs can map to the English word [kʰowt] 'coat', LO will select only the most faithful input /kʰowt/ as the single UR.

(12)
Ω = /kowt/ /kot/ /kowt/ /kʰowt/
by the grammar
W = [kʰowt]
by LO
UR = /kʰowt/

Adhering only to LO, the UR for 'coat' in the past tense would be selected in the same way, stored in the lexicon faithfully as /kʰowɾ/, since the past tense is pronounced [kʰowɾəd], with flapping.[1] But LO is often taken to include the common assumption that each morpheme has only a single UR.

(13) **Lexical Minimization**
Every morpheme has exactly one underlying representation which can be used to derive all of its allomorphs.

(14) **Weak Lexicon Optimization**
Lexicon optimization combined with lexical minimization.

Weak LO ensures that 'coat' is stored as /kʰowt/ only, since this UR, and not /kʰowɾ/, can be used to derive both the present tense and the past tense. However, some research on allomorphy in OT argues that lexical minimization need not be strictly adhered to (Mester 1994, Burzio 1996, Kager 1996, 1999, Rubach 2001; similar non–OT arguments are made in Vennemann 1974, Hudson 1975, Aronoff 1976, Bybee 1988, 1995). If some amount of multiple storage is needed in the lexicon, why do we need lexical minimization at all?

(15) **Strong Lexicon Optimization (SLO)**
Lexicon optimization by itself, without lexical minimization.

I propose that SLO should be maintained, with lexical minimization absent from the phonology. Within a monostratal framework such as OT and FDM–OT, SLO is needed to facilitate opacity, which requires intermediate representations, by storing intermediate forms in the lexicon (§1.6, §5).

[1]An alternative analysis would be to store the entire morphologically complex word in the lexicon, with the past tense morpheme attached to the past tense stem, yielding the UR /kʰowɾəd/. I do not pursue this analysis here.

1.6 Diachronic sound change

Diachronic sound change (DSC) is achieved in FDM–OT by reranking constraints in the hierarchy, with a 'late' grammar that is different from the 'early' grammar, producing a new set of possible words for the language.

(16) early grammar   late grammar

Ω DSC Ω = the default, universal input assigned by RotB

$\downarrow$ G_e $\longrightarrow$ G_l $\downarrow$

W_e $W_l \neq W_e$

The ordering of SLO and DSC determines to possibility for the introduction of opacity into the phonology. If SLO takes place after DSC, the input to the late grammar is still Ω since there is no lexicon, which means the DSC can only be transparent, since it is a one–step direct mapping from Ω to the output.

(17) early grammar   late grammar

Ω DSC Ω = the default, universal input assigned by RotB

$\downarrow$ G_e $\longrightarrow$ G_l $\downarrow$

W_e $W_l \neq W_e$

SLO $\downarrow$

W_l = lexicon

But it is also possible for SLO to precede DSC. In that case, the output set of the early grammar is stored as the lexicon, and those URs become the inputs to the late grammar. In this way, the stored lexicon acts as an intermediate stage, allowing the new DSC to potentially interact opaquely with older phonological patterns which have been frozen in the lexicon.

(18) early grammar   late grammar

Ω DSC W_e = lexicon, overrides RotB

$\downarrow$ G_e $\longrightarrow$ G_l $\downarrow$

W_e $W_l \neq W_e$, potentially opaque

$\downarrow$ SLO

W_e = lexicon

Because of the potential for creating opacity, I will only use the model in (18), though (17) could be used just as easily for transparent DSCs. It must be noted that the type of opacity created by (18) is diachronic only, not synchronic, since SLO (the source of the intermediate representations needed for opacity) only optimizes the lexicon once. This is shown concretely with in §5.

2 The Data: The Polish nasal vowels

All stems are from Jaślan and Stanisławski 1993 (unmarked) or Stanisławski 1978 (marked with S78), inflected according to Bielec 1998, and confirmed by a native speaker.

1.1 Opacity in Modern Polish

The type of opacity I am concerned with here is a situation in which a phonological generalization P_1 is assumed to be true, yet it is masked by a second generalization P_2. In this case, P_2 erases the triggering environment for P_1, making it appear that P_1 has over–applied in a surface environment where it should not. Here, P_1 is backing (and rounding) of the front nasal vowel /ɛ̃/ to [ɔ̃] before word–final, underlyingly voiced oral consonants (this is the same environment seen in the well–known raising of /ɔ/ to [u], which is also opaque).

(19)

stem UR	*[ɔ̃]*	*[ɛ̃]*	*gloss*
/zɛ̃mb/	zɔ̃mp	zɛ̃mbɪ	'tooth/teeth'
/ʐɛ̃nd/	ʐɔ̃nt	ʐɛ̃ndɪ	'row(s)'
/vɛ̃w̃ʐ/	vɔ̃w̃ʂ	vɛ̃w̃ʐɛ	'snake(s)'
/krɛ̃ŋg/	krɔ̃ŋk	krɛ̃ŋʲɡʲi	'circle(s)'

As can be seen in (19), backing of [ɛ̃] is rendered opaque by word–final devoicing of obstruents, which changes /b/ to [p], /d/ to [t], etc. at the end of the word, thus erasing the triggering environment for backing of [ɛ̃]. In a serial framework, such cases of opacity are easily accounted for by use of ordered rules and intermediate representations.

(20)

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

Strictly parallel frameworks with direct mapping between input and output, such as standard OT, have difficulty reproducing this type of opacity (as argued in McCarthy and Prince 1993, Prince and Smolensky 1993, Chomsky 1995, Goldsmith 1996, numerous papers in Roca 1997, Idsardi 1998, and Kager 1999), precisely because there are no facilitative intermediate representations to preserve the results of the opaque generalization (here, backing of /ɛ̃/) before the masking generalization (word–final devoicing) can erase the trigger (word–final voiced oral consonants).

Various extensions to OT have been put forth to analyze opacity: Smolensky 1993, Benua 1995, Inkelas and Orgun 1995, Kirchner 1996, McCarthy 1997, 1999, Kiparsky 1998, Łubowicz 2001, 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 standard OT: direct mapping between the input and the output. I claim 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.

1.2 Lexical Exceptions

In fact, this case of opacity turns out *not* to be synchronically productive (Westfal 1956).[2] Many lexical exceptions can be found (in comparison, word–final devoicing, which is always transparent, is exceptionless).

(21)

stem UR	*[ɛ̃]*	*[ɛ̃]*	*gloss*
/ʑɛ̃mb/	ʑɛ̃mp	ʑɛ̃mba	‘finch (GEN PL/NOM SG)’ (S78)
/ɔbrɛ̃mb/	ɔbrɛ̃mp	ɔbrɛ̃mbɪ	‘extent(s)’
/spɛ̃nd/	spɛ̃nt	spɛ̃ndɪ	‘round–up(s)’ (S78)
/kɔlɛ̃nd/	kɔlɛ̃nt	kɔlɛ̃nda	‘carol (GEN PL/NOM SG)’
/vʲɛ̃ɲʑ/	vʲɛ̃ɲɕ	vʲɛ̃ɲʑɛ	‘bond(s)’
/kravɛ̃ɲdʑ/	kravɛ̃ɲtɕ	kravɛ̃ɲdʑi	‘handful(s)’
/pɔtɛ̃ŋg/	pɔtɛ̃ŋk	pɔtɛ̃ŋga	‘power (GEN PL/NOM SG)’
/prɛ̃ŋg/	prɛ̃ŋk	prɛ̃ŋga	‘stripe (GEN PL/NOM SG)’ (S78)

1.3 History

Because FDM–OT can achieve opacity by SLO followed by a DSC, it is important to consider the history of the case of opacity in question. Backing of /ɛ̃/ to [ɔ̃] arose through a series of four DSCs over the course of six centuries. Throughout this talk, the word ‘tooth’ will be used as the model word for each DSC. Before about AD 1150, this word was pronounced [zɛ̃b] by speakers of West Slavic (the dialect of Slavic which eventually evolved into Polish, Czech, and Slovak).

(22)

	West Slavic	>1150	zɛ̃b	
Step Ia	Lechitic	1150–1350	zɛ̃ːb	vowel lengthening
Step Ib	Lechitic	ca. 1300	zɔ̃ːb	nasal decolorization
Step II	Old Polish	1350–1500	zɔ̃ːp	word–final devoicing
Step III	Middle Polish	1500–1750	zɔ̃w̃p	nasal colorization

Each DSC is described and given an analysis within FDM–OT in the following sections.

[2]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.

3 Step Ia: Lechitic vowel lengthening

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. I analyze vowel lengthening first.

3.1 Step Ia.1: Early Lechitic

In early Lechitic, there was a general contrast in vowel length. By RotB, the input consists of all possible words. The subset I am concerned with contains words of the form [zɛ̃(:){p,b}(i)], which show the vowel length contrast in the first syllable and a voicing contrast in the second consonant. The optional final [i] shows that CVC and CVCV words were both allowed. This subset contains the early Lechitic word [zɛ̃b] 'tooth'.

The survival of vowel length in the output means that 𝓕-duration must outrank 𝓓-duration (which punishes all vowel length contrasts[3]), as well as any 𝓜-constraints that penalize specific vowel lengths (including 𝓜-V̆C̬#, which bans short vowels before word-final voiced codas, and 𝓜-V:, which bans all long vowels).

(23) **Step Ia.1: early Lechitic (before lengthening)**

zɛ̃p$_1$ zɛ̃b$_5$ zɛ̃:p$_2$ zɛ̃:b$_6$ zɛ̃pi$_3$ zɛ̃bi$_7$ zɛ̃:pi$_4$ zɛ̃:bi$_8$	𝓕 voi	𝓕 dur	𝓓 dur	𝓜 V̆C̬#	𝓜 V:	
✓ a. zɛ̃p$_1$ zɛ̃b$_5$ zɛ̃:p$_2$ zɛ̃:b$_6$ zɛ̃pi$_3$ zɛ̃bi$_7$ zɛ̃:pi$_4$ zɛ̃:bi$_8$			×^{4}	×	×^{4}	fully faithful
b. zɛ̃:p$_{1,2}$ zɛ̃:b$_{5,6}$ zɛ̃:pi$_{3,4}$ zɛ̃:bi$_{7,8}$		×^{4}!			×^{4}	vowel lengthening
c. zɛ̃p$_1$ zɛ̃:p$_2$ zɛ̃:b$_{5,6}$ zɛ̃pi$_3$ zɛ̃bi$_7$ zɛ̃:pi$_4$ zɛ̃:bi$_8$		×!	×^{3}		×^{4}	vowel lengthening before word-final voiced codas
d. zɛ̃p$_{1,2}$ zɛ̃b$_{5,6}$ zɛ̃pi$_{3,4}$ zɛ̃bi$_{7,8}$		×^{4}!		×		vowel shortening
e. zɛ̃p$_{1,2}$ zɛ̃:b$_{5,6}$ zɛ̃pi$_{3,4}$ zɛ̃bi$_{7,8}$		×^{4}!			×	vowel shortening plus vowel lengthening before word-final voiced codas
f. zɛ̃p$_{1,5}$ zɛ̃:p$_{2,6}$ zɛ̃pi$_3$ zɛ̃bi$_7$ zɛ̃:pi$_4$ zɛ̃:bi$_8$	×^{2}!		×^{3}		×^{3}	word-final devoicing

Candidates (23b–f) all violate highly marked 𝓕-constraints, so (23a) wins, despite incurring more serious violations of the lower ranked 𝓓- and 𝓜-constraints. This is the correct output for early Lechitic. By SLO, this output is stored as the lexicon for late Lechitic, serving as the input for future DSCs. However, since early Lechitic is faithful to the input, the effects of SLO will not be seen in late Lechitic.

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[3] Actually, the relevant constraint is $\mathcal{D}_2$-duration, as we will see in §6.

1.2 Step Ia.2: Late Lechitic

By the end of the Lechitic era, vowels in final syllables with a voiced coda could only be long (Stieber 1973:28, Carlton 1991:216–217). Thus, all former short vowels in these positions underwent a lengthening process, causing early Lechitic [zĕ̃b] ‘tooth’ to be pronounced as [zẽ:b].

(24)

	West Slavic	>1150	zĕ̃b	
Step Ia	Lechitic	1150–1350	zẽ:b	vowel lengthening
Step Ib	Lechitic	ca. 1300	zɔ̃:b	nasal decolorization
Step II	Old Polish	1350–1500	zɔ̃:p	word-final devoicing
Step III	Middle Polish	1500–1750	zɔ̃w̃p	nasal colorization

This DSC is represented by candidate (23c) above, which can be obtained by promoting *ℳ*–V̌C̬# over *ℱ*–duration. Note that all other rankings from early Lechitic remain, since there is no motivation for spurious rerankings to occur. (As a notational convention, tableaux for late grammars, such as (25), are marked with a shadow.)

(25) **Step Ia.2: late Lechitic lengthening**

			prom	dem			
	zĕ̃p$_1$ zĕ̃b$_5$ zẽ:p$_2$ zẽ:b$_6$ zĕ̃pi$_3$ zĕ̃bi$_7$ zẽ:pi$_4$ zẽ:bi$_8$	*ℱ* voi	*ℳ* V̌C̬#	*ℱ* dur	*𝒟* dur	*ℳ* V:	
a.	zĕ̃p$_1$ zĕ̃b$_5$ zẽ:p$_2$ zẽ:b$_6$ zĕ̃pi$_3$ zĕ̃bi$_7$ zẽ:pi$_4$ zẽ:bi$_8$		×!		×^{4}	×^{4}	fully faithful
b.	zẽ:p$_{1,2}$ zẽ:b$_{5,6}$ zẽ:pi$_{3,4}$ zẽ:bi$_{7,8}$			×^{4}!		×^{4}	vowel lengthening
✓ c.	zĕ̃p$_1$ zẽ:p$_2$ zẽ:b$_{5,6}$ zĕ̃pi$_3$ zĕ̃bi$_7$ zẽ:pi$_4$ zẽ:bi$_8$			×	×^{3}	×^{4}	vowel lengthening before word-final voiced codas
d.	zĕ̃p$_{1,2}$ zĕ̃b$_{5,6}$ zĕ̃pi$_{3,4}$ zĕ̃bi$_{7,8}$		×!	×^{4}			vowel shortening
e.	zĕ̃p$_{1,2}$ zẽ:b$_{5,6}$ zĕ̃pi$_{3,4}$ zĕ̃bi$_{7,8}$			×^{4}!		×	vowel shortening plus vowel lengthening before word-final voiced codas
f.	zĕ̃p$_{1,5}$ zẽ:p$_{2,6}$ zĕ̃pi$_3$ zĕ̃bi$_7$ zẽ:pi$_4$ zẽ:bi$_8$	×^{2}!			×^{3}	×^{3}	word-final devoicing

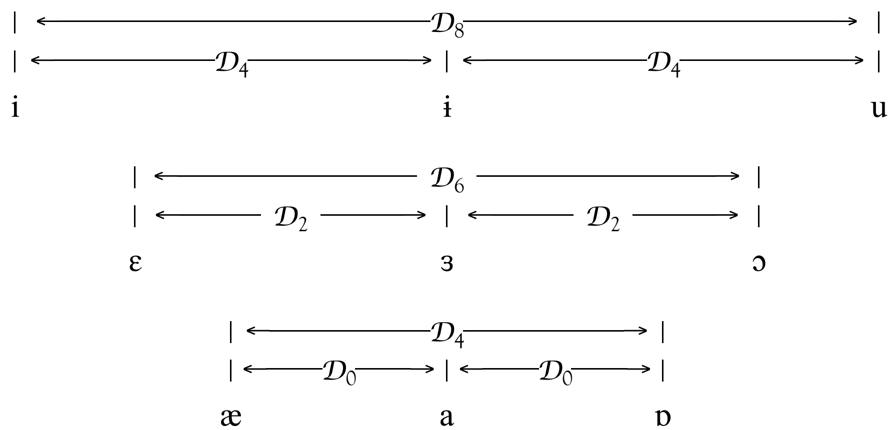
The fully faithful candidate (25a) contains the word [zĕ̃b], which is prohibited by the newly promoted constraint *ℳ*–V̌C̬#. Word-final devoicing in candidate (25f) is not a viable option to satisfy *ℳ*–V̌C̬# because *ℱ*–voicing is still highly ranked. The remaining candidates (25b–e) all violate the demoted *ℱ*–duration, but candidate (25c), with vowel lengthening before word-final voiced codas, violates it the least, so (25c) is correctly selected as the grammatical output for late Lechitic, with early Lechitic [zĕ̃b] (word 5) being pronounced as [zẽ:b].

4 Step Ib: Lechitic nasal vowel decolorization

The next DSC involves changes in vowel color based on dispersion of contrasts, so it is important to lay out the assumptions I am making concerning the closeness of particular vowel color contrasts. For simplicity, I only assume three vowel heights for oral vowels and one vowel height for nasal vowels, given by other constraints in the hierarchy. I also only assume three vowel colors. This yields nine oral vowels and three nasal vowels that must be considered.

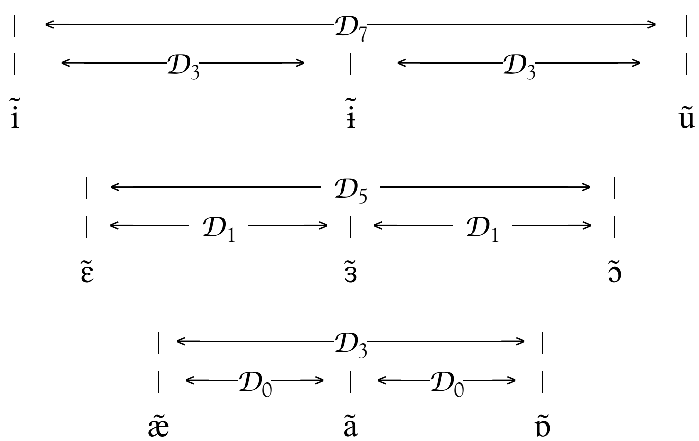
It is well known that the perceptual distinctiveness of color contrasts is worse for low vowels than for high vowels. Thus, the low front and central vowels [æ a] are perceptually less distinct from each other than their high counterparts [i i]. The following diagram summarizes which perceptual distances for vowel color are ruled out by which $\mathcal{D}$-constraints for the oral vowels.

(26)



The apparent skipping of odd-numbered $\mathcal{D}$-constraints is crucial to the analysis presented in this section and relates to the effect of nasality on the perception of vowel quality. Nasal vowels generally have poorer quality contrasts with each other than oral vowels do (Beddor 1993 and references therein). I formalize this by having pairs of particular nasal vowels of the same height be ruled out by $\mathcal{D}_{(n-1)}$-color, where $\mathcal{D}_n$-color is the (even-numbered) constraint which rules out the oral version of that pair (cf. Padgett 1997, in which a similar proposal is made).

(27)



It is also important to consider how the oral vowels and nasal vowels contrast with each other. The simplest solution, which I adopt here, is that they contrast for nasality only and do not contrast at all for any other perceptual dimension (in particular, they do not contrast for color).[4]

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[4]A plausible alternative is to assume that nasality itself is a type of color (or perhaps enhances color contrast; cf. Wright 1986), so that, for example, the mixed oral/nasal pair [ɛ ɜ̃] has a significantly better color contrast than either the purely nasal [ɛ̃ ɜ̃] or purely oral [ɛ ɜ] pairs (and thus, it violates fewer $\mathcal{D}$-color constraints). This alternative is reasonable and worth pursuing, but it is beyond the scope of the current discussion.

1.1 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]. By RotB, this system must be derived from the universal input *Ω*, represented here by the mini-language consisting of nine oral vowels (three heights and three colors) and three nasal vowels (three colors of the same height).

(28) **Step Ib.1: early Lechitic (before decolorization)**

i ɨ u ɛ ɜ ɔ ɛ̃ ɜ̃ ɔ̃ æ a ɒ	$\mathcal{D}_4$ color	$\mathcal{F}$ color	$\mathcal{D}_5$ color	$\mathcal{D}_6$ color	
a. i ɨ u ɛ ɜ ɔ ɛ̃ ɜ̃ ɔ̃ æ a ɒ	✗^{9}!		✗^{10}	✗^{11}	fully faithful
b. i ɨ u ɛ ɜ ɔ ɛ̃ ɜ̃ ɔ̃ a	✗^{6}!	✗^{2}	✗^{7}	✗^{8}	low decolorization
c. i ɨ u ɛ ɔ ɛ̃ ɔ̃ a	✗^{2}!	✗^{4}	✗^{3}	✗^{4}	low decolorization plus loss of mid central
✓ d. i u ɛ ɔ ɛ̃ ɔ̃ a		✗^{5}	✗	✗^{2}	low decolorization plus loss of mid and high central
e. i u ɛ ɔ ɜ̃ a		✗^{6}!		✗	low and nasal decolorization plus loss of mid and high central
f. i u ɜ ɜ̃ a		✗^{7}!			low, mid, and nasal decolorization plus loss of high central

The more faithful candidates (28a–c) have too many poor color contrasts. Candidates (28d–f) satisfy $\mathcal{D}_4$-color because of the lack of front-central and central-back contrasts. Candidate (28d) defeats the less faithful candidates (28e) and (28f), despite having a worse contrast in the nasal vowels as per the lower ranked $\mathcal{D}_5$-color. Candidate (28d) is the winning candidate and represents the output of early Lechitic speakers, before any sound changes occurred. By SLO, this output language will be stored in the lexicon, allowing it to be serve as the input for later sound changes.

1.2 Step Ib.2: Late Lechitic

Originally the spelling of the two nasal vowels was different: ⟨en⟩ or ⟨em⟩ for the front nasal vowel and ⟨an⟩ or ⟨am⟩ for the back one. But later spellings during the Lechitic era blurred the distinction between them, typically with ⟨an⟩, ⟨am⟩, or the new grapheme ⟨ɸ⟩ used for both, indicating that a difference in pronunciation was no longer being maintained, at least not consistently (Stieber 1968:12–13, de Bray 1980:230–231).

The standard analysis of this merger is that the front and back nasal vowels both became low central [ã], matching the quality of the oral vowel [a], as suggested by the spellings ⟨an⟩ and ⟨am⟩. However, I claim that the nasal vowels merged to mid central [ɜ̃] rather than [ã], making the word 'tooth' be pronounced [zɜ̃:b] in late Lechitic:

(29)

	West Slavic	>1150	zɛ̃b	
Step Ia	Lechitic	1150–1350	zɛ̃:b	vowel lengthening
Step Ib	Lechitic	ca. 1300	zɜ̃:b	nasal decolorization
Step II	Old Polish	1350–1500	zɜ̃:p	word-final devoicing
Step III	Middle Polish	1500–1750	zɔ̃w̃p	nasal colorization

There are at least three reasons for taking this unconventional position on the quality of the merged nasal vowel.

- The 14th-century orthographic innovation of ⟨ɸ⟩ to represent the late Lechitic merged nasal vowel color suggests that the vowel quality was different from any extant vowel of the time, rather than being similar to low [a]. Otherwise, scribes might have relied solely on some variation of ⟨a⟩ (such as the digraphs that were already in use) instead of inventing a completely unrelated symbol.

- Within FDM-OT, lowering of the mid nasal vowels to [ã] requires $\mathcal{M}$-ɛ̃,ɔ̃ to outrank $\mathcal{M}$-ã. This ranking must of course be universal, since $\mathcal{M}$-constraints represent universal physiological markedness. However, low vowels require more extreme movement of the jaw than mid vowels (which are closer to rest position), so we would expect low vowels to be more articulatorily marked than mid vowels, giving us the opposite ranking: $\mathcal{M}$-ã over $\mathcal{M}$-ɛ̃,ɔ̃.

- If the former mid nasal vowels did indeed merge and lower to *[ã], some explanation has to be given for why both the lowering and decolorization processes eventually reversed themselves *simultaneously* later in Middle Polish. The simpler analysis I adopt holds that vowel height remains constant through both the Lechitic merger and subsequent split in Middle Polish, requiring only an account of the loss of vowel color.

The late Lechitic merger of the two early Lechitic nasal vowels can be achieved by changing the relative ranking of $\mathcal{F}$-color and $\mathcal{D}_5$-color from early Lechitic so that $\mathcal{D}_5$-color outranks $\mathcal{F}$-color.

(30) **Step Ib.2: late Lechitic 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}	fully faithful
✓ b.	i u ɛ ɔ ɜ̃ a			×^{2}	×	nasal decolorization
c.	i u ɜ ɜ̃ a			×^{4}!		nasal and mid decolorization
d.	i ɜ ɜ̃ a			×^{6}!		decolorization

The languages with a single nasal vowel (30b–d) are better than the more faithful candidate (30a) (recall that by SLO, the output of early Lechitic is used as the input to the late Lechitic sound change, so the fully faithful candidate (30a) looks exactly like early Lechitic). Candidates (30c) and (30d) lose to (30b) due to extraneous violations of $\mathcal{F}$-color that arise as the result of unnecessarily merging the oral vowels. (30b) is the correct output, representing late Lechitic. Thus, 'tooth' was pronounced as [zɜ̃:b] in late Lechitic, with a central nasal vowel:

5 Step II: Old Polish devoicing

This is the crucial stage in which opacity enters the analysis.

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. As always, the input to the early grammar is *Ω*, the set of all possible words. I use the same subset as in the analysis of late Lechitic lengthening, characterized by the expression [zɛ̃(:){p,b}(i)].

(31) **Step II.1: early Old Polish (before devoicing)**

	𝓕 voi	𝓜 V̌Ç#	𝓕 dur	𝓜 Ç#	𝓜 V:	
zẽp$_1$ zẽb$_5$ zẽːp$_2$ zẽːb$_6$ zẽpi$_3$ zẽbi$_7$ zẽːpi$_4$ zẽːbi$_8$						
a. zẽp$_1$ zẽb$_5$ zẽːp$_2$ zẽːb$_6$ zẽpi$_3$ zẽbi$_7$ zẽːpi$_4$ zẽːbi$_8$		×!		×^{2}	×^{4}	fully faithful
✓ b. zẽp$_1$ zẽːp$_2$ zẽːb$_{5,6}$ zẽpi$_3$ zẽbi$_7$ zẽːpi$_4$ zẽːbi$_8$			×	×	×^{4}	vowel lengthening before word-final voiced codas
c. zẽp$_{1,5}$ zẽːp$_{2,6}$ zẽpi$_3$ zẽbi$_7$ zẽːpi$_4$ zẽːbi$_8$	×^{2}!				×^{3}	word-final devoicing

Candidate (31a) contains the word [zẽb], which is banned by high ranking 𝓜-V̌Ç#. Candidate (31c) satisfies this constraint, but at the expense of faithfulness to input voicing specifications. This leaves (31b) as the output.

By SLO, this output is stored in the lexicon via strong lexicon optimization, serving as the input for late Old Polish sound changes, in particular, word-final devoicing of obstruents. This is a crucial step, because word-final devoicing renders historical lengthening (from Lechitic) opaque.

1.2 Step II.2: Late Old Polish

In late 14th century documents, some misspellings of the type ⟨Bok⟩ for ⟨Bóg⟩ 'God' can be found, and by the 15th century, such misspellings were much more frequent. These misspellings suggest that early on in Old Polish and continuing through the 15th century, a sound change emerged which required word-final obstruents to be voiceless (Stieber 1968:77), causing early old Polish [zɔ̃ːb] 'tooth' to be pronounced [zɔ̃ːp].

(32)

	West Slavic	>1150	zẽb	
Step Ia	Lechitic	1150–1350	zẽːb	vowel lengthening
Step Ib	Lechitic	ca. 1300	zɔ̃ːb	nasal decolorization
Step II	**Old Polish**	**1350–1500**	**zɔ̃ːp**	**word-final devoicing**
Step III	Middle Polish	1500–1750	zɔ̃w̃p	nasal colorization

Because Lechitic vowel length was triggered by word-final voicing, devoicing of word-final obstruents opaquely masks vowel length. Devoicing can arise by promoting 𝓜-Ç# over 𝓕-voicing (recall that no other constraint rankings from early Old Polish will change, so the remaining constraints retain their early rankings with respect to each other and to 𝓜-Ç# and 𝓕-voicing).

(33) **Step II.2: late Old Polish devoicing**

		prom	*dem*			
zɛ̃p$_1$ zɛ̃ːp$_2$ zɛ̃ːb$_6$ zɛ̃pi$_3$ zɛ̃bi$_7$ zɛ̃ːpi$_4$ zɛ̃ːbi$_8$	𝓜 V̆C̬#	𝓜 C̬#	𝓕 voi	𝓕 dur	𝓜 Vː	
a. zɛ̃p$_1$ zɛ̃ːp$_2$ zɛ̃ːb$_6$ zɛ̃pi$_3$ zɛ̃bi$_7$ zɛ̃ːpi$_4$ zɛ̃ːbi$_8$		×!		×	×^{4}	fully faithful
✓ b. zɛ̃p$_1$ zɛ̃ːp$_{2,6}$ zɛ̃pi$_3$ zɛ̃bi$_7$ zɛ̃ːpi$_4$ zɛ̃ːbi$_8$			×^{2}		×^{3}	word–final devoicing

The fully faithful candidate (33a) violates the newly promoted 𝓜–C̬# because it contains the word [zɔ̃ːb], with a word–final voiced obstruent. Candidate (33b) is selected as the output of this sound change because it satisfies 𝓜–C̬# (despite violating lower ranked constraints), causing 'tooth' to be pronounced [zɔ̃ːp].

The effects of opacity and its incompatibility with direct mapping can be seen clearly at this stage. In early Old Polish, the word 'tooth' was pronounced [zɔːb], whether it arose from /zɔ̃b/$_5$ (the UR predicted by weak LO with lexical minimization, since there is no vowel length in the plural [zɔ̃bi]) or /zɔ̃ːb/$_6$, since both inputs merged to [zɔ̃ːb]$_6$. As evidenced by candidate (31c), if word–final devoicing occurred before SLO, then /zɔ̃b/$_5$ would transparently map to [zɔ̃p]$_1$ without lengthening, while /zɔ̃ːb/$_6$ would map to [zɔ̃ːp]$_2$, yielding *different* late Old Polish pronunciations for /zɔ̃b/$_5$ and /zɔ̃ːb/$_6$, instead of the same pronunciation [zɔ̃ːp]$_2$ as seen in (33b).

In order for older /zɔ̃b/$_5$ to eventually map to [zɔ̃ːp]$_2$, the opaque vowel length must be stored in the lexicon. Under weak LO, this cannot occur, so SLO must be used. When this happens, /zɔ̃b/$_5$ no longer exists, because no such output could be produced. Older /zɔ̃b/$_5$ is stored in the lexicon as /zɔ̃ːb/$_6$, which acts as the intermediate form needed for opacity to occur. Since /zɔ̃ːb/$_6$ transparently maps to [zɔ̃ːp]$_2$, older /zɔ̃b/$_5$ will also be pronounced (opaquely) as [zɔ̃ːp]$_2$, with both vowel length and word–final devoicing.

6 Step III: Middle Polish colorization

1.1 Step III.1: Early Middle Polish

By RotB, the input to early Middle Polish is the universal input ***Ω***. I use the same subset of ***Ω*** from §4.1, consisting of nine oral vowels (three heights and three colors) and three nasal vowels (one height and three colors). The target language has five oral vowels (the standard five vowel system [i ɛ a ɔ u]) and only one nasal vowel [ɔ̃].

(34) **Step III.1: early Middle Polish (before colorization)**

i ɨ u ɛ ɜ ɔ ɛ̃ ɜ̃ ɔ̃ æ a ɒ	$\mathcal{D}_4$ color	$\mathcal{D}_5$ color	$\mathcal{F}$ color	$\mathcal{D}_6$ color	
a. i ɨ u ɛ ɜ ɔ ɛ̃ ɜ̃ ɔ̃ æ a ɒ	×^{9}!	×^{10}		×^{11}	fully faithful
b. i ɨ u ɛ ɜ ɔ ɛ̃ ɜ̃ ɔ̃ a	×^{6}!	×^{7}	×^{2}	×^{8}	low decolorization
c. i ɨ u ɛ ɔ ɛ̃ ɔ̃ a	×^{2}!	×^{3}	×^{4}	×^{4}	low decolorization plus loss of mid central
d. i u ɛ ɔ ɛ̃ ɔ̃ a		×!	×^{5}	×^{2}	low decolorization plus loss of mid and high central
✓ e. i u ɛ ɔ ɜ̃ a			×^{6}	×	low and nasal decolorization plus loss of mid and high central
f. i u ɜ ɜ̃ a			×^{7}!		low, mid, and nasal decolorization plus loss of high central

Candidates (34a–d) have too many poor color contrasts, in particular, a contrast in the nasal vowels, banned by $\mathcal{D}_5$–color. Candidates (34e) and (34f) fare better, satisfying high ranked $\mathcal{D}_4$– and $\mathcal{D}_5$–color, but at the expense of some faithfulness. Since (34e) is the more faithful, it is selected at the output for early Middle Polish.

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. The input set I consider is the previous subset of Ω plus the long counterparts of each vowel.

(35) **Step III.1 (continued): early Middle Polish (before colorization)**

i ɨ u ɛ ɜ ɔ ɛ̃ ɜ̃ ɔ̃ æ a ɒ iː ɨː uː ɛː ɜː ɔː ɛ̃ː ɜ̃ː ɔ̃ː æː aː ɒː	$\mathcal{F}$ dur	$\mathcal{D}_1$ dur	$\mathcal{D}_2$ dur	
✓ a. i u ɛ ɔ ɜ̃ a iː uː ɛː ɔː ɜ̃ː aː		×	×^{11}	fully faithful length
b. i u ɛ ɔ ɜ̃ a iː uː ɛː ɔː aː	×^{3}!	×	×^{10}	nasal shortening
c. i u ɛ ɔ ɜ̃ a	×^{12}!			shortening

Candidates (35b) and (35c) attempt to alleviate potentially bad contrasts in vowel length by merging some or all of the short/long vowel pairs. But with $\mathcal{F}$–duration undominated, only the fully faithful candidate (35a) can win. Thus, the hierarchies in (34) and (35) derive the correct output for early Middle Polish, with five oral vowel qualities, one nasal vowel quality, and a length contrast.

1.2 Step III.2: Late Middle Polish

During Middle Polish, the colorless nasal vowels split, through colorization, 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. This split is attested by spellings of the short nasal vowel in the 16th–century with the new symbol ⟨ę⟩, or with ⟨e⟩, ⟨en⟩, and ⟨em⟩, while the long nasal vowel was often spelled ⟨un⟩ and ⟨um⟩ (Stieber 1968:23–25, de Bray 1980:230–231). I argue that the back nasal vowel was in fact a nasal diphthong [ɔ̃w̃], contrary to the standard analysis which posits the 'pure' nasal vowel [ɔ̃]. With this sound change, the late Middle Polish word 'tooth' was pronounced [zɔ̃w̃p].

(36)

	West Slavic	>1150	zɛ̃b	
Step Ia	Lechitic	1150–1350	zɛ̃ːb	vowel lengthening
Step Ib	Lechitic	ca. 1300	zɜ̃ːb	nasal decolorization
Step II	Old Polish	1350–1500	zɜ̃ːp	word–final devoicing
Step III	Middle Polish	1500–1750	zɔ̃w̃p	nasal colorization

This departure from the traditional analysis is based a few reasonable assumptions.

- Duration contrasts are not as good for nasal vowels as they are for oral vowels, since nasal vowels are longer than oral vowels, and the difference between two long time periods is harder to perceive than two short time periods due to the logarithmic nature of perception.

- The duration contrast between a short vowel and a diphthong is better than the duration contrast between a short vowel and a long vowel, since diphthongization adds an extra acoustic signal (dynamic formants) as a cue to vowel length.

Thus, in order to enhance the relatively poor duration distinction between [ɜ̃] and [ɜ̃ː], diphthongization of the long vowel occurred. Recall that by SLO, the input to late Middle Polish is the output of early Middle Polish. In order to achieve diphthongization, a constraint such as $\mathcal{F}$–consonantality must be reranked lower than $\mathcal{D}_1$–duration, which punishes vowel length contrasts in nasal vowels (but not in oral vowels). Because vowel color is also changing, $\mathcal{F}$–color must be demoted, too. (Only candidates containing mid vowels are shown in the following tableaux, since the other vowels are not affected).

(37) **Step III.2: late Middle Polish colorization**

		prom	*dem*	*dem*			
ɛ ɔ ɜ̃ ɛː ɔː ɜ̃ː	$\mathcal{F}$ dur	$\mathcal{D}_1$ dur	$\mathcal{F}$ cons	$\mathcal{F}$ color	$\mathcal{D}_2$ dur		
a. ɛ ɔ ɜ̃ ɛː ɔː ɜ̃ː		×!			×^{3}	fully faithful
✓ b. ɛ ɔ ɛ̃ ɛː ɔː ɔ̃w̃			×	×^{2}	×^{2}	nasal diphthongization and colorization
c. ɛ ɔ ɜ̃ ɛː ɔː	×!				×^{2}	nasal shortening
d. ɛ ɔ ɜ̃	×^{3}!					shortening

The fully faithful candidate (37a) violates the newly promoted $\mathcal{D}_1$–duration because [ɜ̃] and [ɜ̃ː] are too perceptually close together. Candidates (37c) and (37d) satisfy this constraint, but by changing the duration of the long nasal vowel, merging it with the short nasal vowel, and thus violating highly ranked $\mathcal{F}$–duration. This leaves (37b) as the selected output for late Middle Polish.

A candidate not yet considered is one in which the long nasal vowel diphthongizes, but does not colorize. I argue that the best nasal off-glides are back [w̃] and [ɰ̃], rather than front [j̃] or central [ɰ̵̃].[5]

Ohala and Ohala (1993) cite evidence that shows that nasal vowels have a tendency to be followed by a velar closure, supporting their contention that back nasal consonants are less consonantal than front nasal consonants due to diminished perceptual cues to consonantality of back nasals; that is, they are more vowel-like. Articulatory concerns seem also 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 better than front nasal glides. Thus, the best nasal off-glide would seem to be a velar one, such as [w̃] or [ɰ̃]. This is represented in FDM-OT by a universal ranking of $\mathcal{M}$-j̃,ɰ̵̃ over $\mathcal{M}$-w̃,ɰ̃. In order to ensure that diphthongization happens, $\mathcal{D}_1$-duration must be ranked over $\mathcal{M}$-w̃,ɰ̃.[6]

(38) **Step III.2 (continued): late Middle Polish colorization**

						prom	*dem*	*dem*	*dem*	
	ɛ ɛː	ɔ ɔː	ɜ̃ ɜ̃ː	$\mathcal{M}$ j̃,ɰ̵̃	$\mathcal{F}$ dur	$\mathcal{D}_1$ dur	$\mathcal{M}$ w̃,ɰ̃	$\mathcal{F}$ cons	$\mathcal{F}$ color	
a.	ɛ ɛː	ɔ ɔː	ɜ̃ ɜ̃ː			✗!				fully faithful
✓ b.	ɛ ɛː	ɔ ɔː	ɛ̃ ɔ̃w̃				✗	✗	✗2	diphthongization plus backing
c.	ɛ ɛː	ɔ ɔː	ɔ̃ ɛ̃j̃	✗!				✗	✗2	diphthongization plus fronting
d.	ɛ ɛː	ɔ ɔː	ɜ̃ ɜ̃ɰ̵̃	✗!						diphthongization

The fully faithful candidate (38a) still loses because of the nasal vowel length contrast. The remaining candidates all solve this problem through diphthongization of the long vowel, but with different colorizations: (38b) backs (and rounds) the newly created diphthong, (38c) fronts it, and (38d) makes no changes to vowel color. Since the front and central nasal off-glides of (38c) and (38d) are worse than a back glide, candidate (38b) is selected as the output.

Two questions remain: Why should the short nasal vowel front? Why should the back diphthong also be round? The answers lie in a constraint ranking already needed, which ensures that color contrasts are distinct. In particular, the oral mid vowels are required to be [ɛ] and [ɔ] in order to satisfy $\mathcal{D}_2$-color which bans a front-central or central-back/round contrast in the mid vowels. This also forces the short nasal vowel to become front [ɛ̃] and the back nasal diphthong to be round [ɔ̃w̃], violating lower ranked $\mathcal{F}$-color, in order to further enhance the color contrast between them. Recall from (34) that $\mathcal{D}_5$-color must be ranked over $\mathcal{F}$-color. Since $\mathcal{D}_2$-color always outranks $\mathcal{D}_5$-color, $\mathcal{D}_2$-color also outranks $\mathcal{F}$-color, which means no reranking is necessary.

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[5]The IPA does not have a symbol for a central glide, so I adopt the symbol [ɰ̵] on analogy with the use of the crossbar in the central vowels [ɨ] and [ʉ]. I use [ɰ] instead of [j] as the base symbol for an unrounded glide because the resulting character [ɰ̵] is more distinct from unrelated symbols than [ɉ] is (the latter is too similar to the IPA symbol for the palatal stop [ɟ], whereas [ɰ̵] is not likely to be confused with any unrelated symbol).

[6]I also assume an undominated constraint banning color contours in diphthongs.

(39) **Step III.2 (continued): late Middle Polish colorization**

	$\mathcal{M}$ j̃,ʉ̃ɥ	$\mathcal{D}_2$ color	$\mathcal{F}$ color	
ɛ ɔ ɜ̃ ɛː ɔː ɜ̃ː				
a. ɛ ɔ ɜ̃ ɛː ɔː ɜ̃ʉ̃ɥ	×!			faithful color
b. ɛ ɔ ɜ̃ ɛː ɔː ɔ̃w̃		×!	×	backing/rounding
✓ c. ɛ ɔ ɛ̃ ɛː ɔː ɔ̃w̃			×2	backing/rounding plus fronting

The faithful candidate (39a) violates highly ranked $\mathcal{M}$–j̃,ʉ̃ɥ, which punishes the central nasal off-glide. Both candidates (39b) and (39c) avoid this marked segment by backing (and rounding) the off-glide. Candidate (39b) involves no other change, leaving poor color contrast in the nasal vowels, central versus back/round. Candidate (39c), though less faithful, satisfies high ranking $\mathcal{D}_2$-color by colorizing both nasal vowels.

7 Comparison with standard OT

The Lechitic merger and Middle Polish split of the nasal vowels provides an interesting problem for standard OT. The problem hinges on OT's use of individual words as inputs and candidates, which do not require any sort of $\mathcal{D}$-constraints to regulate the contrasts between unrelated words. Instead, 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 FAITH–[color] (or alternatively, FAITH–[back] and FAITH–[round]) must be outranked by some constraint which prefers central [ɜ̃] to [ɔ̃] and [ɛ̃]. Clearly, this higher constraint cannot be a faithfulness constraint, since [ɜ̃], [ɔ̃], and [ɛ̃] are identical with respect to every property except color, and FAITH–[color] is already accounted for. Thus, we must rely on markedness constraints for these vowels (OT only has faithfulness and markedness), ranked so that the vowels with color are dispreferred to the colorless vowel.

(40) **OT analysis of late Lechitic decolorization**

/ɛ̃ ɔ̃/	×ɛ̃	×ɔ̃	FAITH [color]	×ɜ̃
a. ɛ̃ ɔ̃	×!	×!		
b. ɛ̃ ɜ̃	×!		×	×
c. ɜ̃ ɔ̃		×!	×	×
✓ d. ɜ̃ ɜ̃			×2	×2

The ranking ×ɛ̃,×ɔ̃ ≫ ×ɜ̃ suggests that the nasal vowels [ɛ̃] and [ɔ̃] are more marked than [ɜ̃], and should therefore appear in fewer inventories (a standard assumption about markedness in OT). This is exactly opposite to what we find cross-linguistically, yet this ranking is required in order to get decolorization of the nasal vowels. If this OT analysis of late Lechitic is correct, then the typological foundation for markedness constraints must be abandoned (not a terrible conclusion, since this is the stance I take in FDM–OT). But the problems for OT do not end there.

Consider the analysis needed for late Middle Polish, when the short nasal vowel fronted to *[ɛ̃] (§6.2). The constraints must be ordered as shown below in order to get the correct output.

(41) *OT analysis of late Middle Polish colorization of the short nasal vowel*

/ɜ̃/	×ɔ̃	×ɜ̃	×ɛ̃	FAITH [color]
a. ɜ̃		×!		
✓ b. ɛ̃			×	×
c. ɔ̃	×!			×

The ranking ×ɜ̃ ≫ ×ɛ̃ is exactly the opposite ranking required for late Lechitic!

The implication of this reranking is that [ɛ̃] is *less* marked than [ɜ̃]. Clearly, these OT markedness constraints cannot represent anything universal, since the relative markedness of [ɛ̃] and [ɜ̃] depends on which stage of Polish we are looking at. This means that the fact that the short nasal vowel fronted is unpredictable and arbitrary; it could just as easily have stayed central [ɜ̃], or even shifted to some other vowel completely.

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 underlying representations that are phonologically identical to their outputs. By having strong lexicon optimization interspersed with ordered diachronic sound changes, the analysis maintains the serialism and intermediate representations required to account for opacity without sacrificing monostratal direct mapping in the synchronic grammar.

A consequence of strong lexicon optimization is that **certain types of opacity cannot be synchronically productive**, though they may still pervade the lexicon. This prediction is born out for Polish, in which the nasal vowel alternation is not productive, yet is plentiful in the extant vocabulary.

In addition, the set-based nature of the inputs and candidates in FDM–OT provide a principled 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 such as standard OT which treat inputs and candidates as individual words that cannot reference the phonetic shape of morphologically unrelated words.

References

Aronoff, Mark. 1976. *Word formation in generative grammar*. MIT Press.

Beddor, Patrice. 1993. Perception of nasal vowels. In Huffman and Krakow 1993. 171–196.

Beckman, Jill, Laura Walsh Dickey, and Suzanne Urbanczyk, eds. 1995. *UMOP 18: Papers in Optimality Theory*. GLSA.

Bielec, Dana. 1998. *Polish: An essential grammar*. Routledge.

Boersma, Paul. 1998. *Functional phonology: Formalizing the interactions between articulatory and perceptual drives*. Holland Academic Graphics.

Burzio, Luigi. 1996. Surface constraints versus underlying representations. In Durand and Laks. 97–122.

Bybee, Joan L. 1988. Morphology as lexical organization. In M. Hammond and M. Noonan, eds. *Theoretical morphology*. Academic Press. 119–141.

Bybee, Joan. 1995. Regular morphology and the lexicon. *Language and Cognitive Processes* 10:425–455.

Carlton, Terence R. 1991. *Introduction to the phonological history of the Slavic languages*. Slavica.

Chomsky, Noam. 1995. *The minimalist program*. MIT Press.

de Bray, R. G. A. 1969. *Guide to the Slavonic languages*. J. M. Dent and Sons.

de Bray, R. G. A. 1980. *Guide to the West Slavonic languages*. Guide to the Slavonic languages, Part 2. 3rd ed. J. M. Dent and Sons.

Durand, J., and B. Laks, eds. *Current trends in phonology: Models and methods*. ESRI.

Flemming, Edward. 1995. *Auditory representations in phonology*. PhD dissertation, UCLA.

Goldsmith, John. 1996. Tone in Mituku: How a floating down nailed down an intermediate level. In Durand and Laks. 267–280.

Gnanadesikan, Amalia. 1997. *Phonology with ternary scales*. PhD dissertation, UMass Amherst.

Gussman, Edmund. 1980. *Studies in abstract phonology*. MIT Press.

Hudson, G. 1975. *Suppletion in the representations of alternations*. PhD dissertation, UCLA.

Huffman, Marie K., and Rena A. Krakow, eds. 1993. *Nasals, nasalization, and the velum*. Phonetics and phonology 5. Academic Press.

Idsardi, William. 1998. Tiberian Hebrew spirantization and phonological derivations. *LI* 29:37–73

Jaślan, Janina, and Jan Stanisławski. 1993. *Wiedza powszechna compact Polish and English dictionary*. Jastrzębska–okoń, Izabella, and Katarzyna Billip, eds. NTC Publishing Group.

Kager, René. 1996. On affix allomorphy and syllable counting. In U. Kleinhenz, ed. *Interfaces in phonology*. Studia Grammatica 41. Akademie Verlag. 155–171.

Kager, René. 1999. Ternary alternations and lexical allomorphy. Paper presented at NELS 30, Rutgers.

Kiparsky, Paul. 1998. Paradigm effects and opacity. Ms., Stanford.

Łubowicz, Anna. 2001. Opacity, recoverability, and constraints on contrast. Paper presented at GLiP–3, Univ. of Warsaw.

McCarthy, John. 1997. Sympathy and phonological opacity. Paper presented at the Hopkins OT Workshop/Univ. of Maryland Mayfest, Johns Hopkins.

McCarthy, John. 1999. Sympathy and phonological opacity. *Phonology*16:331–399.

McCarthy, John, and Alan Prince. 1993. Prosodic morphology I: Constraint interaction and satisfaction. Ms., UMass Amherst and Rutgers.

McCarthy, John, and Alan Prince. 1995. Faithfulness and reduplicative identity. In Beckman, et al. 249–384.

Mester, Armin. 1994. The quantitative trochee in Latin. *NLLT* 12:1–61.

Ní Chiosáin, Máire, and Jaye Padgett. 2001. Markedness, segment realization, and locality in spreading. In Linda Lombardi, ed. *Segmental phonology in Optimality Theory: Constraints and representations*. Cambridge University Press. 118–156.

Ohala, John J., and Manjari Ohala. 1993. The phonetics of nasal phonology: Theorems and data. In Huffman and Krakow. 225–249.

Padgett, Jaye. 1995. Feature classes. In Beckman, et al. 385–420.

Padgett, Jaye. 1997. Perceptual distance of contrast: Vowel height and nasality. In Rachel Walker, Daniel Karvonen, and Motoko Katayama, eds. 1997. *Phonology at Santa Cruz* 5. 63–78.

Padgett, Jaye. To appear. Contrast and post–velar fronting in Russian. *NLLT*.

Prince, Alan, and Paul Smolensky. 1993. Optimality Theory: Constraint interaction in generative grammar. Ms., Rutgers and Univ. of Colorado, Boulder.

Roca, Iggy, ed. 1997. *Derivations and constraints in phonology*. Clarendon Press.

Rubach, Jerzy. 2001. Polish iotation: Allomorphy in Optimality Theory. Paper presented at GLiP–3, Univ. of Warsaw.

Sanders, Nathan. 2001. Preserving synchronic parallelism: Diachrony and opacity in Polish. Paper presented at GLiP–3, Univ. of Warsaw, and TREND, Stanford.

Sanders, Nathan. To appear. Preserving synchronic parallelism: Diachrony and opacity in Polish. In proceedings of CLS 37.

Stanisławski, Jan. 1978. *Wielki słownik polsko–angielski [The great Polish–English dictionary]*. 2 vols. Warsaw: Wiedza Powszechna.

Steriade, Donca. 1995. Positional neutralization. Ms., UCLA.

Stieber, Zdzisław. 1968. *The phonological development of Polish*. Michigan Slavic Materials 8. E. Schwartz, trans. Univ. of Michigan.

Stieber, Zdzisław. 1973. A historical phonology of the Polish language. *Historical phonology of the Slavic languages 5*. Carl Winter Universitätverlag.

Vennemann, Theo. 1974. Words and syllables in Natural Generative Grammar. In Anthony Bruck, Robert A. Fox, and Michael W. La Galy, eds. *Papers from the parasession on Natural Generative Phonology*. CLS. 346–374.

Westfal, S. 1956. The *ę* to *ą* alternation in Modern Polish noun declension. *Slavonic and East European Review* 34:460–484.

Wright, J. T. 1986. The behavior of nasalized vowels in the perceptual vowel space. In Ohala, John J., and Jeri J. Jaeger, eds. *Experimental phonology*. Academic Press. 45–67.