

HARMONY IN GESTURAL PHONOLOGY

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Harmony in Gestural Phonology

Abstract

In this dissertation, I develop the Gestural Harmony Model, a model of harmony situated within a phonological framework that assumes gestures as the units of subsegmental representation. Originally developed within Articulatory Phonology (Browman & Goldstein 1986, 1989, et seq.), gestures are dynamically defined units of phonological representation that are specified for a target articulatory state of the vocal tract. In the Gestural Harmony Model, harmony is triggered when a gesture extends its period of activation and overlaps other segments in a word. To model this ability of a gesture to extend its activation, I propose the addition of two new parameters to the representation of gestures: persistence and anticipation. With the addition of these parameters, gestures can be specified as either self-deactivating or persistent (non-self-deactivating), and as either self-activating or anticipatory (early-activating). A persistent gesture is one that does not self-deactivate when its goal articulatory state is achieved, thus overlapping following segments and triggering progressive (rightward) harmony. An anticipatory gesture is one that is activated early, thus overlapping preceding segments and triggering regressive (leftward) harmony.

In addition to these representational innovations, I develop a phonological grammar, situated within the framework of Optimality Theory (Prince & Smolensky 1993/2004), that operates over gestural representations. The presence of harmony in a language is attributed to whether the segments in a language's surface phonological inventory contain persistent and/or anticipatory gestures. As a result, in the Gestural Harmony Model patterns of harmony triggering result from the interaction of markedness and faithfulness constraints that shape the surface inventory and determine the distributions of the segments in that inventory. One of the major

advantages of the approach to harmony triggering in the Gestural Harmony Model is that harmony systems in which bearers of a harmonizing property idiosyncratically trigger or fail to trigger harmony can be attributed to preservation of a contrast between persistent and self-deactivating gestures in the case of progressive harmony, and anticipatory and self-activating gestures in the case of regressive harmony. This approach to harmony triggering avoids the pathological predictions made by some other analyses of phonological idiosyncrasy and exceptionality.

The Gestural Harmony Model's representation of harmony also proves advantageous in the analysis of transparency and blocking. In this model, transparency and blocking are the results of two distinct theoretical mechanisms, successfully accounting for the distinct crosslinguistic patterns in the attestation of transparent and blocking segments in some types of harmony. I analyze transparent segments as undergoers of harmony that include in their representations a gesture that is antagonistic to a harmonizing gesture. Antagonistic gestures are those that are specified for directly conflicting target articulatory states of the vocal tract, and as a result enter into competition with one another. Transparency arises when intergestural competition is resolved in favor of the gesture of the transparent segment due to its greater specified gestural strength. Blocking of harmony, on the other hand, results from a different theoretical mechanism: intergestural inhibition, by which one gesture deactivates another. The Gestural Harmony Model's splitting of transparency and blocking among two distinct theoretical mechanisms makes several advantageous typological predictions. Chief among these is that in some types of harmony, the set of attested transparent segments is a subset of the set of attested blocking segments. This is attributed to the idea that only certain types of segments possess the gestural makeup necessary to surface as transparent to harmony when overlapped by a harmonizing gesture.

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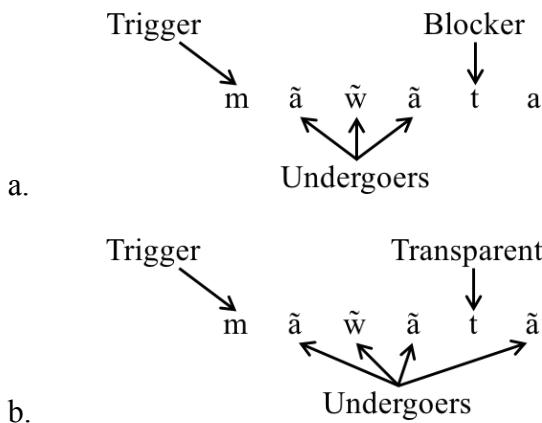
Chapter 1

Introduction

1.1 Overview: A Gestural Model of Harmony

Broadly defined, harmony is a process by which a phonological property of one segment is taken on by one or more additional segments in some domain. The segment that serves as the source of this phonological property is the trigger, while any segment that takes on that property is referred to as an undergoer. In some cases, segments in the domain of harmony do not participate in a harmony process; these are often referred to as neutral segments. These neutral segments may either be blockers, which stop a phonological property from spreading further throughout a word, or transparent segments, which allow a phonological property to spread further while not taking on that property themselves. The figure in (1) illustrates this with a schematic example of nasal harmony. In this figure, a nasal stop triggers harmony by spreading its nasality onto a sequence of following sonorants; the obstruent [t] serves as a blocker in (1a) and as transparent in (1b).

(1) Segmental roles in harmony



While assigning segments these roles within a harmony system is often straightforward from a purely descriptive standpoint, the task of determining what kind of phonological representations and grammar give rise to attested harmony systems is considerably more challenging. A successful model of harmony must be equipped to account for typological asymmetries in the patterning of triggers, undergoers, blockers, and transparent segments. In this dissertation, I claim that the adoption of a phonological framework in which the units of representation are *gestures* (Browman & Goldstein 1986, 1989, et seq.), rather than features (Jakobson, Fant, & Halle 1952/1963; Chomsky & Halle 1968; Goldsmith 1976; Clements & Hume 1995), addresses many of the issues that arise in the analysis of harmony systems.

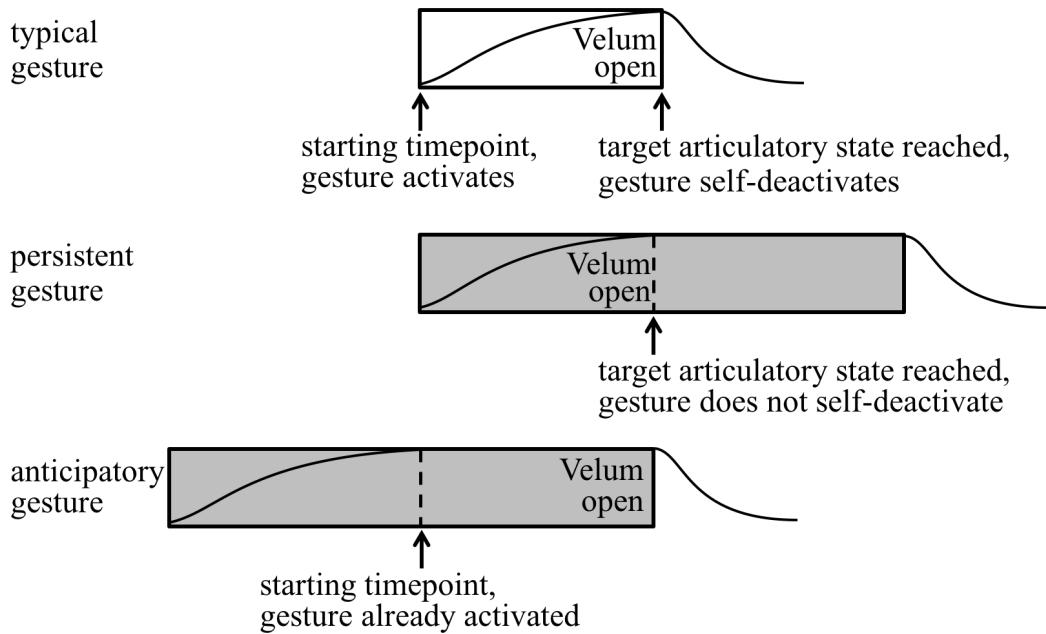
Often, a distinction is made between consonant harmony, in which consonants assimilate at a distance, and vowel or vowel-consonant harmony, in which segments undergo local assimilation (see Hansson (2001/2010) and Rose & Walker (2004, 2011) for discussion of this distinction). In this dissertation, I focus on vowel and vowel-consonant harmonies, which can be represented as the temporal extension of some phonological property from a triggering segment to one or more undergoer segments. I introduce the Gestural Harmony Model, and advance two core components of this model: gestural representational units and a phonological grammar that operates over these units. This grammar is situated within Optimality Theory (Prince & Smolensky 1993/2004; henceforth OT) and operates over gestural representations.

Gestures, originally developed within the framework of Articulatory Phonology (Browman & Goldstein 1986, 1989, et seq.), are goal-based units of phonological representation. Each gesture is specified for a target articulatory state of the vocal tract. Often, this target state is described in terms of (1) the degree of a constriction between an active and a passive articulator, and in some cases (2) the location of that constriction. For instance, the representation of an

alveolar stop includes a gesture with a target articulatory state involving full closure between the tongue tip and the alveolar ridge. Other target articulatory states are described in terms of the degree of displacement of a primary articulator from a neutral position. For instance, the representation of a nasal segment includes a gesture with a target articulatory state involving the lowering and consequent opening of the velum. The achievement of a gesture's target articulatory state unfolds throughout a gesture's period of activation. When sufficient time has passed for this target state to be achieved, the gesture self-deactivates and its control over the vocal tract comes to an end. Gestures are also specified for the articulators they may recruit to achieve their articulatory goals, as well as the strengths with which they can command vocal tract articulators. This is discussed in greater detail in section 1.2.1.

In the Gestural Harmony Model, harmony is triggered when a gesture extends the period during which it is active and overlaps the gestures of other segments in a word. In order to model this potential for a gesture to extend its activation, I propose the addition of two new parameters to the representation of gestures: *persistence* and *anticipation*. A persistent gesture is one that does not self-deactivate when its goal articulatory state is reached, thus triggering progressive (rightward) harmony. An anticipatory gesture is one that activates earlier than it should based on its position in a word, thus triggering regressive (leftward) harmony. These gestural types are illustrated in the figure in (2), which includes three gestures specified for velum opening. In this figure, time is represented along the horizontal dimension, and the horizontal length of each gesture, represented by a box, represents the span of time during which the gesture is active. The gradually climbing and falling line represents the attainment of each gesture's target articulatory state and subsequent return to a neutral, default articulatory state of the vocal tract.

(2) Typical, persistent, and anticipatory gestures



The adoption of gestural representations and the development of the Gestural Harmony Model's persistent and anticipatory gestures provide a unique perspective through which to answer many of the questions that arise in the analysis of harmony systems. These questions include those in (3):

- (3)
- What kinds of rules or constraints drive harmony, and how do they relate to attested patterns of harmony triggering?
 - How can the analysis of harmony account for crosslinguistic asymmetries in the attested patterns of transparency and blocking?
 - How can transparency to harmony be represented while maintaining the local nature of a spreading process?

Regarding the question in (3a), a successful model of harmony must account for systems in which triggers of harmony are restricted to certain positions within a word, and in which only certain types of segments may trigger harmony (see Archangeli & Pulleyblank (2007) for an overview). For example, it is common within the Tungusic languages for rounding harmony to be triggered only by nonhigh round vowels in the initial syllable of a word (Kaun 1995, 2004; Li

1996; Zhang 1996; Walker 2001). In the Gestural Harmony Model, harmony is triggered by a persistent or an anticipatory gesture that surfaces in an output phonological form. Rather than explicitly driving harmony, the grammar serves only to shape a language's surface inventory such that segments that include harmony-triggering gestures may surface in a phonological form, and to set any distributional restrictions on these segments. Because of this, the Gestural Harmony Model is able to straightforwardly capture attested, often seemingly complex, patterns of harmony triggering via the interaction of a small set of markedness and faithfulness constraints.

It is also necessary to account for cases of apparent exceptionality in the triggering of harmony. There are numerous examples of harmony systems in which some words idiosyncratically exhibit harmony while others do not. A well-known case of such a system is Hungarian backness harmony (Vago 1976; Ringen & Vago 1998; Siptár & Törkenczy 2000; Gafos & Beňuš 2006; Hayes & Londe 2006), though it is also attested in the nasal harmony systems of several Malayo-Polynesian languages, as well as various tongue root harmony systems. As discussed by C. Smith (2017a, 2017b), in the Gestural Harmony Model the ability of a gesture to trigger harmony is an encoded parameter of that gesture (persistence in the case of progressive harmony, and anticipation in the case of regressive harmony). In some languages, this parameter serves a contrastive function, and the result of such contrast is the idiosyncratic triggering of harmony.

The Gestural Harmony Model is unique in relying on parameters (persistence and/or anticipation) of a phonological unit to drive harmony, rather than relying on a rule or constraint in the phonological grammar that explicitly requires the spreading of a harmonizing element. Feature-based analyses of harmony (see Clements 1976a; Clements & Sezer 1982; Cole & Trigo

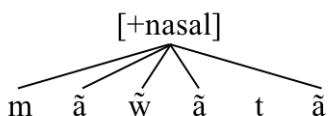
1988; Piggott 1988, 1992; Archangeli & Pulleyblank 1989, 1994, 2007; Cole & Kissoberth 1994, 1995; Kaun 1995, 2004; van der Hulst & van de Weijer 1995; Walker 1998/2000, 2011; Baković 2000; and Kimper 2011, among many others), on the other hand, do not have these parameters at their disposal, and instead rely on explicitly driving harmony by rule or constraint. While feature-based analyses of harmony systems in which conditions are placed on the quality of a trigger of harmony (see, for example, work by Kaun (1995), Kimper (2011), and Walker (2011, 2014)) are largely successful, such conditions do not address cases of idiosyncratic triggering. Rather than rely on a contrastive property that distinguishes triggers from non-triggers, these featural analyses typically rely on mechanisms designed to account for cases of phonological exceptionality, such as constraint indexation (Pater 2000, 2009a; Flack 2008; Becker 2009). As discussed by Finley (2010), such analyses often result in the generation of pathological harmony patterns. The Gestural Harmony Model, on the other hand, does not rely on mechanisms for phonological exceptionality, or on harmony-driving constraints, in the analysis of idiosyncratic harmony triggering patterns. I will therefore argue that this model is able to avoid such pathological predictions.

Turning to the question in (3b), another important contribution of this work concerns the ability of the Gestural Harmony Model to capture the typological patterns and asymmetries among attested neutral segments. C. Smith (2016a) states that among rounding harmony and nasal harmony systems, the set of attested transparent segments is a proper subset of attested blocking segments. In other words, the ability to surface as transparent to a harmony process is limited to significantly smaller classes of segments, while the ability of certain classes of segments to block harmony is less constrained. The Gestural Harmony Model successfully accounts for this typological asymmetry by regarding transparency and blocking as the results of

distinct mechanisms at work within the model. Building upon the insights of Clements (1976b), Piggott (1988), Cole & Kissoberth (1994, 1995), Walker (1998/2000, 2003), Jurgec (2011), and others, the Gestural Harmony Model recasts transparent segments as undergoers of harmony, rather than as truly neutral segments. Because of their unique gestural makeup, transparent segments may be produced without a harmonizing property despite being overlapped by a harmonizing gesture. This unique gestural makeup of a transparent segment is based on its including a gesture whose target articulatory state is in direct conflict with the target state of the harmonizing gesture. Crucially, only certain segments possess the antagonistic gestural makeup that allows them to surface as transparent to harmony, successfully limiting the classes of segments that are predicted to be transparent to harmony to precisely those that are attested within different harmony systems.

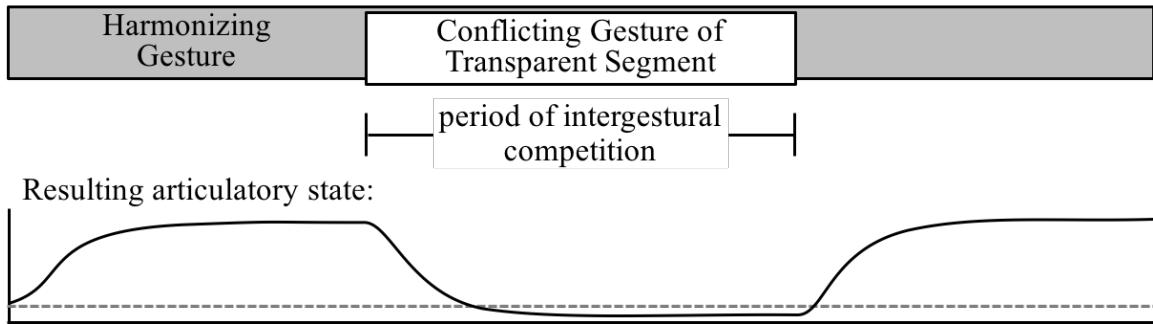
In recasting transparent segments as undergoers of harmony, the Gestural Harmony Model addresses another of the central debates in the study of vowel and vowel-consonant harmonies: how to represent transparency to harmony (see question (3c) above). There is a lack of consensus regarding how phonological forms should be represented when the spreading of a feature seemingly skips a segment. Configurations in which multiple associations of a single feature skip over a potential target segment are widely considered to be universally banned (see Sagey (1988), Archangeli & Pulleyblank (1994), Ní Chiosáin & Padgett (1997, 2001), and Walker (1998/2000) for discussion), and yet it appears that this is just what has happened in the case of transparency in harmony. The figure in (4) illustrates.

(4) Gapped representation of transparency to the spread of feature [+nasal]



By appealing to the idea that gestures may overlap one another in time, and may resist one another's effects when their target articulatory states are in conflict, it is possible to maintain locality of spreading in the form of uninterrupted activation of a harmonizing gesture while still permitting a segment to surface as transparent. Such a configuration is schematized in (5), in which a harmonizing gesture extends to overlap a gesture with a conflicting target articulatory state.

(5) Schematic representation of transparency in the Gestural Harmony Model



In (5), the gradually climbing and falling line represents the state of the vocal tract along some relevant articulatory dimension (e.g., velum aperture). The dashed line represents the neutral, default articulatory state. We see that while the harmonizing gesture is active throughout the period of time displayed here, it is temporarily pulled away from its target articulatory state by the conflicting gesture of the transparent segment during the period in which they are concurrently active.

While transparency arises directly from the gestural representation of transparent segments, the Gestural Harmony Model relies on phonetically grounded gestural co-occurrence constraints to motivate the blocking of harmony. Blocking is implemented in the model via a newly proposed intergestural relation, *inhibition*, by which one gesture may deactivate another in order to avoid their concurrent activation. Many feature-based accounts of segments' failure to

undergo harmony also make use of feature co-occurrence constraints (e.g., Smolensky 1993; Kirchner 1993; Cole & Kisseberth 1994, 1995; Kaun 1995; Walker 1998/2000; Bakovic & Wilson 2000; Wilson 2003). Often, these constraints are utilized in the analysis of both transparency and blocking. However, I will show that such an approach is unable to account for the typological asymmetries in attested blocking and transparent segments identified by C. Smith (2016a). The Gestural Harmony Model, on the other hand, predicts this asymmetry by providing distinct analyses of transparency and blocking.

In addition, by dividing the generation of transparency and blocking among two distinct theoretical mechanisms, the Gestural Harmony Model allows for these mechanisms to operate independently, and in some cases concurrently. As a result, the model successfully accounts for harmony systems that exhibit both transparency and blocking of harmony, such as Halk Mongolian rounding harmony (Svantesson 1985; Svantesson, Tsendina, Karlsson, & Franzén 2005), discussed in section 4.5.2; Coatzospan Mixtec nasal harmony (Gerfen 1999, 2001); and Menominee tongue root harmony (Cole & Trigo 1988; Archangeli & Pulleyblank 1994; Archangeli & Suzuki 1995; Walker 2009, 2018).¹ Feature-based analyses of harmony have met with mixed success in accounting for such patterns. Some analyses can account for harmony systems that exhibit both transparency and blocking. These include analyses utilizing Agreement by Correspondence (Hansson 2001/2010; Rose & Walker 2004), such as those proposed by Walker (2009, 2018) and Rhodes (2012), as well as those analyses that rely on a continuum or scale of segments' propensity to be transparent or to block harmony, as proposed by Kaun (1995) and Kimper (2011). However, I will show that other analyses, such as those in which the relative ranking of two constraints determines whether a harmony system exhibits transparency or

¹ Cole & Trigo analyze this as a case of height harmony. However, later analyses recast this as a harmony system based on tongue root position.

blocking (e.g., Optimal Domains Theory (Cole & Kissoberth 1994, 1995)), encounter difficulty in generating such patterns.

In introducing the Gestural Harmony Model, this dissertation has two primary goals. The first is to provide a novel account of vowel and vowel-consonant harmonies, the full understanding of which has proven elusive despite decades of study. The Gestural Harmony Model is designed to solve many of the persistent puzzles that arise in the study of harmony by drastically reconsidering how to represent harmony, and how to represent phonological forms in general. The second goal of this dissertation is to use the study of harmony to guide and motivate advancements within the framework of gestural phonology. The Gestural Harmony Model redefines several important aspects of gestural representations by proposing new gestural parameters and expanding the phonological role that individual gestural parameters can play. Chief among these is a proposed expansion of the role that gestural strength can play in various phonological processes, including harmony. In addition, in this dissertation I develop a phonological grammar, based in Optimality Theory, that is designed to operate over gestural representations. The development of the Gestural Harmony Model, then, represents an important step forward in the study of both harmony and of gestural phonology.

Before introducing the representation of harmony or the grammatical mechanisms at work in the Gestural Harmony Model, it is necessary to provide theoretical background on gestures and gestural phonology. In the following section, I provide an in-depth look at gestures as the units of representation, as well as the phonological grammar that is assumed to operate over gestural representations.

1.2 Theoretical Background

1.2.1 Gestures in Articulatory Phonology

The analysis of harmony outlined in this dissertation is formulated using gestures as the units of phonological representational; these units were originally conceived within the framework of Articulatory Phonology (Browman & Goldstein 1986, 1989, et seq.). In Articulatory Phonology, gestures are units of representation that are specified for the achievement of some target articulatory state, usually involving the formation of a constriction of the vocal tract. For instance, the consonants /t/, /d/, and /n/ all include a gesture whose target state is closure between the tongue tip and the alveolar ridge. A gesture is specified for certain target *tract variables*, or attributes of a vocal tract constriction. These tract variables usually specify constriction location (labial, alveolar, velar, pharyngeal, etc.) and constriction degree (wide/narrow constriction, full closure, etc.). Some gestures, such as those governing the velum or glottis, may be specified for a single tract variable value, such as open or closed.

In addition to being specified for the tract variables that characterize a target articulatory state, a gesture is specified for a number of additional parameters that determine how and when that target state is achieved, and in some cases whether it is achieved at all. First, a gesture is specified for the vocal tract articulators it may recruit to achieve its articulatory target during the period in which that gesture is active. For instance, the gesture that produces an alveolar consonant specifies that the tongue tip is involved as the primary articulator, the articulator that makes contact with the alveolar ridge. In addition, the tongue body and jaw are also recruited for the production of this tongue tip constriction.

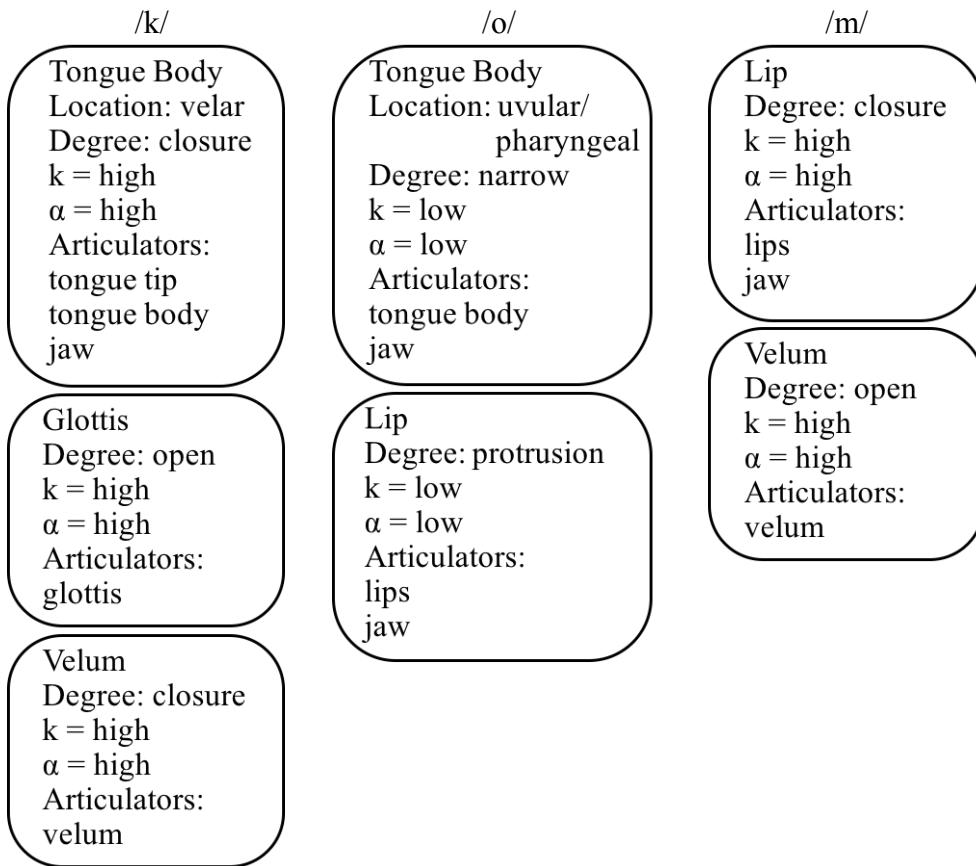
The attainment of a gesture's target articulatory state is modeled by a dynamically defined second-order equation of motion that simulates the gradual attainment of a target state from some initial condition of the vocal tract. The rate at which a dynamical system approaches

its goal is determined by its *stiffness* parameter, often denoted by k . The higher a gesture's stiffness, the more quickly it will reach its target articulatory state. When sufficient time has passed for a gesture's target state to be achieved, the gesture self-deactivates. The period from a gesture's activation to deactivation is referred to as its period of activation. In general, consonantal gestures tend to have high stiffness, and vocalic gestures tend to have low stiffness. As a result, consonantal gestures also have a shorter period of activation than vocalic gestures.

Finally, each gesture has a specified *blending strength*, denoted by α . When the target articulatory states of two gestures conflict with one another, the gestures' relative blending strengths determine the degree to which each gesture must compromise on the achievement of its target. In general, it is commonly assumed that consonantal gestures have a high specified strength, while vocalic gestures have a relatively lower strength. Gestural strength and gestural blending play a large role in the Gestural Harmony Model, particularly in the representation of transparency; this is discussed throughout chapters 4 and 5.

All of these gestural parameters are illustrated in (6), which depicts the gestural makeup of the English word 'comb' [kom].

(6) Gestural makeup of the segments in ‘comb’



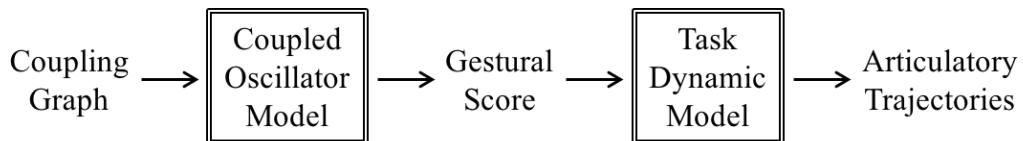
In (6), the initial consonant /k/ is made up of three gestures. A tongue body gesture specifying closure in the velar region of the vocal tract is responsible for the consonant’s primary place, while a glottal opening gesture is responsible for its voicelessness. Finally, as an obstruent this /k/ is assumed to include a velum closure gesture; the reasons for this are discussed in section 4.4.1. The /m/, on the other hand, includes a labial closure gesture and a velum opening gesture, which is responsible for the segment’s nasality. As a voiced consonant, it does not include a glottal opening gesture. The stiffness (k) and strength (α) parameters for these consonantal gestures are both assigned the abstract value ‘high’ here, denoting the relatively high values for these parameters that are typical of consonantal gestures.

As is the case for consonants, vowels in gestural phonology are also specified for constriction location and constriction degree (though see section 6.2.1 for a possible reanalysis of vowel place in gestural phonology). In (6), the /o/ of ‘comb’ includes a gesture for a tongue body constriction in the uvular-pharyngeal region, as well as a lip protrusion gesture that is responsible for rounding. The stiffness k and strength α parameters of these gestures are assigned the abstract value ‘low’ here, denoting the relatively low values for these parameters that are typical of vocalic gestures.

Throughout this dissertation I make the simplifying assumption that all front vowels are specified for palatal constriction, with constriction degree determining the height of these front vowels. High back vowels are specified for constriction in the uvular region, while nonhigh back vowels are specified for constriction in and around the pharyngeal region. The constriction location of the vowel /o/ falls somewhere within the uvular-pharyngeal or pharyngeal regions. I assume here that in languages with a single nonhigh back vowel, that vowel has a pharyngeal constriction location, while in languages that distinguish between mid /o/ and low /a~ɑ/ in terms of height, /o/ is uvular-pharyngeal while /a~ɑ/ is pharyngeal.

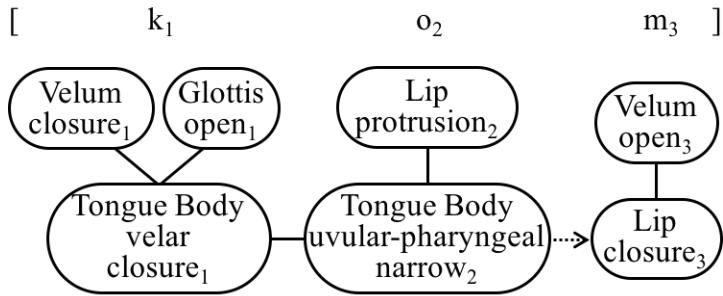
Articulatory Phonology assumes several computational steps in the process of speech production, from the abstract cognitive representation of a phonological form to a set of articulatory instructions. These steps are illustrated in (7), adapted from Browman & Goldstein (1992, p. 160).

(7) Multi-step speech production model assumed by Articulatory Phonology



According to the figure in (7), a lexical item first takes the form of a coupling graph, which specifies the coordination or *coupling* relations between gestures. Two gestures may be coupled so that they are produced either at the same time as or in sequence with one another. Synchronously coordinated gestures are said to be coupled in-phase, while sequentially coordinated gestures are said to be coupled anti-phase to one another. A *coupling graph* for ‘comb’ [kom] is provided in the figure in (8). The segmental transcription is included at the top of the figure, with the subscripts for each segment matching the subscripts of the gestures they comprise. In the coupling graph, two gestures that are connected by a solid line are coupled in-phase (synchronously), and a dashed arrow indicates anti-phase (sequential) coupling of two gestures. Following Browman & Goldstein (2000), a syllable onset is coupled in-phase to a following vowel, and a syllable nucleus is coupled anti-phase to a following coda consonant.

(8) Coupling graph for ‘comb’ [kom]²

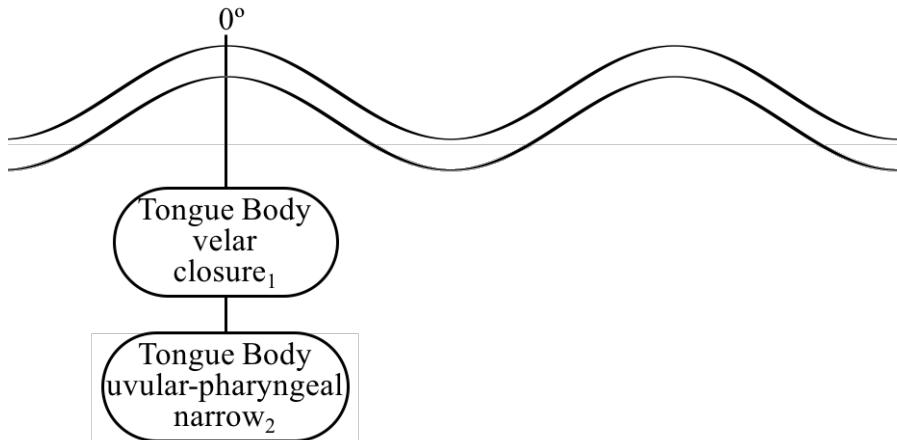


At this level of representation, gestures are temporally abstract; the time points of their individual activations and deactivations are not yet set. Once the coupling relations between gestures have been established, a coupling graph is input to the Coupled Oscillator Model (Saltzman & Byrd 2000; Nam & Saltzman 2003). At this point, the relative timing of gestures is stabilized based on the coupling relations that exist between them, and the activation and

² Often, coupling graphs omit information about gestures’ stiffnesses, strengths, and non-primary articulators for reasons of space and readability. This practice is adopted here.

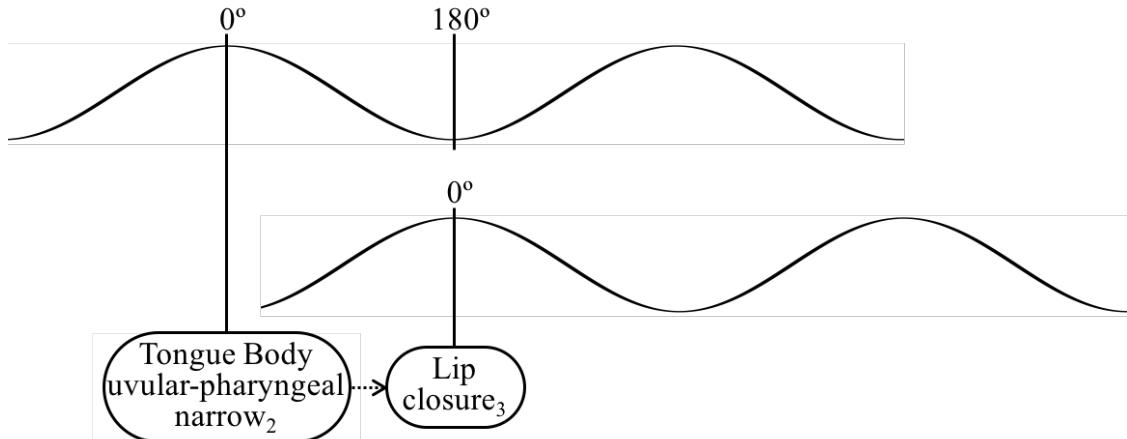
deactivation time points of each gesture are set. The relative timing of gestures and the resulting time points of their individual activations and deactivations are calculated by the Coupled Oscillator Model according to gestures' relative *phases*. Each gesture is associated with an abstract *planning oscillator*. The coupling relation between two gestures is defined with respect to the phases of their individual planning oscillators. When two gestures are coupled in-phase, the 0° phases of their individual oscillators are temporally aligned. This is illustrated in (9) for the velar closure gesture of [k₁] and the vocalic constriction gesture of [o₂] in 'comb.'

(9) Relative phasing of oscillators of two in-phase coupled gestures



When two gestures are coupled anti-phase, the 0° phase of one gesture and the 180° phase of another gesture are temporally aligned. The result is a pair of gestures that are produced in sequence. This is illustrated in (10) for the vocalic constriction gesture of [o₂] and the lip closure gesture of [m₃] in 'comb.'

(10) Relative phasing of oscillators of two anti-phase coupled gestures

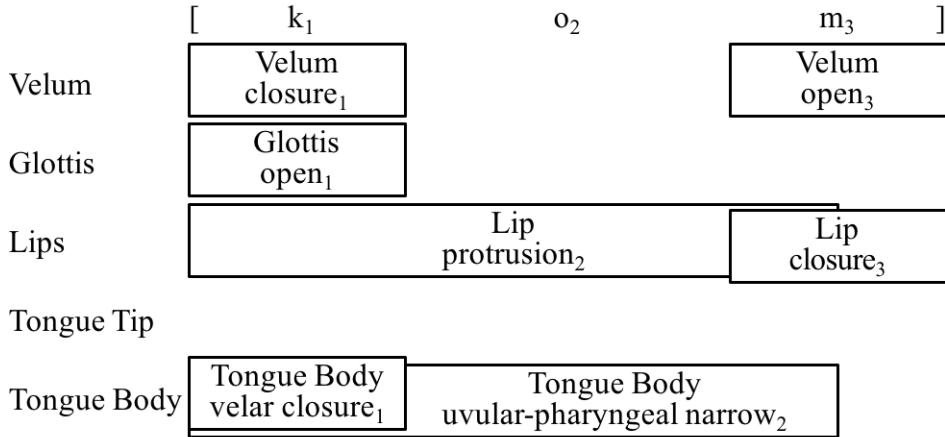


Once the Coupled Oscillator Model has temporally aligned all of the gestures in a coupling graph according to the coupling relations that exist between them, the time points of the activation and deactivation of each gesture are set. A commonly held assumption within Articulatory Phonology is that every gesture automatically activates at the 0° phase of its planning oscillator, and automatically deactivates at some specified phase that corresponds to the point in time at which the gesture's target articulatory state is achieved. However, this assumption is crucially not adopted in the Gestural Harmony Model proposed in this dissertation. Instead, the workings of the model are centered around the idea that the extension of gestural activation responsible for harmony is based on the ability of some gestures to activate before their respective 0° phases, and to remain active after they have achieved their respective target articulatory states. This proposal and the augmentation of the Coupled Oscillator Model necessary to implement it are discussed further in chapter 2.

The output of the Coupled Oscillator Model is a *gestural score*. In a gestural score, each gesture is represented by a box whose horizontal length represents the period of time over which a gesture is active. The horizontal positions of these boxes are the result of the coupling relations

that exist between these gestures in the coupling graph. The figure in (11) shows the gestural score for ‘comb’ [kom] corresponding to the coupling graph in (8).

(11) Gestural score for ‘comb’ [kom]



Due to the in-phase (synchronous) coupling between the gestures of [k] and the gestures of [o], all of these gestures activate at the same point in time. However, the higher stiffness of the gestures of [k] results in their attaining their respective target articulatory states earlier, and thus deactivating earlier. The gestures of [o], which have lower stiffness values, remain active longer. Due to the anti-phase (sequential) coupling between the tongue body gesture of [o] and the labial gesture of [m], the gestures of [m] activate near the end of the activation period of the vocalic gestures. While they overlap slightly, the segments [o] and [m] are produced in sequence.

Based on the specified parameters and activation periods of the gestures represented in a gestural score, the Task Dynamic Model of speech production (Saltzman & Munhall 1989) determines the trajectories of specific articulators necessary to achieve the gestures’ target articulatory states. Of particular interest to the Gestural Harmony Model is the resolution of competition between concurrently active gestures via gestural blending. There are different modes of blending depending upon the specifications of two competing gestures. When two concurrently active gestures call for different values of the same tract variable, as is the case for

the tongue body gestures of [k] and [o] in (8) and (11), for instance, blending of that tract variable is determined by each gesture's specified blending strength (α). The resulting tract variable value for the two competing gestures is a weighted average of the tract variable values for each individual gesture, with the gesture's α values providing the weights. This mechanism for gestural blending is discussed in greater detail in chapters 4 and 5.

1.2.2 *Optimality Theory and Gestural Representations*

Articulatory Phonology's model of speech production assumes several distinct levels of representation, represented in (7), each directly calculated from the output of a previous level. The Coupled Oscillator Model builds a gestural score based on the gestural parameters and coupling relations in a coupling graph, and the Task Dynamic Model in turn determines a set of articulatory trajectories from the gestural parameters and activation periods in a gestural score. What this model lacks, however, is a grammar that is responsible for building the original coupling graph. In this section, I outline such a grammar: Gestural OT (C. Smith 2016b, 2017a).

While Articulatory Phonology provides a rich set of representational primitives, in many of its implementations it is without a grammatical mechanism to determine which phonological structures are licit and illicit within a language. Ladefoged (1990) notes that Articulatory Phonology is not a theory of the relation between underlying and surface phonological forms. Note that in the speech production model in (7) articulatory trajectories are calculated from a gestural score, and that gestural score is calculated from a coupling graph; however, there is no mention of the source of that coupling graph. The coupling graph is usually considered to be lexically specified in Articulatory Phonology, and therefore the underlying form of a lexical item; there is no early level of representation at which coupling relations are not yet set. This is a necessary assumption, as in Articulatory Phonology coupling relations between gestures

represent both syllable structure and basic linear ordering. However, by doing away with this conflation of gestural ordering and prosodic structure, it is possible to construct a coupling graph through the interaction of constraints in an Optimality Theoretic grammar. On the other hand, the linear ordering of segments, conceptualized as sets of gestures, is specified in the input for a lexical item.

The proposals made in this dissertation and by C. Smith (2016b, 2017a) do not represent the first applications of the framework of OT to gestural representations. Several researchers, notably Gafos (2002), Davidson (2003), N. Hall (2003), and Bradley (2005), have proposed analyses in which gestures are coordinated with one another based on constraints on the alignment of gestural landmarks (onset, achievement of target articulatory state, etc.). In a sense, this gestural alignment replaces the workings of the Coupled Oscillator Model to coordinate gestures with one another, and a level of representation analogous to the coupling graph is not assumed. In contrast to that approach, I assume here a model of Gestural OT that leaves the Coupled Oscillator Model in place and allows it to determine the relative timing of gestures automatically from the specifications of a coupling graph. The Gestural OT grammar I assume here is responsible only for generating the coupling graph.

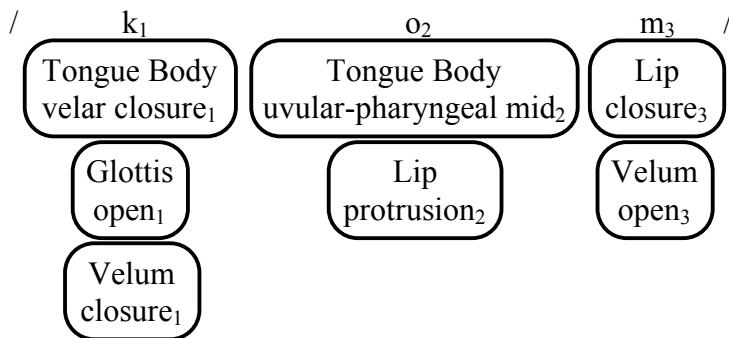
Another notable application of an OT grammar to gestural representations is developed by Tejada (2012), who examines tone spreading as the temporal extension of tone gestures. Tejada's framework employs constraints that operate over coupling relations between gestures, an approach that is adopted here and by C. Smith (2016b, 2017a). However, Tejada assumes that coupling relations are present in the input and that constraints exist to either manipulate or preserve these relations. In contrast, I do not assume input coupling relations here. Instead, I assume that OT constraints build and manipulate coupling graphs, but have access to information

about gestures' periods of activation, including any overlap present in the gestural score, as well as the resulting articulatory trajectories and their acoustic outcomes. The gestural score is calculated by the Coupled Oscillator Model based on the specified gestural parameters and phase relations present in the coupling graph. Similarly, the articulatory trajectories produced by the Task Dynamic Model are calculated based on the gestural parameters and activation periods present in the gestural score. The outputs of the Coupled Oscillator Model and the Task Dynamic Model, then, are merely implementations of the information that is present in the coupling graph. In addition, while it is not part of the formal model of speech production assumed by Articulatory Phonology (see the figure in (7)), the acoustic output of speech can also be calculated from the articulatory trajectories generated by the Task Dynamic Model. The content of the coupling graph, on the other hand, is assumed to be determined by phonological principles. Therefore, I claim that the phonological grammar should operate to produce these coupling graphs.

I assume that the input to the OT grammar that produces output coupling graphs is a string of linearly ordered segments, which are conceptualized here as sets of gestures. There is little consensus across work conducted within gestural phonology as to whether the segment should have any theoretical status. A commonly adopted assumption is Byrd's (1996) claim that the notion of the segment is epiphenomenal, stemming from the fact that certain sets of gestures are underlyingly specified for extremely stable coordination relations. Gafos (2002) and N. Hall (2003, 2006), on the other hand, develop theories that assume that phonological representations include both segmental and gestural units. Following a similar proposal made by Walker (2017a), I will assume here that a segment is defined as a set of gestures.

In the Gestural OT framework I adopt here, an input is represented by a string of segments, each of which comprises one or more gestures. Linear ordering is indicated by a numeric index on each segment. The numeric index on each gesture indicates its affiliation with a segment bearing the same index. This is illustrated in (12) for the word ‘comb’ [kom], in which all of the segments are composed of multiple gestures.

- (12) Input form of ‘comb’ in Gestural OT, with linear ordering indices indicating segmental affiliation



From the underlying linearly ordered segments (sets of gestures), the phonological grammar will generate a set of output candidates with coupling relations between the gestures. The computation of stabilized phase relations and periods of gestural activation by the Coupled Oscillator Model will follow, and application of the Task Dynamic Model will yield articulator trajectories. These stages of speech production follow directly from the content of a coupling graph, and therefore their calculations appear to be non-phonological in nature. The phonological grammar developed here is unable to manipulate gestural representations at any level beyond the coupling graph, the assumed output of EVAL.

The coupling relations between gestures in a coupling graph are determined by several constraints in the phonological grammar. Before defining these constraints, it is necessary to define precisely how the gestures that make up a segment relate to one another. In particular, I

draw a distinction between a segment's primary gesture and its secondary gesture(s). Gafos (2002) recognizes this distinction between oral 'head gestures' and velic or laryngeal 'secondary gestures' and claims that constraints on particular coordination schemes between gestures should operate over head (i.e., primary) gestures only. Though intuitively it is not difficult to pick out the primary gesture of a consonantal or a vocalic segment (for instance, the tongue tip gesture of [t] should likely be considered its primary gesture rather than its glottal opening gesture), the terms 'primary' and 'secondary' remain ill-defined.

It is not within the scope of this dissertation to develop a full definition of what contributes to the primary versus secondary status of a gesture, but some guidelines can be laid out. I adopt Gafos' insight that an oral gesture should gain primary status when it is one of a set of gestures in which one is oral and the others are not. However, this alone is insufficient to account for consonantal and vocalic segments with secondary oral gestures, such as those responsible for rounding or palatalization. In the case of multigestural consonants, we can appeal to the fact that when a consonant or vowel is composed of two oral gestures, one is a consonantal gesture and one is a vocalic gesture.³ Definitions of the terms 'consonantal' and 'vocalic' deserve much further study, but Sproat & Fujimura (1993) offer these preliminary definitions: 'Consonantal gestures are those that produce an extreme obstruction in the mid-sagittal plane. Vocalic gestures are those gestures that do not produce an extreme obstruction; furthermore, vocalic gestures may actually involve opening of a channel as in the case with velum lowering' (p. 304). This definition of a vocalic gesture seems able to capture not only vocalic oral gestures but velic and glottal opening gestures as well. In general, then, it can be assumed that when a segment comprises two or more gestures, the consonantal gesture as defined by Sproat &

³ Notable exceptions to this generalization are labiovelar consonants such as /kp/, which involve the concurrent production of two consonantal constrictions. I set aside the issue of how to classify the consonantal gestures of such segments, though see Danis (2017) for a recent discussion of the representation of doubly articulated consonants.

Fujimura is primary and any vocalic gestures are secondary. In the case of vowels, however, a vocalic gesture is considered primary; therefore, the tongue body gesture of a multigestural vocalic segment is considered primary.

Having defined the relation between the gestures that make up a segment as one between primary and secondary gestures, constraints on the coupling relations between gestures in a coupling graph can be defined. Following C. Smith (2016b), the coupling relations between heterosegmental gestures are determined by the three COUPLE constraints in (13), based on Davidson's (2003) ASSOCIATE constraints.

(13) COUPLE constraints used to determine intergestural coordination relations

- a. COUPLE(C,V): Assign a violation mark for any primary consonantal gesture that is not coupled in-phase to the primary gesture of the following vocalic segment.
- b. COUPLE(C,C): Assign a violation mark for any primary consonantal gesture that is not coupled anti-phase to the primary gesture of the following adjacent consonantal segment.
- c. COUPLE(V,V): Assign a violation mark for any primary vocalic gesture that is not coupled anti-phase to the primary gesture of the following vocalic segment.

Davidson's ASSOCIATE constraints are used to identify pairs of gestures that come under the influence of gestural landmark-aligning COORDINATE constraints (Gafos 2002). However, the version of Gestural OT implemented here eliminates this second step of coordination between the landmarks of associated pairs of gestures, instead leaving the precise coordination of coupled gestures to the calculations of the Coupled Oscillator Model.

The coupling relations that are present in the coupling graph for ‘comb’ in (8) follow straightforwardly from the COUPLE constraints in (13). Satisfying COUPLE(C,V), the primary consonantal tongue body gesture for [k] is in-phase (synchronously) coupled to the primary vocalic tongue body gesture of [o]. In addition, the tongue body gesture of [o] is coupled anti-

phase (sequentially) to the primary consonantal labial closure gesture of the following [m]. This anti-phase coupling between a primary vocalic gesture and a following primary consonantal gesture is assumed to be driven not by a COUPLE constraint, but by the universal prohibition against any gestures remaining uncoupled in an output form. The anti-phase nature of this coupling preserves the linear ordering of these segments.

The in-phase coupling relations between onset consonants and vowels deserve further mention. The constraint COUPLE(C,V) is satisfied by a primary consonantal gesture that is coupled in-phase to a following primary vocalic gesture; however, this in-phase coupling means that the two gestures will activate synchronously, not sequentially. Therefore, it is not clear that the vocalic gesture still follows the onset consonantal gesture, as it does in the input. I will assume that whether a gesture precedes or follows another gesture is defined with respect to the timepoints of the achievement of each gesture's target articulatory state, and not its activation. Therefore, a primary consonantal gesture can be said to precede a primary vocalic gesture to which it is coupled in-phase, owing to the vocalic gesture's lower stiffness and later attainment of its target articulatory state.

The COUPLE constraints defined in (13) will receive little attention here. While they play a significant role in the analyses outlined by C. Smith (2016b), their impact upon the workings of the Gestural Harmony Model is minimal. Therefore, they will be considered high-ranked and inviolable in the analyses that follow.

An additional constraint is necessary to compel the composite gestures of a segment to be coupled to one another in an output form. Note, for instance, that the secondary gestures of the initial [k] in ‘comb’ are coupled to the primary consonantal gesture of that segment in the coupling graph in (8), despite the lack of any COUPLE constraint requiring the presence of these

coupling relations. The motivation for the coupling between the composite gestures of a segment appears to be some form of ensuring that the gestures that are segmentally affiliated in the input are related in some way in the output. I propose that the lack of a coupling relation between a segment's composite gestures should be penalized by a form of INTEGRITY-IO. This constraint was originally conceived by McCarthy & Prince (1995) as a way to prevent the splitting or copying of segments between the input and the output. Within Gestural OT, INTEGRITY-IO is defined as in (14).

- (14) INTEGRITY-IO: Assign a violation mark to a primary gesture and a secondary gesture that are part of the same segment (set of gestures) in the input and are not coupled to one another in the output.⁴

In addition to INTEGRITY-IO, I assume that Gestural OT includes the typical faithfulness constraints penalizing the epenthesis and deletion of material between input and output, as well as any changes in the specifications of representational units (McCarthy & Prince 1995). Of particular importance to the Gestural Harmony Model is the constraint IDENT(parameter_X)-IO, which penalizes any changes to some gestural parameter (e.g. constriction location, stiffness, (de-)activation phase) between the input and the output. It is defined as in (15).

- (15) IDENT(parameter_X)-IO: Assign a violation mark to a gesture whose input and output correspondents do not have identical specifications for parameter X.

Regarding the epenthesis and deletion of material, Gestural OT admits MAX-IO and DEP-IO constraints (McCarthy & Prince 1995) that refer both to whole segments (sets of gestures) and to individual gestures within those segments. The segmental versions of these constraints, MAX(segment)-IO and DEP(segment)-IO, are defined in (16).

⁴ It is also conceivable that INTEGRITY-IO could be defined such that all of the gestures that make up a single segment must be coupled to one another, rather than merely requiring a segment's primary gesture to be coupled to all secondary gestures. The workings of the Gestural Harmony Model do not crucially distinguish between these two possible definitions of INTEGRITY-IO; therefore, the matter is set aside.

(16) Constraints on segmental epenthesis and deletion

- a. MAX(segment)-IO: Assign a violation mark to an input segment (set of gestures) that has no output correspondent.
- b. DEP(segment)-IO: Assign a violation mark to an output segment (set of gestures) that has no input correspondent.

Constraints may also penalize the deletion and epenthesis of individual gestures within a segment. I define these constraints following Pater's (1999) definitions of IDENT-IO and IDENT-OI, which penalize changes in segmental quality due to the deletion and epenthesis of privative features from segments. To avoid confusion with IDENT(parameter_X)-IO constraints, I will refer to constraints on gestural deletion and epenthesis as MAX(gesture_X)-IO and DEP(gesture_X)-IO, respectively. These definitions are provided in (17).

(17) Constraints on gestural epenthesis and deletion

- a. MAX(gesture_X)-IO: Assign a violation mark to a segment (set of gestures) that includes gesture X in the input if its output correspondent does not include gesture X.
- b. DEP(gesture_X)-IO: Assign a violation mark to a segment (set of gestures) that includes gesture X in the output if its input correspondent does not include gesture X.

In addition to the faithfulness constraints above, gestural representations are subject to various markedness constraints. As is the case for features, certain incompatible gestures may be prohibited from occurring with one another, either concurrently or adjacently. These co-occurrence restrictions are enforced within Gestural OT by one of two basic constraint types:

*COUPLE and *OVERLAP.

*COUPLE constraints, as their name suggests, penalize a coupling relation between two or more gestures whose co-occurrence is marked in some way. There are two basic forms a

*COUPLE constraint can take, schematized in (18). The first schema outlined below refers to a pair of incompatible gestures, while the second refers to a set of three incompatible gestures.⁵

(18) Schemas for *COUPLE constraints

- a. *COUPLE(Gest_X, Gest_Y): Assign a violation mark for a pair of gestures of type X and type Y that are in a coupling relation with one another.
- b. *COUPLE(Gest_X, Gest_Y, Gest_Z): Assign a violation mark for a gesture of type X that is in a coupling relation with a gesture of type Y and in a coupling relation with a gesture of type Z.

*OVERLAP constraints penalize the concurrent activation of two or more incompatible gestures, with no reference to whether or not those gestures are coupled to one another. In this sense, they are stricter than *COUPLE constraints. In some cases, including harmony, incompatible gestures might not be near each other in a coupling graph, let alone coupled to one another, and yet end up concurrently active in a gestural score. Therefore, *COUPLE constraints are of no use in capturing their incompatibility. *OVERLAP constraints follow the schema provided in (19). As with the *COUPLE constraints in (18), there are schemas both for pairs of incompatible gestures and for sets of three incompatible gestures.

(19) Schemas for *OVERLAP constraints

- a. *OVERLAP(Gest_X, Gest_Y): Assign a violation mark for a pair of gestures of type X and type Y that are concurrently active.
- b. *OVERLAP(Gest_X, Gest_Y, Gest_Z): Assign a violation mark for a gesture of type X that is concurrently active with a gesture of type Y and with a gesture of type Z.

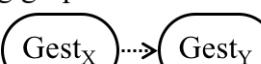
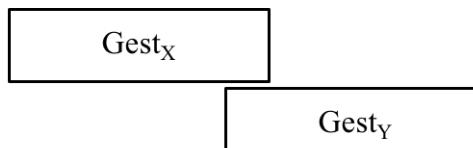
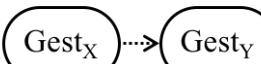
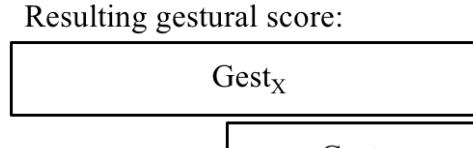
In the version of Gestural OT that I employ here, constraints in the grammar operate to manipulate output candidate coupling graphs. However, I claim that while constraints may only

⁵ It may also be desirable to include *COUPLE constraint schemas that refer to sets of four or more incompatible gestures. However, such configurations are not relevant to the Gestural Harmony Model; therefore, the matter is set aside.

directly manipulate the coupling graph, they may also evaluate information about the gestural score, articulatory trajectories, and acoustic output that are calculated from this coupling graph. This crucially includes information about the outcomes of gestural overlap.

The evaluation of a constraint from the *OVERLAP family is demonstrated by the tableau in (20). Both candidates are displayed both as coupling graphs and as the gestural scores that are calculated from those coupling graphs.

(20) Tableau illustrating violation profile for *OVERLAP

	*OVERLAP (Gest _X , Gest _Y)
Coupling graph:  Resulting gestural score: 	
a. Coupling graph:  Resulting gestural score: 	*

In candidate (a), Gest_X and Gest_Y are antiphase coupled to one another, and Gest_Y activates just before Gest_X deactivates. I assume that the slight gestural overlap that arises between two antiphase coupled gestures does not incur a violation of *OVERLAP. In candidate (b), Gest_X and Gest_Y are also coupled antiphase. However, in this candidate Gest_X extends in duration, resulting in its overlap with Gest_Y. In contrast with candidate (a), the gestural overlap in candidate (b) is sufficient to violate *OVERLAP. The mechanisms behind extended gestural

activation, persistence and anticipation, are introduced and discussed in chapter 2, while the mechanism for preventing gestural overlap, inhibition, is discussed in chapter 4.

Access to information about gestural activation and overlap is assumed in previous OT-based analyses in gestural phonology as well. The gestural coordination grammar developed by Gafos (2002) and adopted by Davidson (2003), N. Hall (2003), and Bradley (2005) relies upon a series of constraints that coordinate the temporal landmarks of gestures with previously determined durations. Additionally, total overlap between two gestures has a highly marked status within these analyses because it impedes perceptual recoverability of the gestural composition of phonological forms. Gafos (2002) and Bradley (2005) use this principle of maximization of perceptual recoverability to motivate the inclusion of constraints calling for little or no gestural overlap. In both of these analyses, constraints in the grammar are able to use information about the acoustic and perceptual consequences of gestural overlap in order to evaluate candidate output forms, despite the fact that this acoustic and/or perceptual information is not explicitly encoded in the candidates' phonological forms.

Similar abilities of the phonological grammar to access information about the acoustic and perceptual consequences of phonological forms are also common in most theories of phonology that assign a large role to speakers' phonetic knowledge. For instance, Steriade's (1995, 1997, 2001, 2009) Licensing by Cue and P-Map theories and Flemming's (1995/2002, 2004) Dispersion Theory rely heavily on the perceptual outcomes of phonological forms. In these frameworks, perceptual cues are used to evaluate output candidates, even if those perceptual cues are not represented in the phonological forms themselves. The phonological grammar accesses this information by referring to the phonetic knowledge the speaker utilizes to anticipate the phonetic outcomes of phonological forms. Boersma's (1998, 2003) Functional

Phonology is also notable for the degree to which the phonological grammar may access and utilize phonetic and perceptual details. This framework recognizes three distinct representations of a phonological form: the segmental (underlying), the articulatory, and the perceptual.

The ability of the Gestural OT grammar to evaluate the gestural score and articulatory trajectories that are directly predictable from a candidate coupling graph therefore does not represent a radical departure from previous theories in terms of what phonetic information a grammar may access about a phonological form. Within the implementation of Gestural OT I assume here, the phonological grammar still operates to manipulate output candidate coupling graphs, but may evaluate candidates based on any information that is available in the gestural score, articulatory trajectories, and acoustic output that a candidate coupling graph produces.

The final markedness constraint type to be discussed here is gestural licensing. In contrast to *OVERLAP constraints that penalize the co-occurrence of certain types of gestures, LICENSE constraints are only satisfied when certain types of gestures do co-occur. They are defined such that one gesture is specified as licensor and the other as licensee, following the schema in (21).

(21) Constraint schema for gestural LICENSE

LICENSE(Gest_X , Gest_Y): Assign a violation mark to an active gesture of type X if a gesture of type Y is not concurrently active.

According to LICENSE(Gest_X , Gest_Y), Gest_X is unlicensed and therefore incurs a violation mark unless it is accompanied by another gesture, Gest_Y . However, the constraint does not require that Gest_Y be accompanied by Gest_X in order to be considered licensed. Unlike *OVERLAP or *COUPLE constraints, which penalize a combination of gestures without singling out certain marked gestures within that combination, LICENSE constraints specify a gesture that is marked in isolation but not in combination within another gesture.

In addition to gestural licensing constraints, I also adopt the use of more traditional positional licensing constraints (Zoll 1996; J. Smith 2002; Walker 2005, 2011; A. Kaplan 2008), which license certain gestures or segments (i.e., sets of gestures) in prominent positions. These constraints are defined such that they penalize gestures or segments that occur outside of a licensed position. The schema for positional licensing is provided in (22).

(22) Constraint schema for positional LICENSE

LICENSE(Gest_X, Position_Y): Assign a violation mark to a segment/gesture of type X that is not in position Y.

The markedness constraints *COUPLE, *OVERLAP, and LICENSE, as well as the faithfulness constraints IDENT(parameter)-IO, MAX(gesture)-IO, DEP(gesture)-IO, and INTEGRITY-IO introduced in this section make up the core of EVAL in the version of Gestural OT I adopt in this dissertation. They share in common the fact that they all have the power to manipulate the contents of a coupling graph, via either the coupling relations between gestures or the gestural content of the coupling graph. Additional constraints specific to the analysis of harmony will be discussed in following chapters as the workings of the Gestural Harmony Model are introduced.

1.3 Organization of the Dissertation

This chapter has introduced the major motivations for developing the Gestural Harmony Model, and has also laid out the basic theoretical assumptions necessary to construct an analysis of harmony within gestural phonology. The remainder of the dissertation is organized as follows.

Chapter 2 introduces the basic representation of harmony within the Gestural Harmony Model. It also introduces the concepts of gestural *persistence* (non-self-deactivation) and *anticipation* (early activation) by which gestures are able to trigger harmony by extending to

overlap other gestures in a word. In addition to introducing the basic gestural representation of harmony and the gestural parameters of persistence and anticipation, this chapter also discusses the criteria a gesture must meet in order to surface as persistent or anticipatory and therefore to serve as a trigger of harmony.

Chapter 3 introduces the constraint set responsible for triggering harmony, and includes analyses of the different triggering patterns of several harmony systems, both simple and complex. By treating a gesture's ability to trigger harmony as the product of a gestural parameter rather than the satisfaction of a grammatical constraint, the grammar developed within the Gestural Harmony Model captures patterns of harmony triggering via the shaping of a language's surface phonological inventory. Because of this, the model is able to straightforwardly capture both simple and complex patterns of harmony triggering while avoiding both over- and under-generation pathologies. Both conditional and contrastive triggering of harmony are the result of the interaction of markedness and faithfulness constraints, both general and position-specific. This chapter also discusses how feature-based analyses of such patterns, which rely on mechanisms such as constraint indexation and contrastive underspecification in order to account for such patterns, come with undesirable typological predictions that are avoided by the Gestural Harmony Model. In particular, the Gestural Harmony Model is able to analyze a gesture's ability to trigger harmony as a potentially contrastive property, providing a straightforward account of harmony patterns that are often treated as cases of phonological exceptionality.

Chapter 4 focuses on transparency and blocking in harmony. The chapter begins with a description of the typological patterns of transparency and blocking in several different types of harmony, and goes on to demonstrate how the Gestural Harmony Model successfully accounts

for these patterns. Crucial to the success of the Gestural Harmony Model in generating a constrained typology of transparency and blocking is the division of the analyses of transparency and blocking among two different theoretical mechanisms. This chapter introduces the idea of transparency via competition between antagonistic gestures, by which certain segments that are overlapped by a harmonizing gesture will automatically surface as transparent to harmony due to their gestural makeup. Blocking, meanwhile, results from high-ranking constraints that penalize the concurrent activation of incompatible gestures, and is implemented via a newly proposed relation between gestures: intergestural inhibition. The chapter concludes by comparing the typological predictions made by various alternative analyses of transparency and blocking.

Chapter 5 presents a closer examination of the concepts of gestural strength and intergestural competition and blending that are central to the Gestural Harmony Model's representation of transparency to harmony. It presents the results of computational modeling of transparency via intergestural competition. The chapter also investigates the possibility that the phonological role played by gestural strength is greater than previously assumed by focusing on cases in which gestural strength appears to serve a contrastive function.

Chapter 6 concludes the dissertation by summarizing the major contributions of the Gestural Harmony Model to the study of both harmony and the framework of gestural phonology. It also identifies avenues for future work and ideas for further innovation of the model. Among these is a possible rethinking of the representation of vowels within gestural phonology that would make it possible to account for additional types of harmonies based on vowel place. The chapter also examines further implications of the Gestural Harmony Model's development of new theoretical mechanisms, such as intergestural inhibition, as well as whether

directional asymmetries can be built into the model via the distinct mechanisms of persistence and anticipation.

Chapter 2

Representing Harmony with Gestures

2.1 Introduction

This chapter introduces the core representational innovations of the Gestural Harmony Model. In particular, it focuses on developing the concepts of gestural *persistence* and *anticipation*, two parameters that lead to the extended period of activation of a gesture. A trigger of harmony is a segment that includes a gesture that is either persistent, anticipatory, or both. A persistent gesture is specified not to self-deactivate once its goal articulatory state is reached. Instead, a persistent gesture remains active and overlaps the gestures of following segments, the undergoers of progressive harmony. An anticipatory gesture, on the other hand, is specified to activate earlier than the specified 0° phase of its planning oscillator. Due to this early activation, it overlaps the gestures of preceding segments, the undergoers of regressive harmony.

Many types of gestures may surface as persistent (non-self-deactivating) or anticipatory (early-activating). These include lip protrusion gestures, which trigger rounding harmony; tongue root advancement gestures, which trigger ATR harmony; and velum opening gestures, which trigger nasal vowel-consonant harmony. Examples of each of these types of harmony are illustrated in this chapter. In Kyrgyz (section 2.2.1), rounding harmony is triggered by round vowels in an initial syllable. In Capanahua (section 2.2.2), nasal stops trigger a process of regressive (leftward) nasal vowel-consonant harmony. In Nandi (section 2.2.3), ATR vowels triggers bidirectional ATR harmony.

There are several elements of the Gestural Harmony Model's representation of harmony as gestural activation extension that are crucial to the model's success in accounting for

crosslinguistic patterns among harmony systems. First, in the Gestural Harmony Model a segment's status as a trigger of harmony is directly encoded in its gestural representation via the parameters of persistence (non-self-deactivation) and anticipation (early activation). Because of this, the model is able to accurately and straightforwardly account for complex patterns of harmony triggering, as detailed in chapter 3. In addition, in the Gestural Harmony Model the undergoers of harmony include both vowels and consonants, regardless of whether a given type of harmony is traditionally described as vowel harmony or as vowel-consonant harmony. In the Gestural Harmony Model, the treatment of these two types of harmony is unified. This is due to one of the crucial aspects of the Gestural Harmony Model: harmony is always strictly local. In other words, in this model the period of activation of a harmony-triggering gesture is uninterrupted throughout a harmony span. Because the Gestural Harmony Model assumes that harmony is strictly local and affects vowels and consonants alike, there is built into the theory a restriction on which types of gestures may surface as persistent or anticipatory. In addition, this local representation of harmony has important consequences for the representation of transparency within the Gestural Harmony Model and the typological predictions the model makes about transparent segments. This is discussed in detail in chapter 4.

The chapter is organized as follows. Section 2.2 introduces the proposed gestural representation of harmony, which is illustrated with examples from rounding harmony, tongue root harmony, and nasal harmony. It also introduces the proposed gestural parameters of persistence (non-self-deactivation) and anticipation (early activation) as the drivers of harmony. Section 2.3 focuses on a discussion of which types of gestures may surface as either persistent or anticipatory, i.e., which gestures may trigger harmony. Section 2.4 summarizes the proposals

made in this chapter and previews the role they play in the development of the Gestural Harmony Model's phonological grammar in chapter 3.

2.2 Harmony as Gestural Extension

Harmony can be interpreted as the temporal extension of some phonological property that is introduced by a triggering segment or morpheme. This section examines how that extension is represented within the Gestural Harmony Model and which gestural parameters must be manipulated in order to generate this extended period of gestural activation. These representational concepts are illustrated by case studies of rounding harmony, tongue root harmony, and nasal harmony.

2.2.1 Rounding Harmony in Kyrgyz

This section demonstrates the basic representational concepts of the Gestural Harmony Model with an analysis of rounding harmony in Kyrgyz (Turkic, Kipchak; Kyrgyzstan). Kyrgyz has a symmetrical surface inventory that distinguishes vowels based on height, backness, rounding, and length (Comrie 1981), as shown in (23).

(23) Kyrgyz vowel inventory⁶

	Front		Back	
	Unround	Round	Unround	Round
High	i i:	y y:	u u:	u u:
Non-High	e e:	ø ø:	a a:	o o:

As in many Turkic languages, all vowels in Kyrgyz are contrastive for height while harmonizing for backness and rounding. In this section, I focus on rounding harmony in Kyrgyz; on the representation of vowel backness in gestural phonology, see section 6.2.1. According to

⁶ These vowel transcriptions vary somewhat from those used by Comrie (1981). The front rounded vowel transcribed by Comrie as /ü/ and /ö/ are represented here by /y/ and /ø/, respectively. The back unrounded vowel transcribed by Comrie as /i/ is represented here by /u/.

Comrie (1981), all round vowels in the inventory trigger rounding harmony, and all vowels are capable of undergoing harmony. Roots surface with vowels that are either all round or all unround and either all back or all front, and suffixes undergo harmony to match the rounding and backness specifications of the root. As there are no prefixes in Kyrgyz, these harmonies are strictly progressive (rightward). In (24a-d), the nonhigh vowel of the ablative suffix surfaces as round following a root with round vowels, while following roots with unround vowels the same suffix surfaces with an unround vowel, as in (24e-h). All data are from Comrie (1981).

- (24) a. [yj-døn] ‘house (ablative)’
 b. [køl-døn] ‘lake (ablative)’
 c. [tuz-don] ‘salt (ablative)’
 d. [tokoj-don] ‘forest (ablative)’
 e. [iʃ-ten] ‘work (ablative)’
 f. [et-ten] ‘meat (ablative)’
 g. [dʒul-dan] ‘year (ablative)’
 h. [alma-dan] ‘apple (ablative)’

High vowels also undergo rounding harmony, as illustrated by the alternation of the ordinal suffix in (25a-d).

- (25) a. [yc-yntʃy] ‘three (ordinal)’
 b. [tørt-yntʃy] ‘four (ordinal)’
 c. [toguz-untsu] ‘nine (ordinal)’
 d. [on-untsu] ‘ten (ordinal)’
 e. [bir-intʃi] ‘one (ordinal)’
 f. [bes-intʃi] ‘five (ordinal)’
 g. [altui-ntsü] ‘six (ordinal)’
 h. [dʒijirma-ntsü] ‘twenty (ordinal)’

Comrie also provides several examples that illustrate that harmony also proceeds throughout multiple suffixes, as in (26).

- (26) a. [køz-yn-dø] ‘in his eye’
 b. [tuz-un-do] ‘in his salt’
 c. [ata-sun-da] ‘at his father’
 d. [ene-sin-de] ‘at his mother’

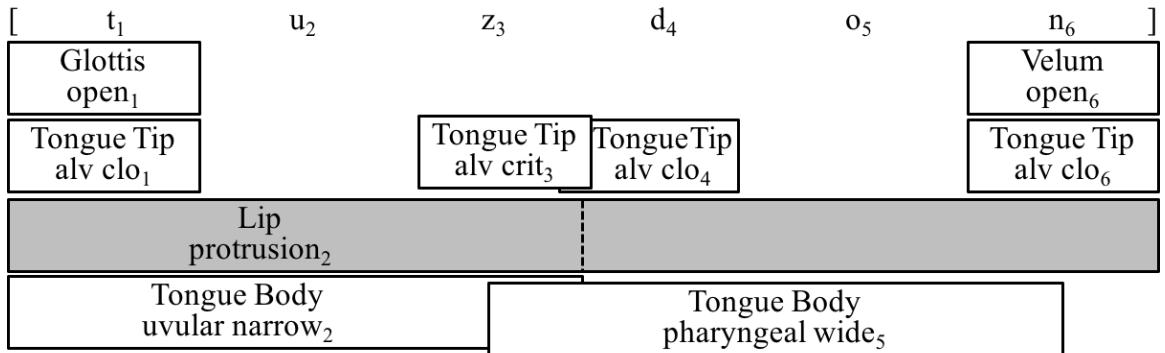
As discussed in section 1.2.1, a round vowel is represented by two gestures, one with a target of tongue body constriction and another with a target of lip protrusion. Based on experimental findings reported by Boyce (1990), I propose that in a language without rounding harmony, such as English, the two gestures of a round vowel begin and end at roughly the same time. The lips return to their neutral position at the end of production of a round vowel.

However, in languages that exhibit progressive rounding harmony, such as Kyrgyz, I propose that the lips do not return to this neutral position upon successful production of a round vowel. Rather, the lips remain protruded for an extended period of time, resulting in the rounding of following segments. In the Gestural Harmony Model, rounding harmony is represented as this extended activation of a lip protrusion gesture that results in its overlap with and rounding of following segments.

This representation of rounding harmony is demonstrated by the figure in (27), which shows a gestural score for the Kyrgyz form [tuz-don] ‘salt (ablative).’ The [u] of the initial syllable, the trigger of rounding harmony, is represented by two gestures: one for tongue body constriction in the uvular region of the vocal tract, and one for protrusion of the lips.⁷ Of note here is the idea that the lip protrusion gesture (shaded) has an extended period of activation such that it overlaps all following gestures. The dashed line within the lip protrusion gesture indicates the time at which a typical lip protrusion gesture would deactivate simultaneously with the deactivation of the uvular narrowing gesture of [u].

⁷ For now, it is assumed that the lip protrusion gesture is associated with the first vocalic segment in the word in Kyrgyz. This is discussed further in section 3.2.1.

(27) Gestural score for [tuz-don] ‘salt (ablative)’



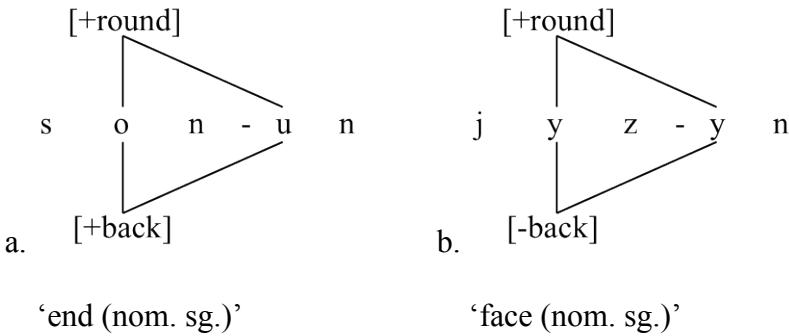
In the gestural score in (27), the segments overlapped by the lip protrusion gesture of [u] are the undergoers of rounding harmony. This includes the suffix vowel, which surfaces as rounded [o], as well as the consonants [z], [d], and [n]. By adopting the view that rounding harmony is the result of the extended activation of a harmonizing lip protrusion gesture, the Gestural Harmony Model contends that harmony is strictly local in the sense that the span of activation of a harmonizing gesture is uninterrupted. A gesture with an extended period of activation, such as the lip protrusion gesture in (27), will overlap any segments that come after it. It makes no distinction between vowel harmony, in which only vowels are potential undergoers and consonants are assumed to be transparent, and vowel-consonant harmony, in which all segments are undergoers. In the Gestural Harmony Model, then, consonants are considered undergoers of what is usually called vowel harmony because they are overlapped by a harmonizing gesture that originates from a vocalic segment.

This is consistent with claims by Gafos (1996/1999) and Ní Chiosáin & Padgett (1997, 2001) that vowel harmony is local at the segmental level but does not affect consonants in a way that is perceptible and/or contrastive. Gafos' model of harmony, like the Gestural Harmony Model, represents harmony as the extended, uninterrupted activation of a gesture, with consonantal gestures being overlapped by vocalic gestures in vowel harmony environments.

Within feature-based phonology, Ní Chiosáin & Padgett also propose that consonants undergo harmony, but that a consonant that bears vowel features such as [±round] or [±back] is not perceptually distinct from a consonant that does not. Likewise, the strict locality inherent in the Gestural Harmony Model leads to the characterization of consonants as undergoers of so-called vowel harmony. The appearance of consonants as transparent to such harmonies is merely an effect of perception; a consonant that has been overlapped by a harmonizing vocalic gesture is not perceptually distinct from a consonant that has not been overlapped. This is referred to as ‘false transparency’ by Walker (1998/2000) and ‘apparent transparency’ by Archangeli & Pulleyblank (2007). This can be contrasted with cases of true transparency, in which transparent segments are produced as if they have not taken on a harmonizing property, discussed in detail in chapter 4.

The representation of consonants as undergoers of so-called vowel harmony is in contrast with autosegmental representations of vowel harmony in which only vowels are considered to be targets of the harmony process. Clements & Sezer (1982) provide such an autosegmental analysis of rounding harmony and backness harmony in Turkish. In their analysis, [±round] and [±back] are the relevant harmonizing features, or p-segments, and vowels are the potential targets, or p-bearing units. Under this analysis, consonants (with the exception of velar and lateral consonants) are completely inert within the harmony system and are skipped by autosegmental spreading. Thus, forms in Turkish are represented by Clements & Sezer as in (28).

(28) Autosegmental representation of Turkish rounding harmony



However, the results of a number of theoretical and experimental studies support the view of consonants as undergoers of vowel harmony. In his seminal study of consonant and vowel coarticulation, Öhman (1966) argues that speech can be characterized as a series of vocalic articulations over which consonants are superimposed, and that the vocal tract postures necessary for vowel articulation are adopted by those superimposed consonants. Consonant gestures are produced concurrently with the vocalic gestures that surround them; therefore, it makes sense that consonants would also be undergoers of vowel harmony, albeit to a degree that is often not perceptible. Additional studies have focused specifically on the articulation of consonants within a harmony span and determined that consonants are affected by harmony processes. For instance, Zhang (1996) reports that in Classical Manchu, dorsal consonants are produced as velars in ATR harmonic words and as uvulars in non-ATR words. Similarly, Clements & Sezer (1982) report that velar and lateral consonants participate in backness harmony in Turkish. Experimental work by Boyce (1990) has also found that consonants produced within the domain of Turkish rounding harmony are also produced as round, indicating a continuous ‘plateau’ of lip rounding. English rounding, on the other hand, exhibits a ‘trough’-like pattern in which the degree of lip protrusion alternates between consonants and vowels. Another language that has been the subject of this

line of study is Kalenjin. The tongue root harmony system of one of the varieties of this language, Nandi, is the subject of section 2.2.3.

I turn now to the question of what generates the extended activation of the lip protrusion gesture of round vowels in Kyrgyz and how it can be accounted for within the Gestural Harmony Model. The literature is replete with analyses that drive harmony via OT constraints, including featural alignment constraints (e.g., Kirchner 1993; Akinlabi 1994; Cole & Kissoberth 1994, 1995; Pulleyblank 1996), EXTEND(F) (Kaun 1995), SPREAD(F) (Padgett 1995; Walker 1998/2000), feature-driven markedness constraints (Beckman 1997, 1998), and AGREE (Baković 2000), to name only a few. Many of these constraints drive harmony by either directly or indirectly motivating a harmonizing feature to maximize the number of segments to which it is associated.⁸ However, a parallel approach in which the time span of gestural activation is directly manipulated by the grammar is not available within the Gestural Harmony Model. As discussed in section 1.2.2, while temporal information that is present in a candidate form's gestural score is available to the phonological grammar, it cannot be manipulated directly. Instead, a candidate's gestural score is calculated by the Coupled Oscillator Model based solely on the content of its coupling graph. Extended gestural activation cannot be achieved by positing a constraint that requires a gesture to remain active for a certain period of time.

The Gestural Harmony Model instead appeals to a parameter of an extended gesture that is present within the coupling graph and indicates that the gesture will extend throughout a word once it has been passed through the Coupled Oscillator Model. Rather than directly requiring the extended activation of a gesture, constraints in the grammar manipulate the setting of that

⁸ Baković's AGREE is a notable exception to this generalization. As their name suggests, AGREE constraints require segments to agree for some feature value, but are indifferent as to whether or not that agreement stems from the association of those segments to the same harmonizing feature.

parameter. I propose that in the case of progressive harmony the crucial parameter within the coupling graph is the (self-)deactivation parameter that determines the end phase of a gesture. Typically, a gesture's activation begins at its planning oscillator's 0° phase and extends until it reaches a specified phase at which it self-deactivates (corresponding to the achievement of that gesture's target articulatory state). However, I propose that the gestures that trigger progressive (rightward) harmony are specified as *persistent*. A persistent gesture does not perform this self-deactivation but instead remains active beyond the phase at which it achieves its target articulatory state. In the case of Kyrgyz rounding harmony, it is the gesture calling for protrusion of the lips that is persistent. The result is the extended activation of the lip protrusion gesture and the progressive spread of rounding throughout a word, as in the gestural score in (27).

The figure in (29) contrasts the parameter specifications of a typical (self-deactivating) gesture with those of a persistent (non-self-deactivating) gesture.

- (29) Parameter specifications of a typical self-deactivating gesture and a persistent non-self-deactivating gesture

Lip Degree: protrusion $k = \text{low}$ $\alpha = \text{low}$ <input checked="" type="checkbox"/> Self-deactivate Articulators: lips jaw	Lip Degree: protrusion $k = \text{low}$ $\alpha = \text{low}$ <input type="checkbox"/> Self-deactivate Articulators: lips jaw
---	--

I also propose that the workings of the Coupled Oscillator Model must be augmented in order to accommodate these persistent (non-self-deactivating) gestures. As discussed in section 1.2.1, in its current instantiation the Coupled Oscillator Model comprises a single mechanism that determines the relative phasing of gestures' planning oscillators according to the coupling relations that exist between them. Once the gestures in a phonological form are temporally

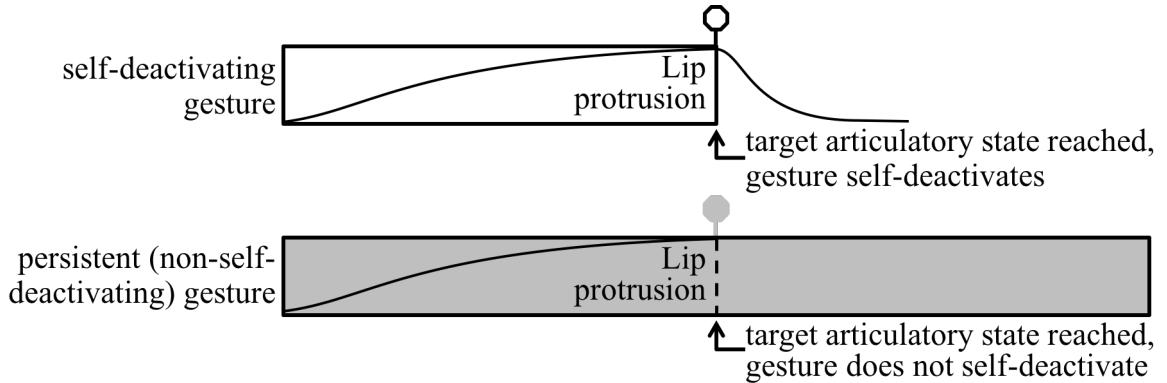
aligned, determining each gesture's activation and deactivation time points requires no further computation on the part of the model. Instead, a gesture automatically activates at its 0° phase and deactivates at a specified phase corresponding to the achievement of its target articulatory state. These typical gestures can be called self-activating and self-deactivating; the Coupled Oscillator Model does not compute the activation and deactivation time points of these gestures, but rather aligns them and then allows them to activate and deactivate themselves at their own specified time points.

The proposed augmentation of the Coupled Oscillator Model involves the addition of a second mechanism that is able to calculate the phases at which a gesture activates and deactivates, based on its position within a coupling graph and its specified activation and deactivation parameters. Gestures that are self-activating and self-deactivating do not rely on this mechanism. However, rather than deactivating itself, a persistent gesture relies on this new mechanism of the Coupled Oscillator Model to determine when it should deactivate. When the model encounters a persistent gesture in a coupling graph, it will maintain that gesture's activation for as long as possible, i.e., until it reaches a blocking segment or a word boundary, at which point the persistent gesture deactivates. It is also possible for a smaller domain boundary, such as a morphemic or prosodic boundary, to deactivate a persistent gesture, though this will not be explored in great detail here. The mechanism of blocking within the Gestural Harmony Model is introduced in section 4.3.

The figure in (30) shows the gestures in (29) as they appear in a gestural score, illustrating the differences in length of activation that result from the differences between the settings of their self-deactivation/persistence parameters. A typical gesture is specified to deactivate itself once it has reached its target articulatory state, indicated by the stop sign icon. A

persistent gesture, on the other hand, is specified not to self-deactivate when it reaches its target articulatory state, indicated by the grayed out stop sign icon. This failure to self-deactivate results in the gesture's extended activation.

- (30) A typical self-deactivating gesture and a persistent (non-self-deactivating) gesture

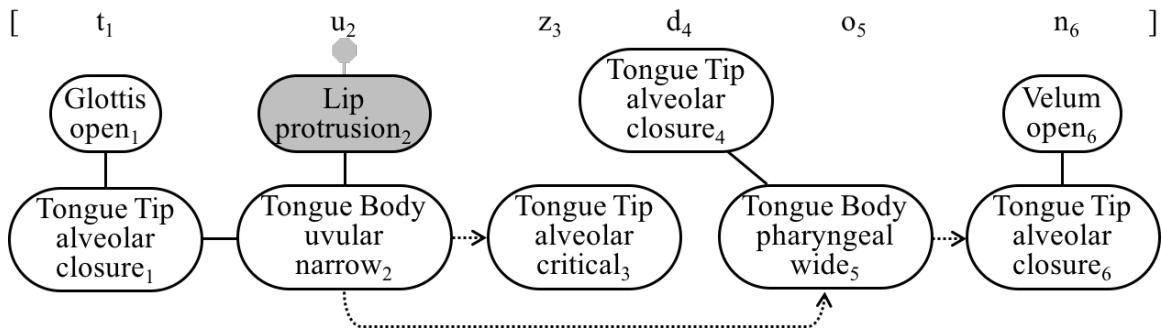


Most previous work within gestural phonology assumes that all gestures self-deactivate without fail. A notable exception is found in work by Tejada (2012), who analyzes tone spreading as the extended activation of tonal gestures. However, Tejada's proposed grammar does not evaluate the types of tone gestures (self-deactivating or persistent) but rather whether those tone gestures are realized with an extended activation. That framework allows for a more direct manipulation of a gesture's period of activation within output candidates than what is assumed by the Gestural Harmony Model. This difference will be discussed further in section 3.6.1.

Appealing to a gestural parameter for self-deactivation versus persistence allows for the representation of gestures as either having a typical period of activation or the potential for extended activation while still only manipulating a candidate output coupling graph, in which information about the temporal extent of gestural activation is not present. When a coupling graph with a persistent gesture is input to the augmented Coupled Oscillator Model, a gestural

score in which that gesture is active throughout an entire word will automatically result (assuming there is no blocker present). Such a coupling graph, for the Kyrgyz form [tuz-don] ‘salt (ablative),’ is shown in (31). As in the figure in (30), the grayed out stop sign icon indicates that the lip protrusion gesture is persistent (non-self-deactivating).

(31) Coupling graph for Kyrgyz [tuz-don] ‘salt (ablative)’⁹



Note that the period of activation of the lip protrusion gesture for the [u], or any other gesture for that matter, is not specified in this coupling graph. However, the coupling graph in (31) will produce the gestural score for [tuz-don] ‘salt (ablative)’ in (27), with the period of activation of the lip protrusion gesture spanning the entire word, due to that gesture’s not self-deactivating the way other gestures in the word do.

In the Gestural Harmony Model, a gesture is a trigger of harmony due to its being specified as persistent (non-self-deactivating). Whenever a round vowel is included in the coupling graph for a Kyrgyz word, it will be represented by a tongue body gesture accompanied by a persistent lip protrusion gesture. Therefore, the fact that Kyrgyz exhibits rounding harmony is due not to the satisfaction of a harmony-driving constraint in its phonological grammar but to a

⁹ For reasons of space, this coupling graph does not include all gestures that are assumed to be included in the representations of certain consonants, such as the velum closure gesture that is part of the representation of obstruents. Such gestures are not crucial to the discussion here, but are the focus of section 4.4.

property of the lip protrusion gesture included in the round vowels in its surface phonological inventory. The inventory of Kyrgyz vowels is represented gesturally as in (32).

(32) Gestural representation of Kyrgyz vowel inventory

/y/	/ø/	/u/	/o/
Lip protrusion	Lip protrusion	Lip protrusion	Lip protrusion
+	+	+	+
Tongue Body palatal narrow	Tongue Body palatal wide	Tongue Body uvular narrow	Tongue Body pharyngeal wide
/i/	/e/	/u/	/a/
Tongue Body palatal narrow	Tongue Body palatal wide	Tongue Body uvular narrow	Tongue Body pharyngeal wide

Because the presence of harmony in a language is dependent upon whether the segments in its surface phonological inventory include persistent gestures, in the Gestural Harmony Model, harmony is driven indirectly via shaping of a language's surface inventory. The result may be a uniform inventory, with all gestures of a certain type (e.g., lip protrusion gestures) surfacing as persistent, as is the case for round vowels in Kyrgyz. However, restrictions on which types of segments may surface with persistent gestures (and in which contexts), are also common and result in non-uniform inventories. The interactions of markedness and faithfulness constraints that result in the shaping of a surface phonological inventory and the placing of distributional restrictions on the members of that inventory are the subject of chapter 3.

2.2.2 Nasal Harmony in Capanhua

The case of Kyrgyz rounding harmony discussed in section 2.2.1 is a progressive (rightward) harmony system, and is analyzed as the result of a persistent (non-self-deactivating) gesture extending to overlap all following gestures in a word. The nasal harmony system of

Capanahua (Panoan; Peru; Loos (1967/1969), Safir (1982), Trigo (1988)), on the other hand, is regressive (leftward), affecting segments that precede the trigger rather than those that follow it. Loos reports the phonological inventory in (33) for Capanahua.

(33) Capanahua phonological inventory¹⁰

Consonants				Vowels	
p	t	k	?	i	u
ts	tʃ			a	o
β	s	f	s		
m	n				
	f				
	j		w		
			h		

Nasal harmony in Capanahua is triggered by a nasal consonant and targets preceding vowels, glides, and glottals, as in (34). All data is from Loos (1967/1969).

- (34) a. [hãmawu] ‘step on it’
 b. [põjã] ‘arm’
 c. [bãwĩn] ‘catfish’
 d. [cĩ?ĩn] ‘by fire’
 e. [cipõnki] ‘downriver’
 f. [wurãnwu] ‘push it’
 g. [wurãnjasa?nvwu] ‘push it sometime’
 h. [bãnawu] ‘plant it’

When a liquid or obstruent precedes a harmony-triggering nasal consonant, it arrests the spread of nasality, and any consonants and vowels preceding the blocking liquid or obstruent surface as oral. This is illustrated by the forms in (34e-h). The analysis of blocking in Capanahua nasal harmony is discussed in section 4.4.4.

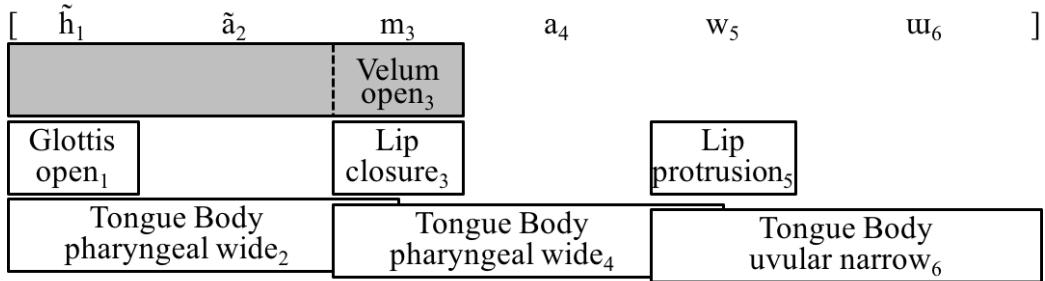
In her analysis of tone spreading as the result of the extended activation of tone gestures, Tejada (2012) claims that all apparently leftward tone spreading is the result of leftward

¹⁰ The vowel transcribed here as /u/ is described by Loos as a high back unrounded vowel and transcribed as /i/, while Safir transcribes both high vowels as /i/.

movement of a tone gesture to a prominent position, accompanied by the rightward extension of that tone gesture. Therefore, leftward harmony is predicted to always target a prominent position. Such an analysis could be proposed for harmony systems in which the spread of a harmonizing property always reaches the beginning of a word, no matter where in that word that property originates. However, maintaining Tejada's strict claim that all regressive harmony is the result of the movement of a triggering gesture and subsequent progressive harmony does not appear to be tenable. This is evidenced by Capanahua nasal harmony, in which nasality spreads regressively but targets no particular position in a word. Many other regressive harmony systems exhibit a similar lack of targeting of prominent positions. Instead, the Gestural Harmony Model must be able to account for harmony systems in which a harmony triggering gesture extends to overlap the gestures that precede it.

As discussed in section 1.2.1, a nasal segment is represented by two gestures, one with a target oral constriction and another with a target of an open velum that will allow air to flow through the nasal cavity. According to the Gestural Harmony Model, nasal harmony is represented as the extended activation of a velum opening gesture, resulting in its overlap with and nasalization of the segments around it. In the case of regressive harmony, it is the segments preceding the trigger that are overlapped by the harmonizing gesture. This representation of nasal harmony is demonstrated by the figure in (35), which shows a gestural score for the Capanahua form [h̄amawu] ‘step on it.’ In this form, the velum opening gesture of the triggering [m] has an extended activation such that it overlaps all preceding segments, resulting in their nasalization. The dashed line indicates the time point at which a typical velum opening gesture would activate simultaneously with the activation of the lip closure gesture of [m].

(35) Gestural score for Capanahua [h̃amawu] ‘step on it’



As discussed in section 2.2.1, the ability of a gesture to extend and overlap the gestures that precede it must be represented in a phonological form’s coupling graph. In parallel with the Gestural Harmony Model’s account of progressive (rightward) harmony, I propose that the gestures that trigger regressive (leftward) harmony are specified as *anticipatory*. These anticipatory gestures rely on the same new mechanism of the augmented Coupled Oscillator Model (section 2.2.1) that is responsible for progressive (rightward) harmony. While a typical gesture activates itself at the 0° phase of its planning oscillator, an anticipatory gesture can be considered non-self-activating. If the Coupled Oscillator Model encounters such a gesture in a coupling graph, it will calculate the gesture’s earliest possible activation point, beginning at its 0° phase and moving regressively (leftward) throughout the word until it reaches a blocking segment or a word boundary. The result of this early activation is the extended activation of a gesture in the regressive (leftward) direction.

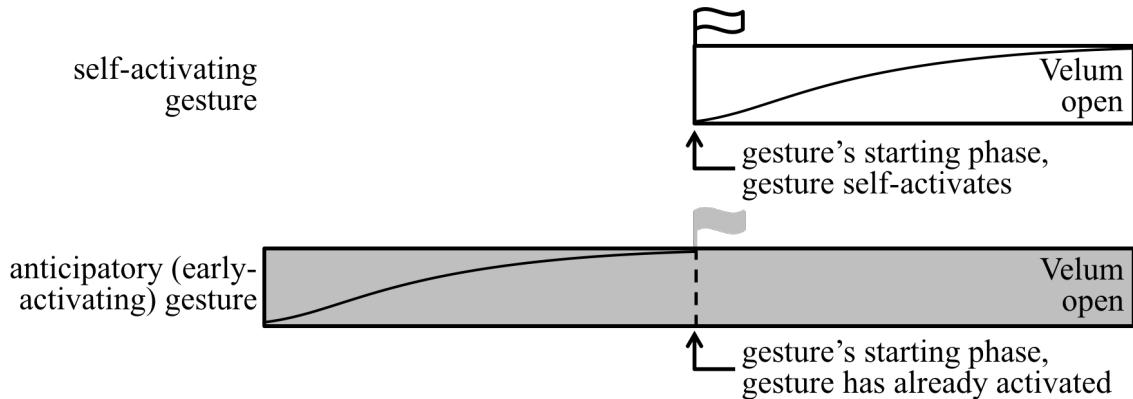
The figure in (36) contrasts the parameter specifications of a typical (self-activating) velum opening gesture with those of an anticipatory, regressive harmony-triggering velum opening gesture.

(36) Parameter specifications of a typical self-activating gesture and an anticipatory gesture

Velum Degree: open $k = \text{low}$ $\alpha = \text{low}$ <input checked="" type="checkbox"/> Self-activate Articulators: velum	Velum Degree: open $k = \text{low}$ $\alpha = \text{low}$ <input type="checkbox"/> Self-activate Articulators: velum
---	--

The figure in (37) shows these same gestures as they appear in a gestural score, illustrating the differences in the time points of gestural activation and resulting periods of activation that result from the differences between their activation parameter settings. A typical gesture is specified to activate itself at the 0° phase of its planning oscillator, indicated by the flag icon. An anticipatory gesture, on the other hand, is non-self-activating and must be activated by the Coupled Oscillator Model, indicated by the grayed out flag icon. This gesture's ability to be activated earlier than its 0° phase results in the gesture's extended activation and the potential overlap of other segments in a word.

(37) A typical self-activating gesture and an anticipatory (early-activating) gesture

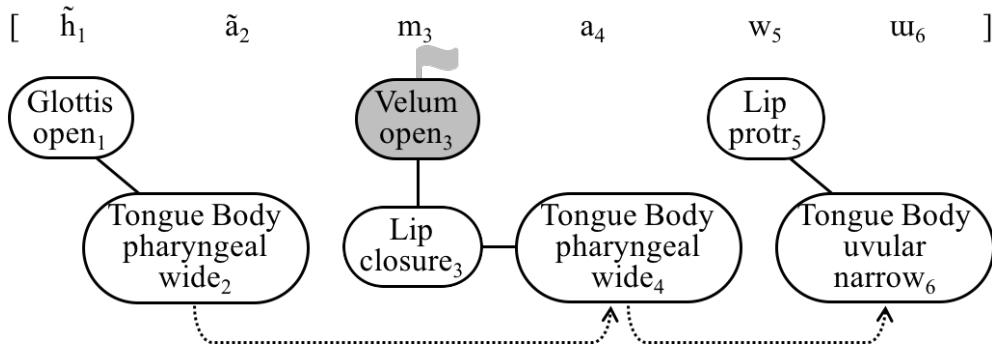


The alignment of the phases that correspond to a typical gesture's activation and deactivation are determined by that gesture's position within a coupling graph. Like a typical gesture, an anticipatory gesture is coupled with other gestures in a coupling graph according to

the phases of its planning oscillator. An anticipatory gesture that activates early relative to its position in a word has not been repositioned within the coupling graph; it has dissociated the time point at which it actually activates from the oscillatory phase at which a typical gesture would activate. Unless an anticipatory gesture is also persistent (non-self-deactivating), the time point of its deactivation is not altered by being anticipatory.

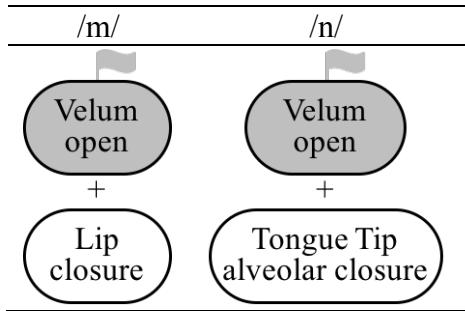
This is illustrated by the coupling graph for the Capanahua form [h̄amawu] ‘step on it’ in (38). While the anticipatory velum opening gesture is word-medial in this coupling graph, in the resulting gestural score in (35) this velum opening gesture extends to activate at the beginning of the word.

(38) Coupling graph for Capanahua [h̄amawu] ‘step on it’



The presence of regressive nasal harmony in Capanahua can be attributed to the fact that the velum opening gesture in its surface phonological inventory is one that is early-activating. The nasal consonant inventory of Capanahua, then, is posited to contain harmony-triggering /m/ and /n/, as in (39).

(39) Gestural representation of Capanahua nasal consonant inventory



With the above inventory, whenever a nasal consonant occurs in a coupling graph in Capanahua, it will be accompanied by an anticipatory (early-activating) velum opening gesture. As a result, these segments will trigger regressive nasal harmony. There are also cases in which nasal harmony in Capanahua is bidirectional, suggesting that the velum opening gesture in this language can surface as simultaneously persistent and anticipatory; such cases will be discussed in section 3.4.3.

2.2.3 *Tongue Root Harmony in Nandi*

Kyrgyz rounding harmony (section 2.2.1) and Capanahua nasal harmony (section 2.2.2) illustrate cases of unidirectional harmony. Progressive harmony in Kyrgyz is triggered by a lip protrusion gesture that surfaces as persistent (non-self-deactivating) but not anticipatory (early-activating). Conversely, regressive harmony in Capanahua is triggered by a velum opening gesture that surfaces as anticipatory but not persistent (though see section 3.4.3 for further discussion). However, it is also possible for a gesture to surface as both persistent and anticipatory and to therefore trigger bidirectional harmony. Such a case is illustrated in this section with an examination of tongue root harmony in Nandi.

Vowel harmonies based upon tongue root position are common throughout the Tungusic languages of Siberia and China as well as the Niger-Congo and Nilo-Saharan languages of Africa. In these languages, vowels can be divided into two sets depending on whether they are

produced with an advanced tongue root (ATR) or not. This is the case in Nandi, a variety of Kalenjin (Southern Nilotic; Kenya), which according to Creider & Creider (1989) has the vowel inventory in (40). (Vowels also contrast for length.)

(40) Nandi (Kalenjin) vowel inventory

	ATR		non-ATR	
	Front	Back	Front	Back
High	i i:	u u:	ɪ ɪ:	ʊ ʊ:
Mid	e e:	o o:	ɛ ɛ:	ɔ ɔ:
Low		a a:		a a:

In Nandi, all vowels in a word must be either ATR or non-ATR. Nandi tongue root harmony is an example of dominant-recessive ATR harmony; if an underlyingly ATR vowel occurs anywhere in a word, either in a root or an affix, all other vowels surface as ATR as well. This is illustrated by the data in (41)-(43). Nandi noun roots may be followed by one or more thematic and number suffixes, many of which agree with roots for tongue root position. The ATR alternant of a suffix appears after an ATR root (41a-e), while a non-ATR suffix appears after a non-ATR root (41f-j). Data are from Creider & Creider (1989); roots are underlined.

- (41) a. [su:me-e:k] ‘hair’ f. [mo:sar-ɛ:k] ‘porridge’
 b. [o:rka:j-ja:t] ‘prophet’ g. [lɔkɔ:ja:t] ‘fruit’
 c. [amt-it] ‘food’ h. [ka:t-it] ‘neck’
 d. [ter-e:nik] ‘pots’ i. [cɛ:rɛ:r-ɛ:nik] ‘babies, monkeys’
 e. [kirk-it] ‘bull’ j. [ki:rt] ‘thing’

ATR harmony in Nandi may also be bidirectional, targeting both prefixes and suffixes, as in (42a-c).

- (42) a. [ka-ke:r-a:t] ‘see (past amb.)’ d. [ka-kas-a:t] ‘hear (past amb.)’
 b. [ka:-pu:k-et] ‘sweeping’ e. [ka:-pu:s-et] ‘breath’
 c. [ka-ke:r-e:] ‘see (past instr.)’ f. [ka-pal-e:] ‘dig (past instr.)’

Evidence that this harmony system is dominant-recessive rather than root-controlled comes from forms in which affixes cause roots to alternate in terms of tongue root position. In

the data in (43), alternating roots and affixes are ATR when they occur with ATR affixes (43a-f), and are RTR when they do not occur with such affixes (43g-l). This is true across the verbal, nominal, and adjectival morphology.

- | | |
|---|-------------------------------------|
| (43) a. [ki:-la:l-ej] ‘cough (imperf.)’ | g. [kɪ:-lə:l] ‘cough (perf.)’ |
| b. [ke:-pal-ci] ‘to dig (dat.)’ | h. [kɛ:-pəl-ɛ:] ‘to dig (instr.)’ |
| c. [<u>intar-o:k</u>] ‘snakes’ | i. [<u>intar-a</u>] ‘snake’ |
| d. [kwe:s-wek] ‘billy-goats’ | j. [<u>kwes-ta</u>] ‘billy-goats’ |
| e. [<u>mo:-o:k</u>] ‘wounds’ | k. [<u>mɔ:-ɛ:t</u>] ‘wound’ |
| f. [<u>tu:-in</u>] ‘blackness’ | l. [<u>tu:j</u>] ‘black’ |

Finally, it is also possible for bidirectional harmony to be triggered by a prefix. Compare, for example, [ka-ki-kas] ‘hear (past 1p),’ in which the fixed-ATR prefix [-ki-] triggers ATR harmony, and [ka-kas] ‘hear (past 3p).’

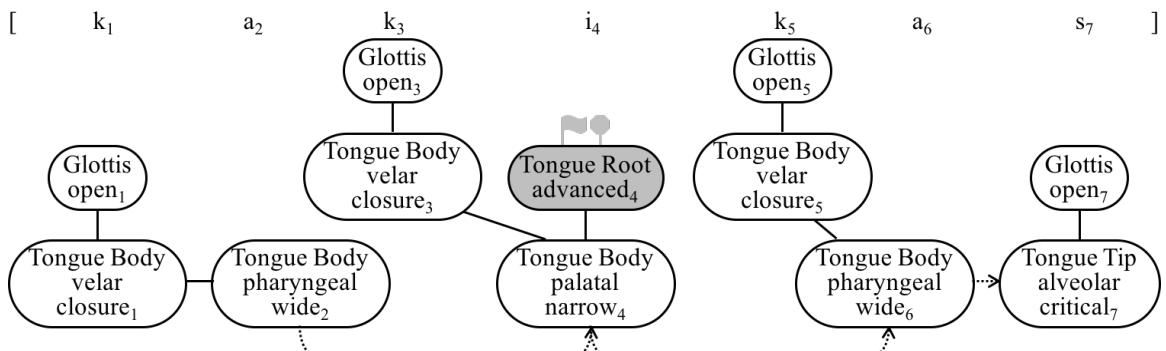
Within gestural phonology, the two sets of ATR and non-ATR vowels in Nandi can be divided based upon whether or not they are produced concurrently with a tongue root advancement gesture. ATR vowels are accompanied by a tongue root advancement gesture, while non-ATR vowels are not. During the production of non-ATR vowels, the tongue root assumes its neutral position considerably farther back in the pharynx. The fact that Nandi exhibits bidirectional tongue root harmony can be attributed to a tongue root advancement gesture that is both persistent (non-self-deactivating) and anticipatory (early-activating) and that accompanies all ATR vowels in its inventory. The full surface inventory of Nandi vowels is illustrated in (44).

(44) Gestural representation of Nandi vowel inventory

/i/	/e/	/a/	/o/	/u/
Tongue Root advanced	Tongue Root advanced	Tongue Root advanced	Tongue Root advanced	Tongue Root advanced
+ Tongue Body palatal narrow	+ Tongue Body palatal mid	+ Tongue Body pharyngeal wide	+ Lip protrusion	+ Tongue Body uvular-pharyngeal narrow
				+ Tongue Body uvular narrow
/ɪ/	/ɛ/	/ɑ/	/ɔ/	/ʊ/
Tongue Body palatal narrow	Tongue Body palatal mid	Tongue Body pharyngeal wide	Lip protrusion	Lip protrusion
			+ Tongue Body uvular-pharyngeal narrow	+ Tongue Body uvular narrow

When an ATR vowel from this vowel inventory appears in an output coupling graph, it serves as a trigger of bidirectional tongue root harmony. An illustration of this bidirectional harmony is provided for the word [ka-ki-kas] ‘hear (past 1p).’ The prefix [-ki-] contains an underlyingly ATR vowel, and thus all vowels in the word surface as ATR.

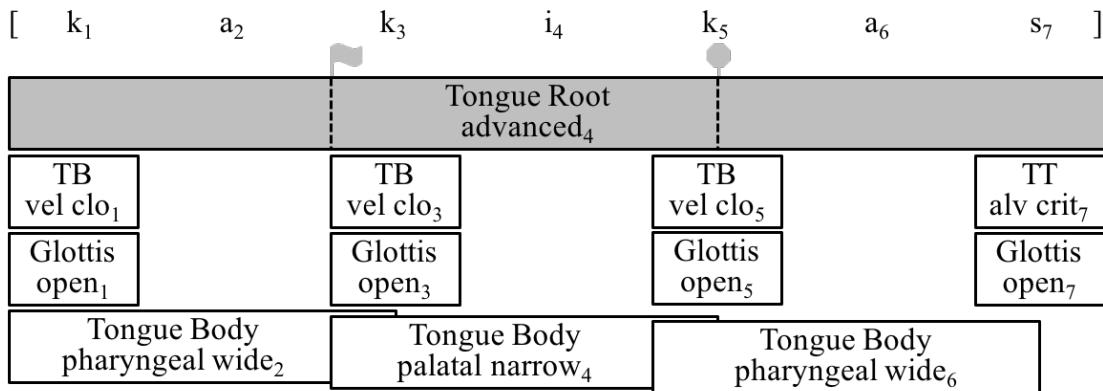
(45) Coupling graph for [ka-ki-kas] ‘hear (past 1p)’



In the coupling graph in (45), the tongue root advancement gesture is in word-medial position. However, due to this gesture’s being both persistent (non-self-deactivating) and

anticipatory (early-activating), its activation will extend throughout the entire word. This is illustrated in the gestural score in (46), which is calculated by the Coupled Oscillator Model from the coupling graph in (45). The dashed lines within the tongue root gesture indicate the gesture's 0° phase, i.e. the starting phase for a typical self-activating gesture, as well as the point at which the gesture reaches its target articulatory state, i.e., the point at which a typical gesture would self-deactivate.

(46) Gestural score for [ka-ki-kas] ‘hear (past 1p)’



In (46), all vocalic and consonantal gestures are overlapped by the harmonizing tongue root advancement gesture. This results in all vowels in the word surfacing as ATR. In addition, the strictly local representation of harmony within the Gestural Harmony Model results in the treatment of consonants as undergoers of ATR harmony. Work by Lodge (1995) and Local & Lodge (2004) on the status of Kalenjin consonants under the influence of tongue root harmony supports this. They find a number of differences in the articulations of consonants in ATR versus non-ATR words, particularly in terms of duration and degree of intervocalic lenition. This provides support for the status of consonants as undergoers of vowel harmony in Nandi, rather than as skipped segments.

2.3 Properties of Harmony Triggers

Section 2.2 introduced gestural persistence (non-self-deactivation) and anticipation (early activation) as a means of representing the ability of a gesture to trigger harmony. This was illustrated with examples of rounding harmony via a persistent lip protrusion gesture, nasal harmony via an anticipatory velum opening gesture, and tongue root harmony via a persistent and anticipatory tongue root advancement gesture. In all of these cases, the harmonizing gesture overlaps and affects consonantal and vocalic gestures alike.

However, this is not an exhaustive list of the attested types of harmony. Local harmonies based on vowel height and backness, tongue dorsum and/or root retraction, and tone are also attested, and thus the gestures associated with each of these properties may presumably be persistent and/or anticipatory in some languages. Many other gestures, meanwhile, are not attested triggers of local harmony. This section addresses why some types of gestures surface as persistent or anticipatory, and which types of gestures can be triggers of harmony.

A great deal of work has focused on the idea that harmony is perceptually driven. Kaun (1995, 2004), Flemming (1995), Walker (2005, 2011), and Kimper (2011), among others, argue that harmony is driven by the desire to maximize the temporal extent of a perceptually vulnerable feature, thus enhancing the contrast between its presence versus its absence. This temporal maximization increases a listener's exposure to this feature and therefore increases the odds that a listener will correctly perceive it. The maximization of a gesture's period of activation is achieved in the Gestural Harmony Model via the gestural parameters of persistence and anticipation. By surfacing as either persistent or anticipatory (or both), it is ensured that a gesture will remain active for as long as possible within a word. According to this view, then, a gesture is predicted to be more likely to trigger harmony if it is perceptually disadvantaged in some way. In at least some languages, this perceptual disadvantage will motivate a gesture's

surfacing as persistent and/or anticipatory. How this is implemented within the phonological grammar is the subject of chapter 3.

It is important not just to determine which gestures are most strongly motivated to trigger harmony but also which gestures are able to trigger harmony. If the extension of a harmonizing property is a means of perceptual enhancement, then any gesture should be predicted to benefit from being a trigger of harmony. While some gestures are at more of a perceptual disadvantage than others, a perceptually enhanced gesture of any kind will always be preferred over its unenhanced counterpart. By this logic, any gesture should be attested as a trigger of harmony in some language. However, this is not the case; local harmonies triggered by primary consonantal gestures and glottal gestures, for instance, are apparently unattested.¹¹ Recall from section 1.2.1 that primary consonantal gestures are those that are specified for either full closure of the vocal tract or for constrictions that are narrow enough to result in turbulent airflow. It is necessary to rule out the possibility of such gestures surfacing as persistent and/or anticipatory and therefore serving as triggers of harmony.

The strictly local nature of harmony in the Gestural Harmony Model has important consequences for which types of gestures are predicted to be able to surface as triggers. A consonantal gesture cannot extend to overlap a vocalic gesture without significantly disrupting the acoustic transmission of that vocalic gesture. If an alveolar tongue tip closure gesture of a consonant such as /d/ were persistent or anticipatory, its overlap with any other gestures would result in a closed vocal tract with a completely silent acoustic output. Under this scenario, this

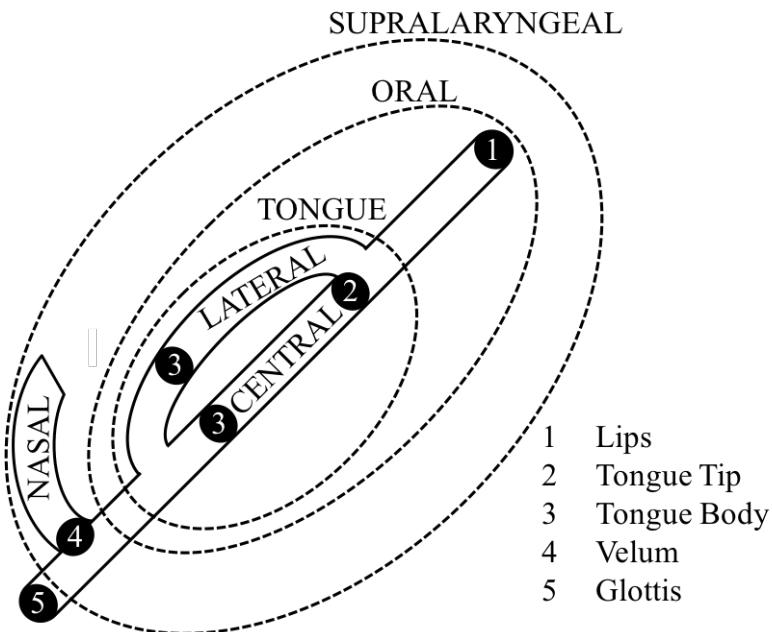
¹¹ While glottal gestures do not trigger local harmony, consonant harmony based on voicing, aspiration, and glottalization are attested (see Hansson (2001/2010), Rose & Walker (2004, 2011), and Gallagher (2010) for discussion). However, such cases are usually analyzed as cases of non-local agreement or assimilation rather than local spreading of a harmonizing property. I adopt the assumption that such apparently non-local harmony is due to a phonological mechanism that is distinct from the mechanism responsible for local harmony.

period of silence could potentially span multiple syllables and even an entire word. Obviously, such a form is problematic for a number of reasons, chief among them that a word composed entirely of a span of silence is unable to transmit any information about phonological contrast and therefore has no communicative function.

This line of reasoning is promoted by Gafos (1996/1999) and Ní Chiosáin & Padgett (1997) for explaining the asymmetry between consonants and vowels in their ability to trigger local harmony. This asymmetry can be understood in terms of what Ní Chiosáin & Padgett call the ‘bottleneck effect,’ the idea that a segment’s stricture is equal to its most constricted component. According to this idea, features such as those for rounding, nasality, and vocalic place are predicted to be able to spread onto a consonant without affecting its stricture or its identity as a consonant. However, if consonantal place or stricture features were to spread onto a vowel, the resulting segment would no longer be a vowel but rather some kind of segment specified for full closure of the vocal tract. Gafos (1996/1999) and Ní Chiosáin & Padgett (1997) maintain that such a scenario must be universally ruled out.

The asymmetrical triggering ability of consonantal and vocalic gestures can also be understood in terms of ‘tube geometry,’ a more elaborate model of vocal tract stricture within gestural phonology proposed by Browman & Goldstein (1989). According to this model, the vocal tract is abstractly represented as a series of tubes and articulators that are either parallel to or in sequence with one another. Each gesture is specified for a target articulatory state defined within one of these tubes, and at any given time each tube has its own constriction degree that is the result of any constrictions caused by active gestures. This abstract representation of the vocal tract is shown in (47).

- (47) Tube geometric representation of the vocal tract (adapted from Browman & Goldstein (1989, p. 236)



In (47), the vocal tract branches into several tubes that run parallel to one another. Each of the numbered black discs represents an articulator either within or at the terminus of a tube. These articulators can create constrictions that determine a tube's constriction degree. There are three main tubes represented here: the Central, Lateral, and Nasal tubes. In addition, tubes and articulators may be grouped together to form compound tubes. The Central and Lateral tubes run parallel to one another, and together with the tongue tip and tongue body articulators make up the Tongue tube. The Tongue tube runs in sequence with the Lips articulator, and together they make up the Oral tube. The Nasal tube, which includes the velum articulator, runs in parallel with the Oral tube; these tubes combine to form the Supralaryngeal tube. The Supralaryngeal tube is in sequence with the Glottis articulator.

When two elements combine, the constriction degree of the compound tube is determined by the constriction degree of each of its composite tubes or terminal articulators. When a compound tube is made up of two elements in parallel, that compound tube takes on the wider of

the two constriction degrees. For instance, if the Nasal tube is open while the Oral tube is closed, the constriction degree of the Supralaryngeal tube will be open. However, if a compound tube is made up of two elements in a sequence, the compound tube takes on the narrower of the two constriction degrees, consistent with Ní Chiosáin & Padgett's bottleneck effect. For instance, if the Tongue tube is open but the Lips articulator is closed, then the constriction degree of the Oral tube is closed. By these principles, the constriction degree of the entire vocal tract at any given time can be determined by the constriction degrees in each of the individual tubes. Browman & Goldstein (1989) refer to this as percolation. The overall constriction degree of the vocal tract takes on one of three values at any given time: open, closed, or critical (a constriction narrow enough to produce turbulent noise). When multiple gestures are active at the same time, they will each affect the overall constriction degree of the vocal tract according to the principles of tube combination and percolation.

This principle of percolation within the tube geometry framework can be used to set a baseline for determining whether or not a gesture may surface as persistent and/or anticipatory and therefore whether it may trigger harmony. I propose that a gesture in a surface form may only be persistent or anticipatory if it is able to overlap other gestures without (1) increasing the constriction degree of the vocal tract to either closed or critical and/or (2) producing turbulent noise. These conditions are met when a supralaryngeal gesture contributes an open constriction degree to a tube. Gestures for lip protrusion and tongue root position each contribute an open constriction degree, and may therefore overlap both consonantal and vocalic gestures without affecting the constriction degree of the Oral and Supralaryngeal tubes. Therefore, these gestures may be persistent and/or anticipatory. A velum opening gesture will always result in an open Nasal tube and Supralaryngeal tube, no matter the constriction degree of the Oral tube. A velum

opening gesture is only able to decrease the constriction degree of the vocal tract, no matter what it overlaps, and therefore it may extend its period of activation via persistence or anticipation.

On the other hand, the closure gesture of an oral consonant results in full closure in the Oral tube via percolation from a closure in either the Central tube or at the Lips articulator. If this consonantal closure gesture were to overlap a vocalic gesture, which is specified for an open constriction in the Central tube, the result would be a closed constriction degree for the Central, Oral, and Supralaryngeal tubes, and therefore for the entire vocal tract. In the case in which a consonantal and a vocalic gesture are concurrently active, it is the consonantal gesture that determines the constriction degree of the vocal tract. This scenario indicates the asymmetry between the effects that consonants and vowels can have on each other's constriction degrees. A vocalic gesture is permitted to surface as persistent or anticipatory because it does not affect the constriction degree of a concurrently active consonantal gesture. However, a consonantal gesture that involves full closure or a critical constriction degree that causes turbulent airflow must always surface as self-deactivating and self-activating because its overlap with other gestures increases the constriction degree of the vocal tract.

In addition to oral consonantal gestures, glottal gestures are also ruled out as possible triggers of local harmony. The glottis is in sequence with the Supralaryngeal tube; therefore, closure at the glottis results in closure of the vocal tract via percolation. Glottal spreading gestures that are responsible for voicelessness and/or aspiration are also ruled out as possible triggers of local harmony, as they result in turbulent noise.

Based on the principles of the bottleneck effect and tube geometry, it is possible to rule out glottal gestures and oral consonantal gestures as possible triggers of harmony. I assume that persistent and/or anticipatory consonantal gestures and glottal gestures are universally banned

from the set of forms that the phonological grammar can produce. In an OT grammar, this is akin to stating that GEN does not produce candidate forms that include persistent or anticipatory consonantal and glottal gestures. Other types of gestures may surface with either setting of the persistence and anticipation parameters based on the ranking of constraints that make reference to these parameters. This is the subject of chapter 3.

Alternatively, it may be possible to explain the asymmetry between gestures that may or may not serve as triggers of harmony by appealing to the split gesture hypothesis (Nam 2007). Nam proposes that each consonantal constriction should be represented by two gestures, one for the closure and one for the release of that closure. The effect of this release gesture is a rapid and controlled movement of an articulator away from the closure gesture's target articulatory state and toward the articulator's neutral default state. The representation of a split consonantal gesture is provided in (48).

(48) Closure and release gestures



Nam provides evidence from patterns of coordination between an onset consonant and a following vowel as well as relative speech planning times across the production of different syllable shapes to support the split gesture representation of consonantal constrictions. Based on his findings, he proposes that release gestures are unique to the representation of consonants, and that all consonants should be represented by a closure-release sequence of gestures. Vocalic gestures are assumed not to be accompanied by such release gestures; instead, when a vocalic gesture deactivates, the articulators involved in the attainment of that gesture's target articulatory state return to their default positions gradually. In the Gestural Harmony Model, the inability of a

consonantal gesture to extend its period of activation and trigger harmony could be attributed to its always being accompanied by a following release gesture. Even if a consonantal closure gesture were to surface as persistent (non-self-deactivating), the following release gesture would deactivate the closure gesture upon the attainment of the gesture's target articulatory state.

While appealing to an independently motivated aspect of gestural representation such as the split consonantal gesture in order to capture the asymmetry between triggering and non-triggering gestures is appealing, there are issues with this approach. Chief among these is a lack of clarity as to how to use split gesture representations to prevent consonantal gestures from surfacing as anticipatory and triggering regressive (leftward) harmony. At present, there is no equivalent of a release gesture that immediately precedes a consonantal gesture and prevents it from activating early. Without such a gesture, there does not appear to be any way to prevent a consonantal gesture from triggering regressive harmony based solely on the split gesture hypothesis. On the other hand, appealing to tube geometry and the bottleneck effect comes with no such directional asymmetry. Gestures are ruled out as potential triggers of harmony based on their aerodynamic and acoustic effects on the vocal tract, and these effects hold whether a gesture extends its activation regressively (leftward) or progressively (rightward).

In addition, it is unclear what predictions the split gesture hypothesis makes regarding the ability of glottal gestures to act as triggers of local harmony. Glottal gestures often surface as secondary gestures that are responsible for the voicelessness or glottalization of an oral consonantal segment. The split gesture, on the other hand, appears to be exclusive to the representation of primary consonantal gestures. Without accompanying release gestures, these glottal gestures would not be ruled out as possible triggers of local harmony. This result is undesirable. By appealing to tube geometry, however, glottal gestures are ruled out as possible

triggers of local harmony due to their aerodynamic and acoustic effects. An active glottal closure gesture produces closure of the entire vocal tract, while an active glottal spreading gesture results in turbulent noise. This renders both of these types of gestures unable to surface as persistent or as anticipatory according to the conditions on triggers proposed in this section. Thus, appealing to tube geometry correctly predicts that glottal gestures are not triggers of any local harmony processes. However, despite these issues, the split gesture hypothesis offers an intriguing explanation of the asymmetry in harmony triggering ability between consonantal and vocalic gestures. Examination of the predictions made by appealing to split consonantal gestures is a subject worthy of further study.

2.4 Summary

This chapter has introduced the basic representation of harmony within the Gestural Harmony Model as overlap by a gesture with extended activation. The ability of a gesture to surface with this extended activation is the result of two new gestural parameters that are central to the operation of the Gestural Harmony Model. One of these parameters, persistence, determines whether a gesture self-deactivates upon the achievement of its target articulatory state, or whether it is a persistent gesture that remains active and triggers progressive harmony. The other gestural parameter, anticipation, determines whether a gesture activates at the 0° phase of its planning oscillator, or whether it activates before this phase and triggers regressive harmony. Both of these parameters necessitate a new mechanism that operates within the Coupled Oscillator Model. This mechanism calculates the activation and de-activation time points of anticipatory and persistent gestures, respectively.

As a direct consequence of appealing to the gestural parameters of persistence and anticipation in the Gestural Harmony Model, a segment's status as a trigger of harmony is

directly encoded in its gestural representation. If a gesture is persistent, it will trigger progressive harmony; if it is anticipatory, it will trigger regressive harmony. Under this approach, whether a language exhibits harmony is a property of its surface phonological inventory and whether it contains segments that include either persistent or anticipatory gestures. Accounting for patterns of harmony triggering in the Gestural Harmony Model, then, involves developing a phonological grammar that shapes a language's inventory and places restrictions on the distributions of the members of that inventory. This is the subject of chapter 3.

Chapter 3

Patterns of Harmony Triggering

3.1 Introduction

As discussed in chapter 2, the presence of harmony in Kyrgyz, Nandi, and Capanahua is attributed in the Gestural Harmony Model to the idea that these languages include either persistent (non-self-deactivating gestures) or anticipatory (early-activating) gestures in their respective surface phonological inventories. This approach to harmony as arising from a property of a trigger provides an interesting contrast with previous analyses of harmony processes within feature-based phonological frameworks. In featural analyses, harmony is often analyzed as being driven by a rule or constraint that requires the addition of association lines between features and segments. Under this approach, the imperative to spread a feature value comes directly from the grammar rather than resulting automatically from a property of the trigger itself. In contrast, the Gestural Harmony Model relies on the gestural parameters of persistence and anticipation to account for a gesture's ability to extend its period of activation and trigger harmony either regressively or progressively.

In the harmony systems presented in chapter 2, the patterns of harmony triggering are uncomplicated; any segment bearing a harmonizing property serves as a trigger of harmony. In Kyrgyz, lip protrusion gestures always surface as persistent, and as a result round vowels in this language always trigger progressive (rightward) rounding harmony. In Nandi, any ATR vowel will trigger bidirectional ATR harmony due to the inclusion in its gestural makeup of a tongue root advancement gesture that is both persistent and anticipatory. In Capanahua, the nasal stops in its inventory include anticipatory velum opening gestures, rendering them triggers of

regressive (leftward) nasal harmony. In each of these languages, the ability of all segments of a certain type to trigger harmony is the result of the language's surface inventory containing only a persistent and/or anticipatory gesture of a certain type.

However, there are many harmony systems with more complicated patterns of harmony triggering, and a successful model of harmony must be able to account for several sources of these complications. For instance, many languages restrict harmony triggers to certain prominent positions in a word, such as the initial syllable or the stressed syllable. Other languages place conditions on the identities of triggers; in particular, they tend to favor triggering by segments that are perceptually disadvantaged in some way. In addition, some harmony systems involve the idiosyncratic triggering of harmony. While these more complicated patterns of harmony triggering bring up issues with many feature-based analyses of harmony, the Gestural Harmony Model is able to successfully account for all of these complications. In this model, patterns of harmony triggering arise directly from the shape of a language's surface phonological inventory, and the distributional restrictions the phonological grammar places on the members of that inventory.

The Gestural Harmony Model must account for systems in which restrictions are placed on the triggers of harmony, in terms of both the position of these triggers within a word and the quality of the triggering segments. In this model, harmony is triggered by the presence of either a persistent or an anticipatory gesture in an output phonological form. Because of this, it is straightforward for the Gestural Harmony Model to capture attested, often seemingly complex patterns of harmony triggering via co-occurrence constraints that require certain segment types to be accompanied by gestures of a certain type (typical, persistent, or anticipatory), or licensing constraints that require these gestural types to appear in certain positions in a word.

The Gestural Harmony Model must also be able to account for cases of idiosyncratic triggering of harmony, in which some forms exhibit harmony while others do not. There are numerous examples of harmony systems in which some words idiosyncratically exhibit harmony while others do not. Such patterns are attested in the nasal harmony systems of several Malayo-Polynesian languages, as well as various tongue root harmony systems. As demonstrated in section 2.2, in the Gestural Harmony Model the ability of a gesture to trigger harmony is the result of a specified gestural parameter (persistence in the case of progressive harmony, and anticipation in the case of regressive harmony). These parameter settings serve a contrastive function in some languages, and the result of such contrast is the idiosyncratic triggering of harmony.

This approach to harmony triggering, in which the Gestural Harmony Model relies on a parameter of a phonological unit to drive harmony, can be contrasted with feature-based analyses of harmony that do not have access to such parameters and instead rely on rules or constraints that explicitly drive harmony. While such analyses are able to account for harmony systems that place conditions on harmony triggers, they do not perform as well in accounting for patterns of idiosyncratic or contrastive triggering, often over- and/or undergenerating attested patterns. Instead of relying on a contrastive property, such as persistence versus self-deactivation, to account for such patterns, featural analyses of harmony triggering typically rely on theoretical mechanisms designed for dealing with phonological exceptionality. Such mechanisms produce several undesirable typological predictions that are avoided by the Gestural Harmony Model and its reliance on gestural parameter settings, rather than grammatical rules or constraints, to drive harmony.

The chapter is organized as follows. Section 3.2 discusses the constraint set that is used to drive harmony via the shaping of a language’s surface inventory to either include or exclude harmony-triggering persistent or anticipatory gestures. The following sections present typological patterns of harmony triggering and present analyses of systems in which harmony triggering is contrastive, as in the nasal harmonies of Acehnese and Rejang (section 3.3) and systems in which conditions are imposed on the triggers of harmony, as in Baiyina Oroqen rounding harmony (section 3.4.2). Section 3.5 demonstrates the ability of the Gestural Harmony Model to produce even quite complex patterns of harmony triggering by examining the case of Classical Manchu, which exhibits both conditional and contrastive triggering of tongue root harmony. Section 3.6 examines some of the issues that beset feature-based analyses of complex harmony-triggering patterns. The strengths of the Gestural Harmony Model in accounting for patterns of harmony triggering are summarized in section 3.7. An appendix with the definitions of all of the constraints used throughout is included at the end of the chapter.

3.2 Harmony Triggers: Inventory Shaping & Distributional Restrictions

Within the Gestural Harmony Model, harmony within a language is not driven directly by the grammar but by a property of a certain gesture in that language. When a persistent (non-self-deactivating) gesture occurs in a language’s surface phonological inventory, it will serve as a trigger of progressive harmony. Likewise, when an anticipatory (early-activating) gesture occurs in a language’s inventory, it will serve as a trigger of regressive harmony. It is necessary, then, for a phonological grammar to shape the surface inventory of a language with harmony such that it includes segments with persistent and/or anticipatory gestures. According to the principle of Richness of the Base (Prince & Smolensky 1993/2004), neither type of gesture may be excluded from the set of possible inputs in any language. It is up to the interaction of markedness and

faithfulness constraints to shape the surface inventories and distributional restrictions of languages such that their harmony-triggering patterns are accurately generated by the grammar. This inventory shaping is the subject of this section, with illustrations of the basic markedness and faithfulness constraints necessary to capture basic patterns of harmony triggering in the Gestural Harmony Model.

3.2.1 Revisiting Kyrgyz: Progressive Rounding Harmony

Recall that in Kyrgyz, all vowels harmonize for backness and rounding, and all round vowels are triggers of rounding harmony (Comrie 1981). In the Gestural Harmony Model, this is accounted for by positing a phonological inventory in which all round vowels are accompanied by persistent (non-self-deactivating) lip protrusion gestures, as in the inventory in (49), repeated from (32) in section 2.2.1.

(49) Gestural representation of Kyrgyz vowel inventory

/y/	/ø/	/u/	/o/
Lip protrusion	Lip protrusion	Lip protrusion	Lip protrusion
+	+	+	+
Tongue Body palatal narrow	Tongue Body palatal wide	Tongue Body uvular narrow	Tongue Body pharyngeal wide
/i/	/e/	/u/	/a/
Tongue Body palatal narrow	Tongue Body palatal wide	Tongue Body uvular narrow	Tongue Body pharyngeal wide

The grammar of a language like Kyrgyz, in which all round vowels include persistent lip protrusion gestures on the surface, must ensure that even an underlying self-deactivating lip protrusion gesture will surface as persistent. This can be achieved by ranking a markedness constraint that penalizes a self-deactivating lip protrusion gesture over a faithfulness constraint

that requires a gesture not to alter its specified deactivation parameter between the input and the output. This markedness constraint, PERSIST(Gest_X), is defined following the schema in (50).

- (50) PERSIST(Gest_X): Assign a violation mark to a gesture of type X that is self-deactivating.

Note that this constraint is satisfied whenever a gesture of type X surfaces as persistent (non-self-deactivating), regardless of whether or not it actually overlaps any following segments. PERSIST(Gest_X) evaluates only the setting of a gesture's deactivation parameter, and not whether that gesture's activation actually extends beyond the timepoint at which it achieves its target articulatory state.

In Kyrgyz, the constraint PERSIST(lip protrusion) penalizes a lip protrusion gesture that self-deactivates as soon as its target articulatory state (fully protruded lips) is achieved. As discussed in section 2.3, this constraint's phonetic grounding is rooted in the claims made by Kaun (1995, 2004), Flemming (1995), Walker (2005, 2011), Kimper (2011), and others that temporally extending a feature or a gesture is perceptually advantageous. The non-self-deactivating nature of a persistent gesture, enforced by PERSIST(Gest_X), ensures that a gesture will remain active for as long as possible, deactivating only when it reaches the end of a domain or a blocking segment (discussed in detail in chapter 4). In doing so, that gesture's chance of being perceived correctly increases relative to that of its self-deactivating counterpart.

One crucial distinction in the analysis of harmony within the Gestural Harmony Model versus those within many featural frameworks lies in how the phonological grammar penalizes harmony. Many featural analyses of harmony rely on the ranking of a harmony driver over a faithfulness constraint such as IDENT-IO that assigns violations for any changes in undergoers' specifications for a harmonizing feature. In contrast, in the Gestural Harmony Model the overlap of an undergoer segment by a harmonizing gesture does not incur any faithfulness violations. As

discussed in section 1.2.2, the Gestural Harmony Model assumes the faithfulness constraints $\text{IDENT}(\text{parameter}_X)\text{-IO}$ constraints, which penalize changes in a gesture's setting for parameter X, and $\text{DEP}(\text{gesture}_X)\text{-IO}$, which penalizes the addition of a gesture of type X to a segment. Neither of these types of constraints is violated by the undergoers of harmony. $\text{DEP}(\text{gesture}_X)\text{-IO}$ is not violated when a segment is overlapped by a harmonizing gesture, because being overlapped by a gesture does not mean that that gesture is considered to have joined that segment. $\text{IDENT}(\text{parameter}_X)\text{-IO}$, meanwhile, is also not violated by gestural overlap; while this overlap may alter how a segment is produced, it does not alter any parameters of the gestures of a segment.

I instead attribute the lack of harmony in a language to the constraint SELFDEACTIVATE . This constraint penalizes persistent gestures, thus preventing harmony from arising in a language. In contrast with constraints from the $\text{PERSIST}(\text{Gest}_X)$ family, each of which refers to a specific type of gesture, SELFDEACTIVATE penalizes persistent gestures of all types. This constraint is defined in (51).

(51) SELFDEACTIVATE : Assign a violation mark to a gesture that is not self-deactivating.

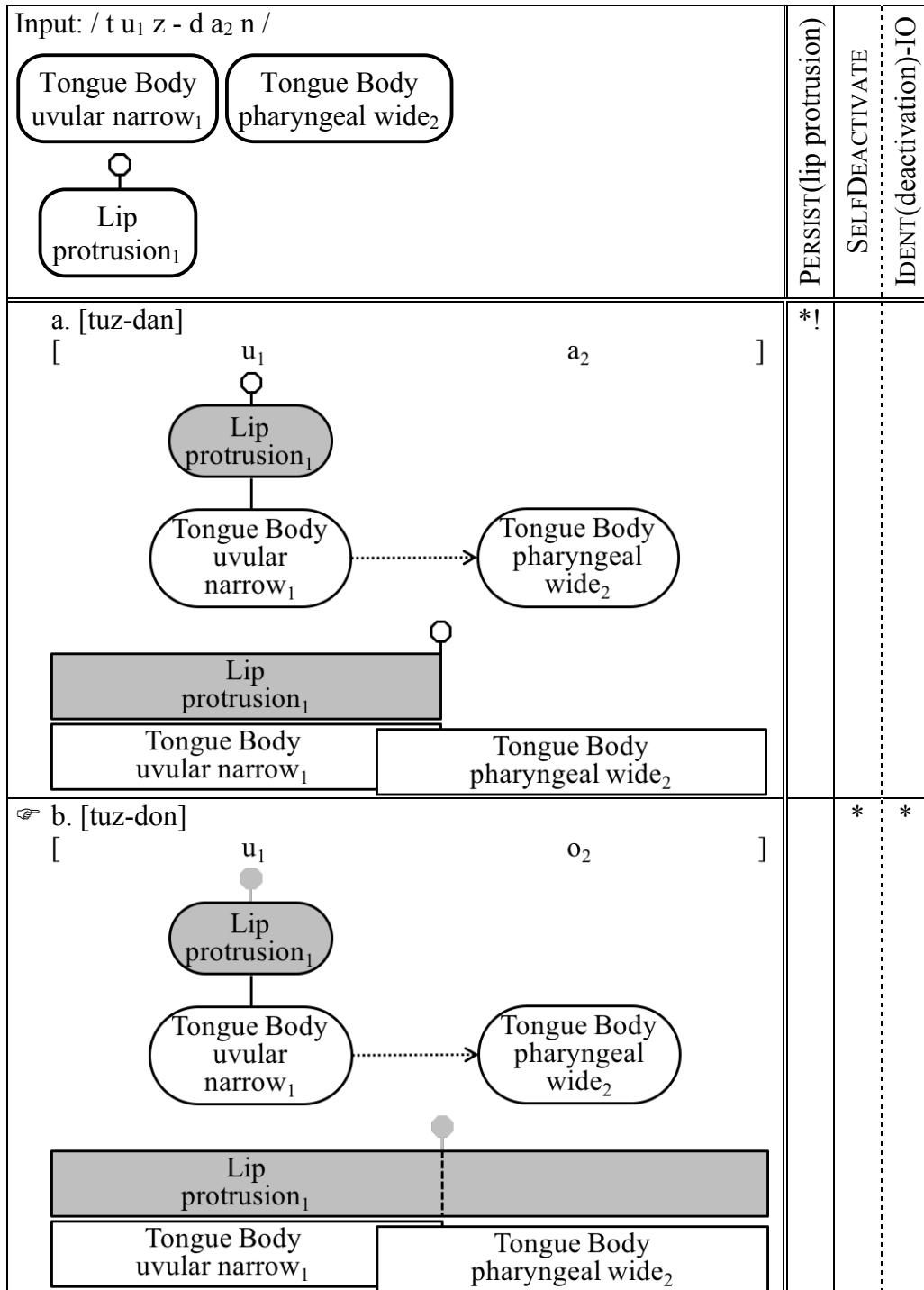
Both $\text{PERSIST}(\text{Gest}_X)$ and SELFDEACTIVATE , markedness constraints that each penalize a specific gestural parameter setting in the output form, potentially conflict with the faithfulness constraint $\text{IDENT}(\text{deactivation})\text{-IO}$, which preserves gestures' underlying deactivation parameter settings. It is defined in (52); note that it is defined with respect to the potential trigger of harmony, and not any potential undergoers.

- (52) IDENT(deactivation)-IO: Assign a violation mark to a gesture whose input and output correspondents do not have identical deactivation specifications.

The relative ranking of the constraints in (50)-(52) determines whether or not a language exhibits harmony of a certain type (e.g., rounding harmony). When SELFDEACTIVATE is ranked above IDENT(deactivation)-IO and PERSIST(lip protrusion), the result is a language with no rounding harmony, such as English, in which all lip protrusion gestures surface as typical self-deactivating gestures. When PERSIST(lip protrusion) is ranked above IDENT(deactivation)-IO and SELFDEACTIVATE, round vowels in that language will always trigger rounding harmony, whether they are underlyingly specified as persistent or self-deactivating. All possible input gestures will neutralize to the persistent type. This is the case in Kyrgyz, as the tableaux in (53) and (54) illustrate for the form [tuz-don] ‘salt (ablative).’

In order to illustrate the effect of a deactivation parameter setting on the ability of a gesture to extend its period of activation, these tableaux contain both the candidate forms’ coupling graphs and the gestural scores that are calculated by the Coupled Oscillator Model from those graphs. It is important to remember that while the temporal information in a gestural score is visible to the OT grammar assumed by the Gestural Harmony Model, this grammar still operates only on the material that is present in a coupling graph. For reasons of space and clarity, only the vowel gestures are included in the following tableaux; however, this should not be taken to mean that consonants are not undergoers of harmony, as discussed in section 2.2. Lip protrusion gestures in output candidates are shaded for emphasis.

- (53) Tableau for Kyrgyz [tuz-don] ‘salt (ablative)’ with underlying self-deactivating lip protrusion gesture



The input in (53) contains a typical self-deactivating lip protrusion gesture (indicated by the stop sign) accompanying the tongue body gesture of /u/. In output candidate (a) [tuz-dan] the

lip protrusion gesture is also self-deactivating; this satisfies IDENT(deactivation)-IO, which requires the deactivation specifications of a gesture to be identical between the input and the output. However, this violates higher-ranked PERSIST(lip protrusion), which penalizes the ability of a gesture to self-deactivate. The winning candidate (b) [tuz-don] contains a persistent lip protrusion gesture, violating IDENT(deactivation)-IO but satisfying higher-ranked PERSIST(lip protrusion). Note that in this candidate the representation of the second vowel is not altered, despite having undergone harmony. The persistent lip protrusion gesture overlaps that vocalic segment, but is not associated (i.e., coupled) with it. The lip protrusion gesture remains a part of the first vocalic segment (set of gestures), and has not in any way joined the second vocalic segment.

- (54) Tableau for Kyrgyz [tuz-don] ‘salt (ablative)’ with underlying persistent lip protrusion gesture

Input: / t ₁ u ₂ z ₃ - d ₄ a ₅ n ₆ /	Tongue Body uvular narrow ₁	Tongue Body pharyngeal wide ₂	Lip protrusion ₁	PERSIST(lip protrusion)	SELFDEACTIVATE	IDENT(deactivation)-IO
a. [tuz-dan]	[u ₁ Lip protrusion ₁ Tongue Body uvular narrow ₁] a ₂]	Tongue Body pharyngeal wide ₂		*!	*	
b. [tuz-don]	[u ₁ Lip protrusion ₁ Tongue Body uvular narrow ₁] o ₂]	Tongue Body pharyngeal wide ₂	Lip protrusion ₁ Tongue Body uvular narrow ₁ Tongue Body pharyngeal wide ₂		*	

The tableau in (54) uses the same candidate set as in (53), but here the input /u/ is accompanied by a persistent lip protrusion gesture (indicated by the grayed out stop sign).

Candidate (a) [tuz-dan] violates both PERSIST(lip protrusion) and IDENT(deactivation) by altering the deactivation parameter of the velum opening gesture from persistent to self-deactivating. Again, the winner is candidate (b) [tuz-don], in which the lip protrusion gesture is persistent in both the input and the output, thereby violating neither constraint.

One final point must be accounted for in this analysis: according to Comrie (1981), in all Kyrgyz words, the vowel of the first syllable determines whether all vowels in the word are round or unround.¹² It is impossible for a Kyrgyz word to contain disharmonic vowel sequences such as [o-a-a] or [a-o-o]. The first of these sequences, [o-a-a], is ruled out in the Gestural Harmony Model by representing the triggering (initial) [o] as containing a persistent lip protrusion gesture. However, the second of these sequences, [a-o-o], cannot be ruled out by the current constraint set alone. In the Gestural Harmony Model, such a form could be represented by a coupling graph and gestural score in which the vowel of the second syllable of a word contains a persistent lip protrusion gesture and therefore acts as a trigger of rounding harmony. Such forms must be ruled out in Kyrgyz and many other Altaic languages. It appears to be necessary not only to restrict the inventory of Kyrgyz such that all round vowels are harmony triggers, but to restrict the distributions of those round vowels as well.

In the Gestural Harmony Model, the distribution of round vowels in Kyrgyz can be accounted for by restricting lip protrusion gestures to the initial syllable of the word via a positional LICENSE constraint (section 1.2.2). This constraint is defined in (55).

¹² This vowel also determines whether all vowels in a word are front or back; this is set aside here, though see section 6.2.1 for a discussion of how to represent vowel height and backness, as well as harmonies involving these properties, in gestural phonology.

- (55) LICENSE(lip protrusion, first σ): Assign a violation mark to a lip protrusion gesture that is not in an initial syllable.

In Kyrgyz, the licensing constraint in (55) will ensure that round vowels are restricted to the privileged position of the initial syllable.¹³ When a lip protrusion gesture appears in a non-initial syllable in an input in Kyrgyz, the high ranking of LICENSE(lip protrusion, first σ) will ensure that this lip protrusion gesture is either reordered such that it is coupled to the tongue body gesture of the vowel in the initial syllable, or that it is deleted. In this analysis I assume the latter; any underlying lip protrusion gesture that is introduced by a vowel outside of the initial syllable will be deleted rather than moving to the initial syllable. This ensures that suffixes in Kyrgyz will never introduce their own rounding specifications to a word. In order to favor the deletion of an unlicensed lip protrusion gesture over its movement to the initial syllable, the constraint INTEGRITY-IO (section 1.2.2), which penalizes the splitting of gestures that make up a single segment between the input and the output, must be ranked over a constraint from the MAX(gesture)-IO family, which penalizes the deletion of gestures between the input and the output. This constraint is defined in (56).

- (56) MAX(lip protrusion)-IO: Assign a violation mark to a segment (set of gestures) that includes a lip protrusion gesture in the input if its output correspondent does not include that gesture.

The tableau in (57) demonstrates the result of this ranking for the Kyrgyz word [alma-dan] ‘apple (ablative)’ with a hypothetical input in which the vowel of the second syllable includes a lip protrusion gesture. All lip protrusion gestures in the output candidates are assumed to be persistent, satisfying PERSIST(lip protrusion). Again, for reasons of space, only the vowel

¹³ Walker (2011) notes that restricting round vowels to the initial syllable of a word can operate independent of a harmony process, citing the case of Ola Lamut, in which there is no active process of rounding harmony but there is an active restriction of round vowels to an initial syllable.

gestures of the word are included in the candidate coupling graphs and the gestural scores that are calculated from them.

- (57) Tableau for Kyrgyz [alma-dan] ‘apple (ablative)’ with hypothetical underlying lip protrusion gesture in non-initial syllable

Input: / a ₁ l m o ₂ - d a ₃ n /	LICENSE(LP, first σ)	INTEGRITY-IO	MAX(LP)-IO
a. [almo-don]	*!		
b. [olmo-don]	*!		
c. [alma-dan]	*		

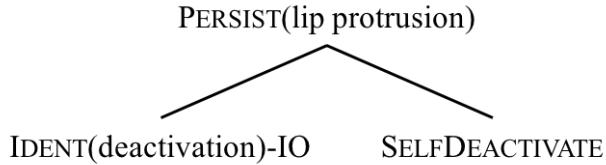
In (57), the hypothetical input /almo-dan/ includes a round vowel in the second syllable. In output candidate (a) [almo-don] the gestures of underlying $/o_2/$ are coupled to one another, satisfying INTEGRITY-IO in addition to MAX(lip protrusion)-IO. However, this candidate fatally violates higher-ranked LICENSE(lip protrusion, first σ), as the lip protrusion gesture of [o₂] is not in the first syllable of the word. Candidate (b) [olmo-don] eliminates this violation of LICENSE(lip protrusion, first σ) by coupling the lip protrusion gesture to the tongue body gesture of the vowel in the initial syllable. This segmental reassocation of the lip protrusion gesture earns a fatal violation of INTEGRITY-IO. In the winning candidate (c) [alma-dan] the lip protrusion gesture has been deleted, thereby vacuously satisfying LICENSE(lip protrusion, first σ) and INTEGRITY-IO but violating low-ranked MAX(lip protrusion)-IO.

This analysis accounts for the presence of harmony in Kyrgyz, as well as the restriction on the distribution of harmony-triggering round vowels to the initial syllable of a word. That the position of a gesture is determined by its position in the coupling graph accounts for the fact that non-initial round vowels may occur in a word provided that they are undergoers of harmony. These undergoer vowel segments surface as round because they are overlapped by the lip protrusion gesture of another vowel segment, and not because they include their own lip protrusion gestures. As the tableau in (57) shows, an underlying round vowel in a non-initial syllable will surface without its lip protrusion gesture. Such vowels may only surface as round when overlapped by the lip protrusion gesture of a triggering round vowel in an initial syllable.

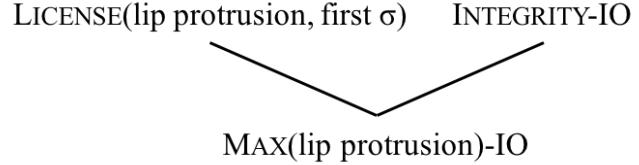
The constraint ranking necessary to capture the patterns of harmony triggering in Kyrgyz is summarized in the Hasse diagrams in (58).

(58) Constraint ranking for Kyrgyz rounding harmony

a. Triggering by round vowels



b. Contrastively round vowels only in first syllable



The relative ranking of the constraint types introduced in this section are able to account for additional patterns of harmony triggering via restrictions on which gestures may appear in a language's surface inventory, and on the positional distributions of the members of that inventory. One such additional pattern is exemplified by the ATR harmony of Nandi introduced in section 2.2.3. The following subsection revisits this harmony system and provides an analysis of its pattern of harmony triggering.

3.2.2 Revisiting Nandi: Dominant-Recessive Tongue Root Harmony

As discussed in section 2.2.3, Creider & Creider (1989) report that Nandi has a bidirectional dominant-recessive tongue root harmony system. If an underlyingly ATR vowel occurs anywhere in the word, the entire word takes on that ATR quality. Recall that in Nandi tongue root harmony is bidirectional, and may be triggered by ATR vowels in roots, prefixes, and suffixes. Compare, for example, [ka-ke:r-a:t] ‘see (past amb.),’ in which the ATR root vowel [e:] triggers harmony that affects the vowels of surrounding affixes, and [ka-kas-a:t] ‘hear (past amb.)’ As an example of harmony triggered by an affix, compare [ka-ki-kas] ‘hear (past 1p.)’ in which the underlyingly ATR /i/ of prefix [-ki-] triggers harmony, and [ka-kas] ‘hear (past 3p.)’

In the Gestural Harmony Model, the bidirectional ATR harmony seen in Nandi is attributed to the fact that the ATR vowels in the language's surface inventory all include tongue root advancement gestures that are both persistent and anticipatory. I attribute the surfacing of

each of these gestural parameter settings to two distinct sets of constraints. The set of constraints that reference gestural persistence and self-deactivation were already introduced in the analysis of Kyrgyz rounding harmony in section 3.2.1. The same basic constraint ranking of PERSIST(Gest_X), SELFDEACTIVATE, and IDENT(deactivation)-IO used to shape the Kyrgyz vowel inventory can be used to ensure that tongue root gestures in Nandi trigger progressive harmony. The relevant constraint for the progressive component of harmony is PERSIST(tongue root advancement), which penalizes self-deactivating tongue root advancement gestures. The constraint ranking in (59) ensures that an ATR vowel will always surface as persistent and will therefore trigger progressive ATR harmony in Nandi.

(59) Constraint ranking for progressive ATR harmony in Nandi

PERSIST(tongue root advancement) >> SELFDEACTIVATE, IDENT(deactivation)-IO

The grammar must also ensure that tongue root advancement gestures in Nandi always surface as anticipatory in order to account for the regressive (leftward) component of the ATR harmony system. In the Gestural Harmony Model, this is achieved by a set of constraints that is distinct from those responsible for progressive harmony. Paralleling the approach to progressive harmony triggering, regressive harmony can be achieved via the high ranking of a markedness constraint that penalizes a non-anticipatory tongue root advancement gesture over a faithfulness constraint that requires a gesture not to alter its activation parameter between the input and the output. This markedness constraint, ANTICIPATE(Gest_X), is defined following the schema in (60).

(60) ANTICIPATE(Gest_X): Assign a violation mark to a gesture of type X that is non-anticipatory.

Like PERSIST(Gest_X), the presence of ANTICIPATE(Gest_X) in the constraint set is rooted in the claim that temporally extending some properties is perceptually advantageous. Both

constraints motivate the extension of gestural activation, albeit in different directions. Also like PERSIST(GestX), ANTICIPATE(GestX) is satisfied not based on whether a gesture actually extends its period of activation, but instead on whether that gesture is specified for a certain setting of a gestural parameter.

As discussed in section 3.2.1, the overlap of an undergoer segment by a harmonizing gesture does not incur any violations of faithfulness. This is true of both progressive harmony via overlap by a persistent gesture, and regressive harmony via overlap by an anticipatory gesture. Therefore, another markedness constraint penalizing anticipatory gestures (and therefore regressive harmony) is necessary to account for languages without regressive harmony. This constraint, SELFACTIVATE, is defined in (61).

- (61) SELFACTIVATE: Assign a violation mark to a gesture that is anticipatory (a gesture that activates before its 0° phase).

The constraints ANTICIPATE(Gest_X) and SELFACTIVATE are potentially in conflict with the faithfulness constraint IDENT(activation)-IO, which preserves gestures' underlying activation parameter settings. It is defined in (62); again, note that this constraint is defined with respect to the potential trigger of regressive harmony, and not the potential undergoers of harmony.

- (62) IDENT(activation)-IO: Assign a violation mark to a gesture whose input and output correspondents do not have identical activation specifications.

The relative ranking of these constraints determines whether or not a language exhibits regressive harmony. When SELFACTIVATE is ranked above ANTICIPATE(Gest_X) and IDENT(activation)-IO, the result is a language with no harmony based on property X. However, when ANTICIPATE(Gest_X) is ranked above SELFACTIVATE and IDENT(anticipation)-IO, a gesture of type X will always trigger harmony for property X, whether they are underlyingly specified as anticipatory or self-activating.

The relevant constraints for the regressive component of ATR harmony in Nandi is ANTICIPATE(tongue root advancement), which penalizes self-activating tongue root advancement gestures. The constraint ranking in (63) ensures that an ATR vowel will always surface as anticipatory and will therefore trigger regressive ATR harmony in Nandi.

(63) Constraint ranking for regressive ATR harmony in Nandi

ANTICIPATE(tongue root advancement) >> SELFDEACTIVATE, IDENT(activation)-IO

The rankings in (59) and (63) are demonstrated in the tableau in (64) for the Nandi form [ka-ki-kas] ‘hear (past 1p),’ in which the vowel of the non-initial prefix [-ki-] contains the tongue root advancement gesture. In order to demonstrate that a tongue root gesture will always surface as both persistent (non-self-deactivating) and anticipatory (early-activating) in Nandi, a hypothetical input is included in which the tongue root gesture is self-deactivating and self-activating. For reasons of space and clarity, depictions of candidate forms in this tableau include only vocalic gestures, and only the gestural scores that are calculated from candidate forms’ coupling graphs.

(64) Tableau for Nandi [ka-ki-kas] ‘hear (past 1p)’

Input: / k a ₁ - k i ₂ - k a ₃ s /	Tongue Body pharyngeal wide ₁	Tongue Body palatal narrow ₂	Tongue Body pharyngeal wide ₃	Tongue Root advanced ₂	PERSIST(ATR)	SELFDEACTIVATE	IDENT(deactivation)-IO
a. [ka-ki-kas]	[a ₁]	i ₂	a ₃]	Tongue Root advanced ₂	*!		
b. [ka-ki-kas]	[a ₁]	i ₂	a ₃]	Tongue Root advanced ₂	*	*	
c. [ka-ki-kas]	[a ₁]	i ₂	a ₃]	Tongue Root advanced ₂	*!		
d. [ka-ki-kas]	[a ₁]	i ₂	a ₃]	Tongue Root advanced ₂	*	*	
							ANTICIPATE(ATR)
							SELFACTIVATE
							IDENT(activation)-IO

In (64), candidate (a) [ka-ki-kas] preserves the underlying activation and deactivation parameter settings of the tongue root advancement gesture of the medial [i]. In this candidate, neither regressive nor progressive harmony is triggered, fatally violating both PERSIST(ATR) and

ANTICIPATE(ATR). In candidate (b) [ka-ki-kas] the tongue root gesture surfaces as persistent but not anticipatory, triggering progressive but not regressive ATR harmony. This satisfies PERSIST(ATR) at the expense of lower-ranked SELFDEACTIVATE and IDENT(deactivation)-IO, but still incurs a fatal violation of high-ranked ANTICIPATE(ATR). In candidate (c) [ka-ki-kas] the tongue root gesture surfaces as anticipatory but not persistent, triggering regressive but not progressive ATR harmony. This satisfies ANTICIPATE(ATR) while violating lower-ranked SELFACTIVATE and IDENT(activation)-IO. However, it still fatally violates high-ranked PERSIST(ATR). The winning candidate (d) [ka-ki-kas], in which the tongue root gesture surfaces as both persistent and anticipatory and triggers bidirectional ATR harmony, satisfies both PERSIST(ATR) and ANTICIPATE(ATR).

While Nandi and many other languages exhibit bidirectional tongue root harmony due to the presence in their respective surface phonological inventories of tongue root gestures that are both persistent and anticipatory, it should be noted that the Gestural Harmony Model also predicts the existence of unidirectional harmony. As demonstrated in this section, bidirectional harmony in this model is actually the result of concurrently operating progressive and regressive harmony processes. The model relies on the distinct gestural parameter settings of persistence and anticipation, which are subject to different sets of constraints, to drive regressive and progressive harmony. Because the constraint rankings in (59) and (63) above do not interact with one another, it is possible within the Gestural Harmony Model to generate systems in which progressive and regressive harmony operate entirely independently from one another, or in which harmony operates in one direction and not another. For instance, purely regressive ATR would result if the constraints in (59) were reranked such that SELFDEACTIVATE outranked PERSIST(tongue root advancement) and IDENT(deactivation)-IO, resulting in a language's ATR

vowels surfacing with tongue root advancement gestures that were anticipatory but not persistent.

In this way, the Gestural Harmony Model mirrors featural approaches to harmony that rely on constraints that not only drive harmony but also specify the direction in which a feature should spread. These include constraints on featural alignment (Kirchner 1993; Akinlabi 1994; Cole & Kissoberth 1994, 1995; Pulleyblank 1996), which specify both the harmonizing feature and the edge of a domain to which that feature should be aligned (e.g., ALIGN(+F,R) for progressive harmony). Walker (1998/2000) also proposes directional versions of the constraint SPREAD(F), which drive spreading of a feature to segments preceding the trigger (SPREAD(F)-L) and following the trigger (SPREAD(F)-R). Similarly, the Gestural Harmony Model makes use of two distinct sets of constraints that determine the triggering of harmony: one for the surfacing of anticipatory gestures for regressive harmony, and one for the surfacing of persistent gestures for progressive harmony. By using distinct constraints or sets of constraints to account for progressive and regressive harmony, these theories are able to account for harmony systems in which harmony is unidirectional, or in which patterns of triggering of harmony differ between the two directions of a bidirectional harmony system.

There is some debate as to whether this ability to independently derive progressive and regressive harmony is a desirable aspect of a theory of harmony. Baković (2000) claims that the directionality of harmony need not be specified within the phonological grammar, because the directionality of tongue root harmony in a language is directly predictable from its morphological structure. According to this idea, harmony by default operates bidirectionally, and any appearance of unidirectionality is attributed to a lack of possible undergoers to one side of a trigger. For instance, an ATR harmony process that is triggered by root vowels and appears to be

purely regressive (leftward) can be attributed to the language's only having prefixes and not suffixes.

However, there are a number of harmony systems that call this proposal into question and point to the importance of the phonological grammar's ability to derive progressive and regressive harmony independently of one another. Tongue root harmony systems with regressive directionality that is unpredictable from morphological structure have been reported in Pulaar (Niger-Congo; Paradis (1986)), Assamese (Indo-Aryan; Mahanta (2007)), and Karajá (Macro-Jê; Brazil; Ribeiro (2002)). Unidirectional harmonies that are not derivable from morphological structure, both progressive and regressive, are also widely reported among nasal harmony systems (see Walker (1998/2000) for an overview). Therefore, the ability of the Gestural Harmony Model to independently derive progressive and regressive harmony from distinct gestural parameter settings is an asset, making it possible to account for both unidirectional and bidirectional harmony processes. This also allows the model to account for harmony systems in which the conditions placed on the triggers of progressive and regressive harmony are distinct. One example of such a system is Capanahua nasal harmony, discussed in section 3.4.3.

3.2.3 *Summary*

This section has demonstrated the Gestural Harmony Model's account of the presence versus absence of harmony in a language as a consequence of the phonological grammar shaping the surface inventory of a language such that it contains harmony-triggering gestures. As is typical in OT grammars, surface inventory shaping and the restriction of the distributions of harmony-triggering gestures in the Gestural Harmony Model is achieved via the relative ranking of markedness and faithfulness constraints. The relative ranking of the constraints PERSIST(Gest_X), SELFDEACTIVATE, and IDENT(deactivation)-IO determines whether a language's

phonological inventory contains persistent (non-self-deactivating) gestures and therefore whether or not that language exhibits progressive harmony. Similarly, the relative ranking of ANTICIPATE(Gest_X), SELFACTIVATE, and IDENT(activation)-IO determines whether a phonological inventory contains anticipatory (early-activating) gestures and therefore whether or not that language exhibits regressive harmony.

In addition, the relative ranking of the constraints LICENSE(Gest_X , prominent position), INTEGRITY-IO, and MAX(gesture)-IO determine the positional distributions of the gestures in a language's inventory. The rounding harmony system of Kyrgyz restricts a harmony-triggering gesture to the privileged position of the initial syllable, which is enforced via positional licensing. Analyzing triggering patterns as the result of both inventory shaping and distributional restrictions also proves useful when analyzing more complex patterns of harmony triggering. These include patterns in which the ability to trigger harmony is restricted to a certain class of segments, as well as patterns in which the ability to trigger harmony appears to be contrastive in a language. Such cases are the focus of sections 3.3 to 3.5.

3.3 Contrastive Triggering of Nasal Harmony in Acehnese and Rejang

Thus far the discussion of how harmony is driven in the Gestural Harmony Model has focused on cases in which constraints require a gesture of a certain type to surface as persistent and/or anticipatory. In the straightforward case of progressive rounding harmony in Kyrgyz, for instance, this constraint is PERSIST(Gest_X). When it outranks IDENT(deactivation)-IO and SELFDEACTIVATE, all bearers of a harmonizing property act as triggers. Not yet discussed is the result of ranking the faithfulness constraint IDENT(deactivation)-IO over the markedness constraints PERSIST(Gest_X) and SELFDEACTIVATE. While the ranking of these markedness constraints over faithfulness favors neutralization of contrast in favor of some uniform setting of

a gesture's deactivation parameter, the ranking of faithfulness over markedness can be used to capture instances of contrast preservation. The high ranking of the faithfulness constraint IDENT(deactivation)-IO then introduces the possibility that a gesture's deactivation parameter may be contrastive in some languages. This is a desirable prediction that falls out of the Gestural Harmony Model's representation of harmony triggering as the result of a gestural parameter. Such cases of contrastive triggering in the nasal harmony systems of several Malayo-Polynesian languages are examined in this section.

Many languages with progressive nasal harmony can be analyzed straightforwardly within the Gestural Harmony Model as having surface inventories containing only persistent velum opening gestures. However, the model also predicts that languages with both self-deactivating and persistent velum opening gestures should be able to occur in the same phonological inventory and act as contrastive phonological units. Such a system is exemplified by Acehnese (Malayo-Polynesian, Chamic; Indonesia; Durie (1985), Cowan (1981)), whose inventory is provided in (65).

(65) Acehnese phonological inventory¹⁴

Consonants					Vowels		
p	t	c	k	?	i	ɯ	u
b	d	ɟ	g		e	ə	o
s	ʃ				ɛ		ɔ
m	n	j̪	ŋ			a	
ŷ	ñ	ŷ	ŷ				
f							
l							
j	w						
				h			

¹⁴ The vowel transcribed by Cowan as /ə/ is transcribed by Durie as /ʌ/. Both describe it as a central vowel.

In Acehnese, some forms show progressive nasal harmony triggered by a nasal consonant and proceeding among vowels, glides, and glottals (66a-c), while others do not (66d-f). All data are from Durie (1985) and Cowan (1981).

Durie (1985) attributes this pattern to a distinction between plain nasals, which trigger the progressive nasal harmony that is common among Austronesian languages, and so-called ‘funny’ nasals, which do not trigger harmony. Similarly, McGinn (1982) and Coady & McGinn (1982) propose a contrast in Rejang (Malayo-Polynesian, Land Dayak; Indonesia) between plain and ‘barred’ nasals. McGinn reports the phonological inventory in (67).

- (67) Rejang phonological inventory¹⁵

Consonants					Vowels		
p	t	c	k	?	i	u	
b	d	J	g		e	ə	o
		s				a	
m	n	ŋ	ŋ				
ṁ	ñ	ŋ̪	ŋ̪				
	f						
	l						
	j	w					
			h				

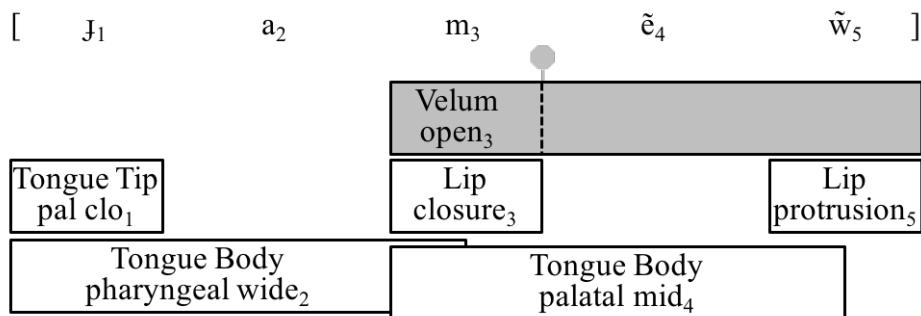
The inventory in (67) contains two series of nasal consonants, which McGinn (1982) and Coady & McGinn (1982) claim contrast in their ability (68a-d) or inability (68e-h) to trigger nasal harmony.

¹⁵ The palatal stop transcribed here as /j/ is transcribed by McGinn as /j/, while the palatal glide transcribed here as /j/ is transcribed by McGinn as /y/. Also, the vowel transcribed by McGinn as /e/ and described as a central vowel is transcribed here as /ə/.

- (68) a. [jamẽ̃w] ‘guava’ e. [jamew] ‘party’
 b. [tanjẽn] ‘hand’ f. [tuŋew] ‘wait’
 c. [mĩjõwã] ‘coconut’ g. [mu?] ‘eat’
 d. [mĩjẽ] ‘cooked rice’ h. [net] ‘sew’

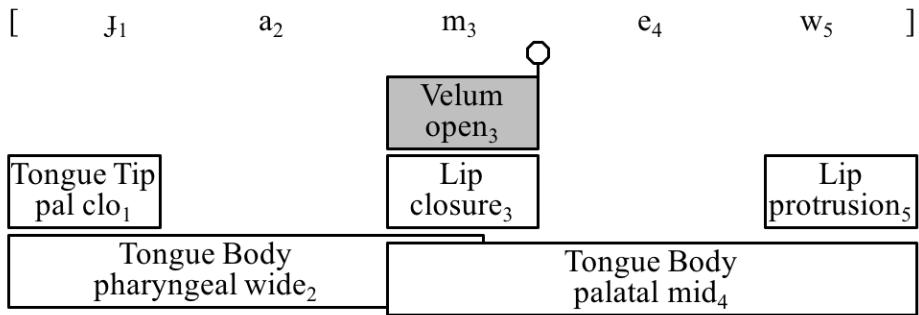
The distinction between plain and funny/barred nasals in Acehnese and Rejang and their ability or inability to trigger nasal harmony is captured straightforwardly in the Gestural Harmony Model. C. Smith (2017b) proposes that the only difference between these two nasal stop series lies in which velum opening gesture, self-deactivating or persistent, accompanies a nasal stop’s oral closure gesture. Plain (harmony-triggering) nasals in both Acehnese and Rejang can be represented as segments with an oral closure gesture accompanied by a persistent velum opening gesture. Acehnese and Rejang words that include these gestures will exhibit nasal harmony. This is illustrated in the figure in (69), which provides a gestural score for the Rejang form [jamẽ̃w] ‘guava.’

- (69) Gestural score for Rejang [jamẽ̃w] ‘guava’



In contrast, the funny or barred nasals that do not trigger nasal harmony can be represented as segments with an oral closure gesture accompanied by a self-deactivating velum opening gesture. This is shown in the gestural score for the Rejang form [jamew] ‘party’ in (70).

(70) Gestural score for Rejang [ʃamew] ‘party’



These two Rejang words form a minimal pair that contrasts only in the presence versus absence of nasal harmony. Consistent with previous analyses of nasal harmony in Rejang and in Acehnese, the Gestural Harmony Model represents this as a contrast between triggering nasal stops, which are accompanied by persistent velum opening gestures, and non-triggering nasal stops, which are accompanied by self-deactivating velum opening gestures. The patterns of harmony triggering in these languages, then, are the result of a property of the surface phonological inventories of these languages. This is illustrated in (71), which depicts the Rejang nasal consonant inventory as containing segments with both persistent and self-deactivating velum opening gestures.

(71) Gestural representation of Rejang nasal stop inventory

Non-triggers			
/m/	/n/	/ɲ/	/ŋ/
 Velum open	 Velum open	 Velum open	 Velum open
+	+	+	+
Lip closure	Tongue Tip alveolar closure	Tongue Body palatal closure	Tongue Body velar closure

Triggers			
/m/	/n/	/ɲ/	/ŋ/
 Velum open	 Velum open	 Velum open	 Velum open
+	+	+	+
Lip closure	Tongue Tip alveolar closure	Tongue Body palatal closure	Tongue Body velar closure

The preservation of the contrast between the two nasal stop series in (71) is enforced in the Gestural Harmony Model by the high ranking of IDENT(deactivation)-IO, which will allow both self-deactivating and persistent velum opening gestures to surface when they appear in input forms. Before presenting an analysis of contrastive triggering of nasal harmony in Acehnese and Rejang, however, a final aspect of the distribution of triggering and non-triggering nasals must be mentioned. Durie (1985) states that in Acehnese ‘funny’ nasals may only occur in the final (stressed) syllable of a word, while plain nasals are unrestricted in their distribution. While McGinn (1982) and Coady & McGinn (1982) do not explicitly say that the same restriction holds for barred nasals in Rejang, the data they provide shows a distributional pattern identical to that in Acehnese.

It appears, then, that the contrast between self-deactivating and persistent velum opening gestures in Acehnese and Rejang is limited to the privileged position of the final syllable. This

type of pattern in which a contrast is preserved only in privileged positions is common among phonological systems, and can be captured by relativizing faithfulness constraints to those privileged positions (Beckman 1997, 1998). In this case, it is a specific version of IDENT(deactivation)-IO that holds only over final syllables (following work by Hyman (1998), Krämer (2003), Sasa (2009), Walker (2011) and others) that preserves the deactivation parameter contrast in that position.¹⁶ This relativized constraint, IDENT(deactivation)-IO_{Finalσ}, must be ranked above PERSIST(velum opening) and SELFDEACTIVATE.

In non-final syllables, the contrast between triggering and non-triggering nasals is neutralized; in these positions, only triggering nasals may appear. Therefore, PERSIST(velum opening), which penalizes nasals that do not trigger harmony, must be ranked above the general constraint IDENT(deactivation)-IO, as well as SELFDEACTIVATE. The full ranking of constraints necessary to generate the pattern of context-specific contrastive triggering in Acehnese and Rejang is shown in (72).

(72) Constraint ranking for nasal harmony triggering in Acehnese and Rejang

$$\text{IDENT(deactivation)-IO}_{\text{Final}\sigma} \gg \text{PERSIST(velum opening)} \gg \begin{matrix} \text{IDENT(deactivation)-IO} \\ \text{SELFDEACTIVATE} \end{matrix}$$

The results of this ranking are demonstrated in the following tableaux, beginning with the final-syllable preservation of contrast of a gesture's deactivation parameter setting. This is exemplified by the Rejang minimal pair [jamẽw] ‘guava’ and [jamew] ‘party.’ The tableau in (73) demonstrates the evaluation for [jamẽw] ‘guava,’ in which [m] serves as a trigger of nasal harmony.

¹⁶ In Acehnese and Rejang, the final syllable is also privileged by its status as the main stressed syllable. Whether IDENT(deactivation)-IO is relativized to this syllable based on its stress or its position at the end of the word has no effect on the outcome of the analysis presented in this section.

(73) Tableau for Rejang [jamẽw] ‘guava’

Input: / $\text{J}_1 \text{ a}_2 \text{ m}_3 \text{ e}_4 \text{ w}_5 /$	Tongue Tip palatal clo ₁	Tongue Body pharyng wide ₂	Lip closure ₃	Tongue Body palatal mid ₄	Lip protr ₅	Velum open ₃	IDENT(deactivation)-IO _{Finalσ}	PERSIST(velum opening)	IDENT(deactivation)-IO	SELFDEACTIVATE
a.	[J_1 a_2 m_3 $\tilde{\text{e}}_4$ $\tilde{\text{w}}_5$]									*
b.	[J_1 a_2 m_3 e_4 w_5]						*!	*	*	

In the tableau in (73), the input contains an /m/ that includes a persistent velum opening gesture. The winning candidate (a) [jamẽw] surfaces with that persistent gesture, resulting in nasal harmony throughout the final syllable of the word. It satisfies high-ranked IDENT(deactivation)-IO_{Finalσ} while violating low-ranked SELFDEACTIVATE. In candidate (b) [jamew], the velum opening gesture is self-deactivating and does not trigger harmony, resulting in a fatal violation of IDENT(deactivation)-IO_{Finalσ}. It also satisfies SELFDEACTIVATE while violating PERSIST(velum opening).

Turning to non-triggering nasals, the tableau in (74) demonstrates the evaluation for [jamew] ‘party,’ in which [m] does not trigger nasal harmony.

(74) Tableau for Rejang [jamew] ‘party’

Input: / $J_1 \ a_2 \ m_3 \ e_4 \ w_5 /$						IDENT(deactivation)-IO _{Finalσ}	PERSIST(velum opening)	IDENT(deactivation)-IO	SELFDEACTIVATE
	Tongue Tip palatal closure ₁	Tongue Body pharyngeal wide ₂	Lip closure ₃	Tongue Body palatal mid ₄	Lip protrusion ₅	Velum open ₃			
a.	[J_1	a_2	m_3	\tilde{e}_4	\tilde{w}_5]		*	*	*
b.	[J_1	a_2	m_3	e_4	w_5]		*		

In (74), the input contains an /m/ that includes a self-deactivating velum opening gesture. For this input, candidate (a) [jamēw̚] fatally violates IDENT(deactivation)-IO_{Finalσ} by surfacing with a persistent velum opening gesture that triggers nasal harmony. Winning candidate (b)

[jamew] satisfies IDENT(deactivation)-IO_{Finalσ} by surfacing with a self-deactivating velum opening gesture that is faithful to its input deactivation parameter.

As for the distribution of nasals in non-final syllables, the tableau in (75) shows the evaluation of the Rejang form [m̩jɛ] ‘cooked rice.’ In this form, [m] in a non-final syllable triggers harmony. In order to demonstrate that an /m/ in this position will surface as a trigger of harmony no matter its input specification, the tableau in (75) assumes a hypothetical input in which /m/ includes a self-deactivating velum opening gesture.

(75) Tableau for [m̩j̩e] ‘cooked rice’

Input: / m ₁ i ₂ j ₃ e ₄ /	Lip closure ₁	Tongue Body palatal narrow ₂	Tongue Body palatal narrow ₃	Tongue Body palatal mid ₄	Velum open ₁	IDENT(deactivation)-IO _{Finalσ}	PERSIST(velum opening)	IDENT(deactivation)-IO	SELFDEACTIVATE
a.	[m ₁ i ₂ j ₃ e ₄]						*	*	
b.	[m ₁ i ₂ j ₃ e ₄]						*!		

In (75), the high-ranked constraint IDENT(deactivation)-IO_{Finalσ} is not active, as neither output candidate contains a nasal in the privileged position of the final syllable. Winning candidate (a) [m̩j̩e], in which the velum opening gesture of [m] is persistent, violates only the low-ranked general version of IDENT(deactivation)-IO, as it is not faithful to the self-deactivating velum opening gesture of the input. The deactivation parameter of the velum opening gesture of candidate (b) [mije] is faithful to the hypothetical input, and therefore satisfies IDENT(deactivation)-IO. However, it fatally violates higher-ranked PERSIST(velum opening). This

tableau demonstrates, then, that outside of the final syllable, a nasal must surface as a trigger of nasal harmony no matter the deactivation parameter specification of its velum opening gesture. The contrastiveness of this deactivation parameter is only preserved in the privileged position of the final syllable, and neutralized elsewhere in favor of persistent velum opening gestures.

Patterns similar to those in Acehnese and Rejang, in which nasal harmony is triggered by one nasal consonant series and not another, have also been noted in Bukar-Sadong (Land Dayak; Indonesia, Malaysia) and Iban (also known as Sea Dayak; Indonesia, Malaysia) by Scott (1957, 1964) and Court (1970). However, in these languages the non-triggering nasals have usually been described as either homorganic nasal-stop sequences or as prenasalized stops. If this is the case, the inability of these nasals to trigger progressive nasal harmony can be attributed to the blocking of nasal harmony by the following obstruent rather than to a difference in the representation of a nasal consonant's velum opening gesture. On the other hand, many sources that described nasal-stop sequences and prenasalized stops in these languages also note that they are usually produced as something approximating a simple nasal stop. Scott (1957) describes the production of voiced obstruents following nasals in Iban as 'very gentle.' Taking this a step further, Court (1970) claims that in many of these Indonesian languages the voiced stop portion of a homorganic nasal-stop sequence disappears entirely. Similarly, 'funny' nasals in Acehnese are analyzed by Cowan (1981) as prenasalized stops that have fused into a simple nasal consonant.

While the synchronic status of non-triggering nasal consonants in these languages remains uncertain, they are likely historically derived from prenasalized stops or nasal-stop clusters. McGinn (1982) and Coady & McGinn (1982) point to a number of cognate pairs between Rejang and Indonesian (a variety of Malay) to show that the 'barred' (non-triggering)

nasal consonants of Rejang correspond to nasal-stop clusters in related languages. For instance, the word for ‘guava’ is [jamew] in Rejang, and [jambu] in Indonesian. In earlier forms of languages with contrastively triggered nasal harmony, then, there may have been a single persistent velum opening gesture in the phonological inventory, resulting in nasal harmony in that language. However, some nasal consonants that included this persistent velum opening gesture were immediately followed by obstruents, which blocked the spread of nasality. Because in these forms the extended activation of the velum opening gesture never surfaced, a learner would have had no reason to posit that the velum opening gesture in these forms was persistent rather than self-deactivating. A possible result of such a pattern is the assumption by the learner of an allophonic distribution of velum opening gestures, with the self-deactivating velum opening gesture present before obstruents (however weakly they were produced), and the persistent gesture elsewhere. It is possible that this is the case in some present-day Malayo-Polynesian languages. In others, it appears that the obstruent portion of these prenasalized stops has been lost entirely, but the ability of the velum opening gesture to self-deactivate, rather than spreading nasality throughout a word, has remained. In these languages, there are now two contrastive types of nasal consonants: one accompanied by a self-deactivating velum opening gesture, and one accompanied by a persistent velum opening gesture.

The attestation of patterns of contrastive triggering in Acehnese and Rejang lends further support to the Gestural Harmony Model’s treatment of harmony triggering ability as part of a gesture’s representation. By admitting a gesture’s ability or inability to trigger harmony into the set of parameters that make up a gesture’s representation, the model admits the possibility that such a parameter should be able to serve a contrastive function in some languages. This

prediction is borne out, as evidenced by the patterns of contrastive triggering in Acehnese, Rejang, and several other Malayo-Polynesian languages.

The question remains as to why such systems are not more widespread. The cluster of Malayo-Polynesian languages discussed in this section is the only set of languages to receive analyses explicitly based on the contrastive ability to trigger harmony. C. Smith (2017b) proposes that one possibility for their relative rarity is that a harmony system with contrastive triggering represents an intermediate stage in the diachronic development or loss of a harmony system, suggesting that such systems might be unstable. Alternatively, the apparent rarity of contrastive triggering may be an artifact of how such harmony systems are described. There are considerably more harmony patterns that are described in terms of exceptionality in harmony triggering. One harmony system that has previously been promoted as an example of exceptionality in harmony is Classical Manchu tongue root harmony, whose reanalysis within the Gestural Harmony Model as a case of contrastive triggering is presented in section 3.5.

3.4 Conditional Triggering of Harmony

3.4.1 *Conditional Triggering via Co-occurrence Constraints*

Among all types of harmony, the sort of symmetry of triggering exhibited by a language like Kyrgyz (sections 2.2.1 and 3.2.1), in which all round vowels trigger rounding harmony, is relatively uncommon. Far more common are systems in which conditions are placed on the types of segments that may serve as triggers of harmony. The Gestural Harmony Model is also successful in generating these conditional triggering patterns.

In section 3.2, PERSIST(Gest_X) is proposed to be a perceptually grounded constraint. By surfacing as persistent, a gesture of type X has the opportunity to extend its period of activation and improve its perceptual salience. The same is true of gestures that surface as anticipatory and

extend in the regressive (leftward) direction. This is in keeping with assertions by Kaun (1995, 2004), Flemming (1995), Walker (2005, 2011), and Kimper (2011) that harmony is perceptually motivated as a means to increase a listener's exposure to a perceptually difficult element. There is a constraint PERSIST(lip protrusion), for example, because the contrast between a round vowel (with a lip protrusion gesture) and an unround vowel (without a lip protrusion gesture) is potentially difficult to perceive unless a lip protrusion gesture is of a sufficient length.

However, it is not the case that all round vowels are equally perceptually disadvantaged or that they trigger harmony with equal frequency across languages. Kaun (1995) discusses this at length and claims that vowels that are perceptually weak transmitters of a rounding contrast, i.e., nonhigh vowels and front vowels, are more likely to act as triggers of harmony, a principle she summarizes with the statement that 'Bad Vowels Spread.' If harmony is a phenomenon that extends the period of activation of hard-to-perceive gestures, it is predicted that the harder it is to accurately perceive the presence of a gesture, the more likely it will be to trigger harmony. In the case of rounding harmony, a lip protrusion gesture is more difficult to perceive when it accompanies a nonhigh vowel or a front vowel. Therefore, when included in the representation of such vowels, a lip protrusion gesture will be more likely to surface as persistent and/or anticipatory.

This sort of conditional triggering is not limited to rounding harmony. In nasal harmony, triggers are sometimes limited to perceptually weak bearers of nasality. Perhaps the most well-known example of a triggering condition in nasal harmony comes from Inor (also known as Ennemor; Semitic, Western Gurage; Ethiopia). In Inor, nasal stops do not trigger nasal harmony, while nasalized continuants (derived by a process of nasal stop spirantization) act as triggers of bidirectional nasal harmony (Chamora & Hetzron 2000). There are also cases in which nasal

harmony is triggered by nasal vowels and not nasal consonants, as in Moba Yoruba (Ajiboyè 2001; Ajiboyè & Pulleyblank 2008; Walker 2014).

Many feature-based analyses of harmony capture these sorts of trigger asymmetries by including restrictions on triggering segments directly within the definition of a harmony-driving constraint. Kaun (1995), for instance, assumes a general harmony constraint EXTEND(round) for driving rounding harmony, as well as the specific constraints EXTEND(round)IF[-high] and EXTEND(round)IF[-back]. Because the Gestural Harmony Model does not utilize any constraints that serve directly as harmony drivers, this strategy for capturing triggering asymmetries is not available.

However, it is still possible to capture patterns of conditional harmony triggering in the Gestural Harmony Model via the shaping of surface phonological inventories. Simple inventory shaping was discussed in section 2.3 for Kyrgyz and Nandi, whose inventories are shaped by the high ranking of the constraints PERSIST(Gest_X) and (in the case of Nandi) ANTICIPATE(Gest_X). Conditions on triggers can be captured by assuming additional markedness constraints that require persistent or anticipatory gestures to co-occur only with certain types of segments. The analysis of conditional harmony triggering via co-occurrence constraints is the subject of this section. A simple case of conditional harmony triggering is exemplified by the conditional triggering observed in Baiyina Oroqen rounding harmony. In addition, in this section I return to the case of Capanahua nasal harmony (section 2.2.2), which presents an interesting case of bidirectional harmony in which a triggering condition is placed on one direction of harmony and not the other.

3.4.2 Rounding Harmony in Baiyina Oroqen

Baiyina Oroqen¹⁷ rounding harmony (Li 1996; Kaun 2004; Walker 2014; Dresher & Nevins 2017) presents a unique case in which only a subset of round vowels trigger rounding harmony, and in which non-triggers of rounding harmony may either propagate or block harmony. By representing harmony as the result of overlap of undergoing segments by a single persistent (non-self-deactivating) gesture, the Gestural Harmony Model is able to straightforwardly account for both of these aspects of harmony triggering in the language.

Baiyina Oroqen (Northern Tungusic; China) exhibits harmony for both tongue root position and rounding. The vowel inventory can be split into symmetric sets of ATR and non-ATR vowels, while rounding is present only on the back vowels. Length is contrastive on all but the front nonhigh vowels, which are diphthongized. The vowel inventory in (76) is reported by Li (1996).

(76) Baiyina Oroqen vowel inventory

	ATR Vowels		Non-ATR Vowels	
	Front	Back	Front	Back
High	i i:	u u:	ɪ ɪ:	ʊ ʊ:
Nonhigh	ie	ə ə:	o o:	ɛ ɛ:

As in many Tungusic languages, harmony in Baiyina Oroqen is triggered by a vowel in the initial syllable of a word. Following vowels may agree with the initial vowel in both tongue root position and rounding, the latter of which is the focus of this section. Rounding harmony in Baiyina Oroqen holds among the set of non-high back vowels. The vowels /ə/ and /ə:/ alternate with /o/ and /o:/, respectively, with respect to rounding, while /a/ and /a:/ alternate with /ɔ/ and /ɔ:/.. While there are a number of round vowels in the language's inventory, both high and

¹⁷ This variety of Oroqen should not be confused with the standard dialect, for which the patterns of triggering of rounding harmony are somewhat different.

nonhigh, harmony is triggered only by the nonhigh short vowels /o/ and /ɔ/, as in (77). All data are from Li (1996).

- (77) a. [somsok-jo] ‘pasture (indef. acc.)’ d. [ələ-jo] ‘fish (indef. acc.)’
 b. [noño-xo:n-mo] ‘bear (dim. def. acc.)’ e. [dʒələ-xo:n-mo] ‘stone (dim. def. acc.)’
 c. [olo:-wko:n-no] ‘to cook (caus. pres.)’ f. [bɔðə-wko:n-no] ‘to think (caus. pres.)’

Nonhigh round vowels may surface in non-initial syllables only as the product of harmony, i.e., after triggers /o/ and /ɔ/. If the initial syllable contains an unround vowel, all following nonhigh vowels must be unround as well. The long vowels /o:/ and /ɔ:/ may surface as the products of harmony, as in (77b-c) and (77e-f). However, when they occur in an initial syllable they do not trigger rounding harmony. Any nonhigh vowels that follow /o:/ or /ɔ:/ in an initial syllable must surface as their unround alternants, as in (78).

High round vowels are unrestricted in their distribution and do not participate in rounding harmony in Baiyina Oroqen. Along with the high unround vowels, they act as blockers of harmony. The analysis of the status of high vowels as blockers within this harmony system is left until section 4.5.3. The analysis presented in this section focuses on the distribution of the nonhigh round vowels and their ability or inability to trigger harmony.

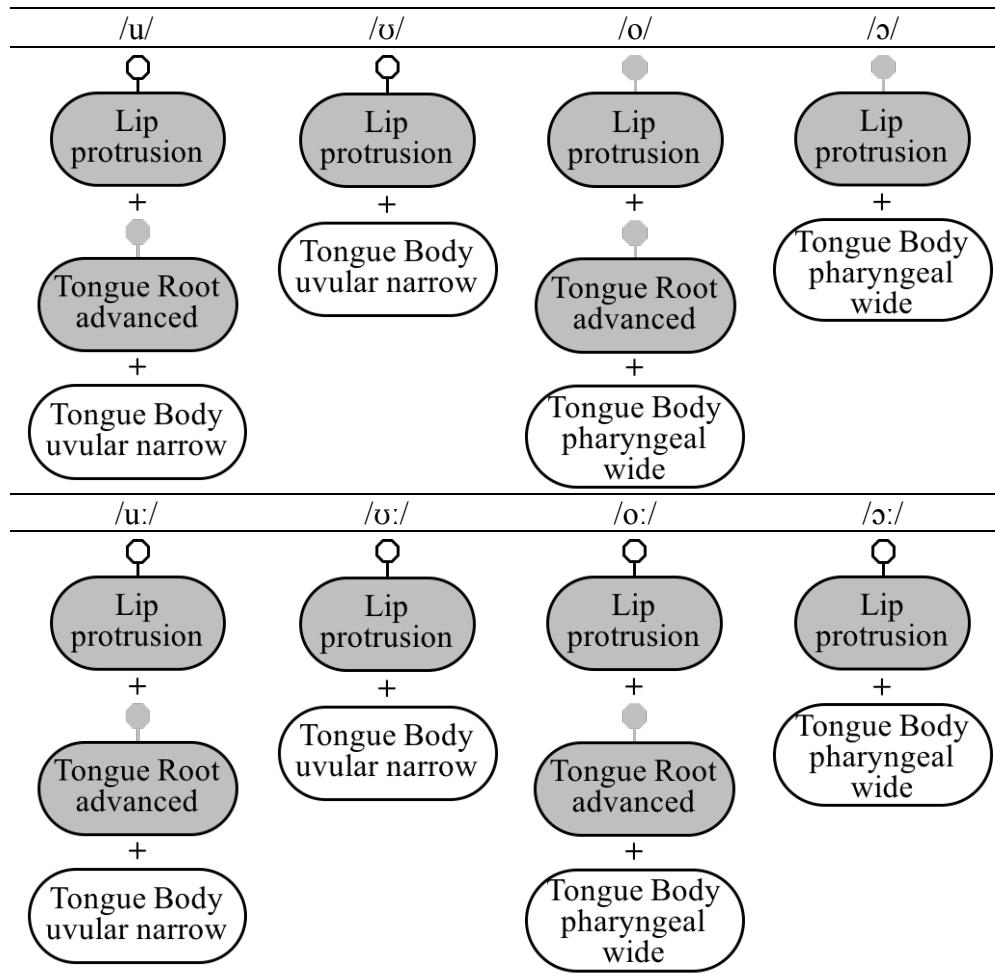
The pattern of rounding harmony triggering in Baiyina Oroqen represents a case of conditional triggering, in which restrictions are imposed on the types of vowels that may act as harmony triggers. While the Baiyina Oroqen inventory includes a number of round vowels, only the short nonhigh /o/ and /ɔ/ trigger round harmony. This is in keeping with the widespread assertion, discussed in section 2.3, that the intent of harmony is to increase the temporal extent of a perceptually vulnerable harmonizing property in order to maximize its perceptibility. In the case of Baiyina Oroqen, however, it is not rounding in general that is deemed perceptually

vulnerable and therefore targeted for temporal extension, but rather rounding that accompanies nonhigh vowels. As discussed at length by Kaun (1995, 2004), nonhigh round vowels are at a perceptual disadvantage in comparison with high round vowels due to the lowered position of the jaw and its interference in the production of lip protrusion. According to Kaun, this accounts for the fact that high round vowels do not trigger rounding harmony in Baiyina Oroqen and many other languages with rounding harmony.

Furthermore, within the class of nonhigh round vowels, short /o/ and /ɔ/ are at a perceptual disadvantage relative to long /o:/ and /ɔ:/. While short /o/ and /ɔ/ trigger harmony in order to increase the perceptibility of rounding, long /o:/ and /ɔ:/ need not trigger harmony as they are already long enough to render rounding sufficiently perceptible. The perceptual weakness of round vowels based on height and length serves as the basis of the analyses of the pattern of rounding harmony triggering in Baiyina Oroqen proposed by Kaun (2004) and Walker (2014).

Within the Gestural Harmony Model, the triggering of Baiyina Oroqen rounding harmony can be accounted for via the interaction of markedness and faithfulness constraints that shapes its surface inventory of vowels with persistent and self-deactivating lip protrusion gestures. The inventory of round vowels in Baiyina Oroqen is represented gesturally as in (79).

(79) Baiyina Oroqen round vowel inventory represented gesturally



In the inventory in (79), all high vowels include self-deactivating lip protrusion gestures that will not trigger rounding harmony. Among the nonhigh vowels, short /o/ and /ɔ/ are triggers of harmony and thus include persistent lip protrusion gestures, while non-triggers /o:/ and /ɔ:/ are accompanied by self-deactivating lip protrusion gestures.

This inventory can be generated within the Gestural Harmony Model as follows. Because round vowels in general do not trigger harmony, SELFDEACTIVATE must be ranked above IDENT(deactivation)-IO and PERSIST(lip protrusion). However, the short round vowels /o/ and /ɔ/ always trigger harmony; therefore, they must be banned from co-occurring with self-deactivating lip protrusion gestures. This can be achieved via a constraint from the *COUPLE family.

Introduced in section 1.2.2, *COUPLE constraints ban gestures of certain types from being coupled to one another in a coupling graph. The *COUPLE constraint relevant to Baiyina Oroqen rounding harmony is provided in (80).

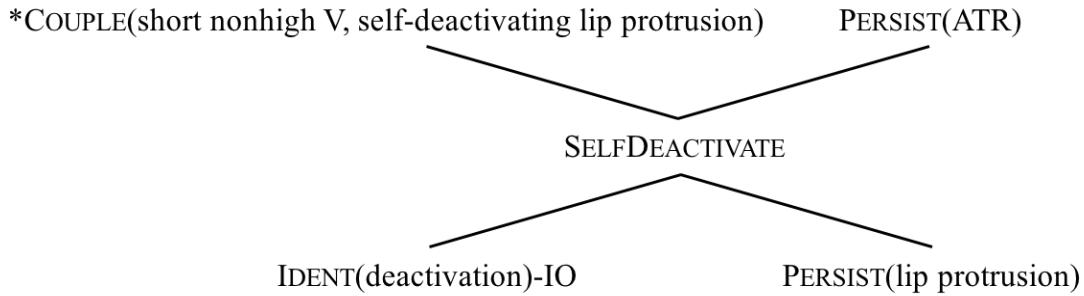
- (80) *COUPLE(short nonhigh V, self-deactivating lip protrusion): Assign a violation mark to a short nonhigh vocalic gesture and a self-deactivating lip protrusion gesture that are coupled to one another in an output.

The constraint in (80) penalizes a short nonhigh vowel gesture that is coupled to a self-deactivating lip protrusion gesture. When this constraint is ranked above SELFDEACTIVATE, a short nonhigh round vowel will be compelled to surface with a persistent lip protrusion gesture, and will therefore trigger harmony.

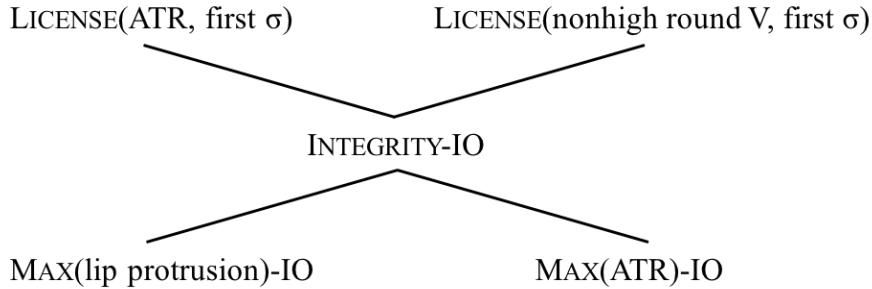
In addition, tongue root harmony in Baiyina Oroqen is triggered by all ATR vowels in the inventory, indicating that PERSIST(ATR) is also ranked above SELFDEACTIVATE, though this will not be a major focus of the analysis presented in this section. In order to capture the fact that rounding and ATR harmony are triggered by a vowel in an initial syllable and that only roots may introduce harmonizing gestures, I assume the high ranking of two positional licensing constraints. The constraint LICENSE(nonhigh round V, first σ) penalizes a nonhigh vowel that includes a lip protrusion gesture that occurs outside of the first syllable of a word, and LICENSE(ATR, first σ) penalizes a tongue root gesture that occurs outside of the first syllable of a word. These must both be ranked above INTEGRITY-IO, which must itself outrank MAX(lip protrusion)-IO and MAX(ATR)-IO. The full constraint ranking is given in the Hasse diagrams in (81).

(81) Constraint ranking for Baiyina Oroqen rounding and ATR harmony

a. Constraint ranking for triggering of rounding harmony by nonhigh short round vowels



b. Constraint ranking limiting rounding and ATR harmony triggers to initial syllable



The workings of the constraint ranking in (81a) are demonstrated by the following tableaux. In order to focus solely on the pattern of rounding harmony triggering in Baiyina Oroqen, I consider only non-ATR forms that do not include a tongue root advancement gesture going forward. Illustrating the importance of high-ranked **COUPLE(short nonhigh V, self-deactivating lip protrusion)* to the triggering of rounding harmony by a short nonhigh round vowel, the tableau in (82) for the form [əlɔ̃-jɔ̃] ‘fish (indef. acc.)’ includes a hypothetical input in which the lip protrusion gesture that accompanies the initial /ɔ/ is self-deactivating. Again, for reasons of space and clarity, only the vocalic gestures are included for each candidate, which is represented by the gestural score that is calculated from an output coupling graph. Recall from the discussion in chapter 2, however, that consonants are considered to be undergoers of rounding and tongue root harmony.

(82) Tableau for Baiyina Oroqen [ɔlɔ̃-jɔ̃] ‘fish (indef. acc.)’

Input: /ɔ̃₁ l a₂ - j a₃ /	*COUPLE(short nonhigh V)	SELFDEACTIVATE	IDENT(deactivation)	PERSIST(lip protrusion)
	*	*	*	
	*!			*

In (82), winning candidate (a) [ɔlɔ̃-jɔ̃] violates SELFDEACTIVATE by including a persistent lip protrusion gesture in the representation of the word-initial harmony-triggering /ɔ/. In addition, this candidate violates low-ranked IDENT(deactivation)-IO due to the change in the lip protrusion gesture’s deactivation parameter between input and output. However, this candidate crucially satisfies high-ranked *COUPLE(short nonhigh V, self-deactivating lip protrusion). Candidate (b), on the other hand, in which the nonhigh vowel is accompanied by a self-deactivating lip protrusion gesture, fatally violates *COUPLE while satisfying SELFDEACTIVATE.

When a word contains a long round vowel in the initial syllable, rounding harmony is not triggered, as in the tableau for [kɔ:ŋakta] ‘handbell’ in (83), which includes a hypothetical input with an initial persistent lip protrusion gesture.

(83) Tableau for Baiyina Oroqen [kɔ:ŋakta] ‘handbell’

Input: /k ɔ:₁ ŋ a₂ k t a₃ /	Tongue Body pharyngeal wide ₁	Tongue Body pharyngeal wide ₂	Tongue Body pharyngeal wide ₃	Lip protrusion ₁	*COUPLE(short nonhigh V)	SELFDEACTIVATE	IDENT(deactivation)-IO	PERSIST(lip protrusion)
a. [kɔ:ŋoktɔ]	[ɔ:₁]	ɔ₂	ɔ₃]	Lip protrusion ₁	*	!		
b. [kɔ:ŋakta]	[ɔ:₁]	a₂	a₃]	Lip protrusion ₁	*	*	*	*

Because the round vowel in this form is long, the constraint *COUPLE(short nonhigh V, self-deactivating lip protrusion) is not relevant and is therefore unable to compel the vowel to surface with a harmony-triggering persistent lip protrusion gesture. In candidate (a) [kɔ:ŋoktɔ] rounding harmony is triggered by a non-self-deactivating lip protrusion gesture, fatally violating SELFDEACTIVATE. Candidate (b) [kɔ:ŋakta], which contains a self-deactivating lip protrusion

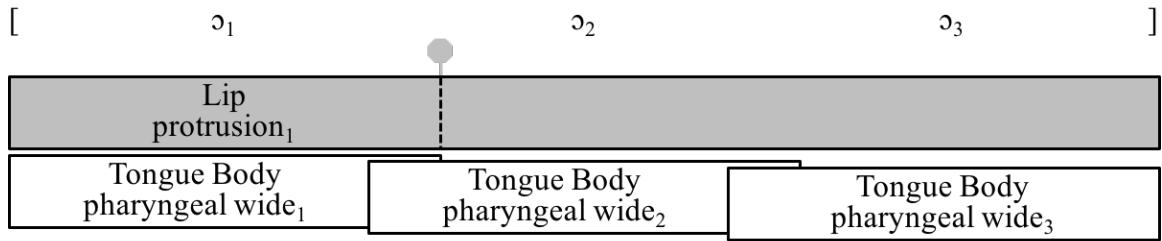
gesture accompanying [ɔ:], violates only the low-ranked IDENT(deactivation)-IO and PERSIST(lip protrusion) and is therefore the winner.

The constraint set used here accurately captures the patterns of harmony triggering and non-triggering by nonhigh round vowels in the initial syllable in Baiyina Oroqen. The language imposes a condition on which round vowels may trigger rounding harmony, restricting triggering to the set of nonhigh short round vowels. This conditional triggering is captured straightforwardly in the Gestural Harmony Model via the use of a constraint on gestural co-occurrence, in this case a constraint from the *COUPLE family.

In Baiyina Oroqen, nonhigh round vowels may only occur in non-initial syllables as the result of rounding harmony, i.e., if harmony-triggering [o] or [ɔ] occur in the initial syllable. Thus, sequences of vowels such as [a-o-o] or [a-a-o] are disallowed while sequences such as [o-o-o] are tolerated. In the Gestural Harmony Model, this can be captured straightforwardly by restricting lip protrusion gestures to the initial syllable of the word via a positional LICENSE constraint. This effectively restricts round vowels from occurring in non-initial syllables unless they receive their rounding as a result of overlap from a persistent lip protrusion gesture in an initial syllable. The vowels that undergo rounding harmony will surface as round without being coupled to their own lip protrusion gestures or being associated with the triggering vowel's lip protrusion gesture in any way. A similar account of the distributional restrictions of round vowels in Kyrgyz is provided in section 3.2.1.

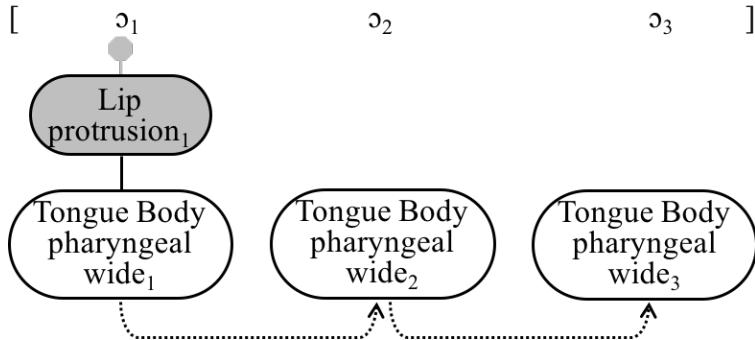
This is demonstrated by examining in greater detail the gestural representation of harmony in the word [ɔlo-jɔ] ‘fish (indef. acc.)’ Its gestural score is provided in (84).

- (84) Gestural score for vocalic portion of Baiyina [ɔlɔ̯-jɔ̯] ‘fish (indef. acc.)’



In this gestural score, there is a single lip protrusion gesture that overlaps all other segments in the word. As a result, these segments surface as rounded. However, none of these segments has taken on this property as a result of any kind of association (i.e., coupling) with this lip protrusion gesture. This is apparent when examining the coupling graph from which the Coupled Oscillator Model computes the gestural score in (84). This coupling graph is provided in (85).

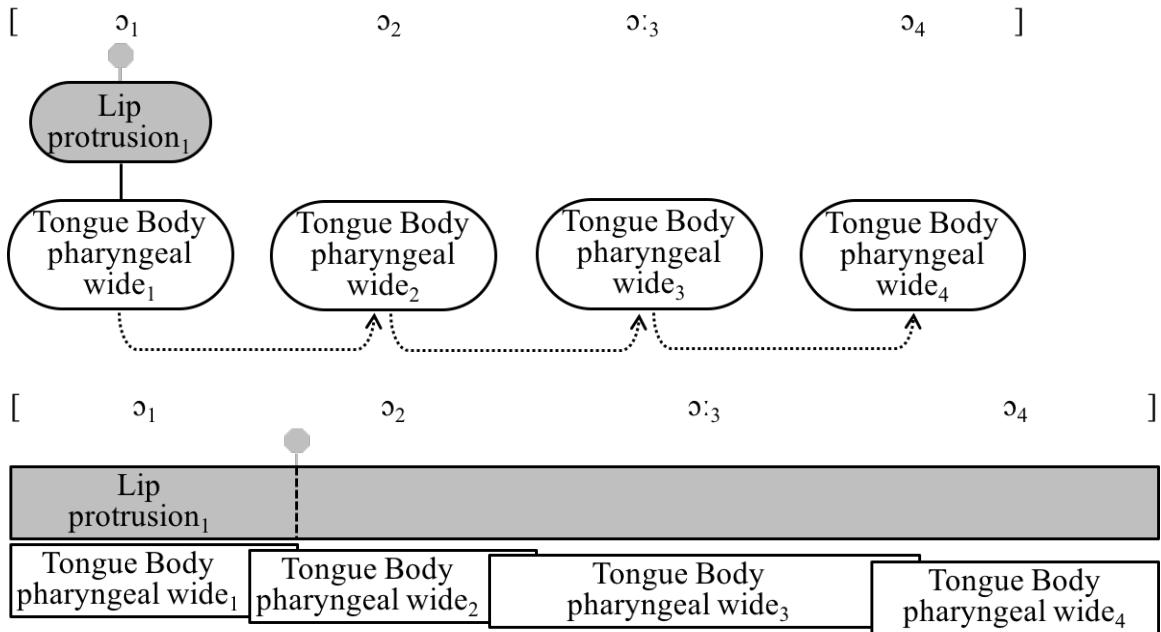
- (85) Coupling graph for vocalic portion of [ɔlɔ̯-jɔ̯] ‘fish (indef. acc.)’



In the coupling graph for [ɔlɔ̯-jɔ̯] ‘fish (indef. acc.)’ in (85), the word’s sole lip protrusion gesture is coupled only to the first vocalic gesture. The following vowels surface as rounded because they are overlapped by this lip protrusion gesture and not because they are coupled to it, nor are they coupled to lip protrusion gestures of their own. These vowels are able to surface as rounded without violating the ban on lip protrusion gestures being coupled to nonhigh vowels in non-initial syllables only.

The fact that undergoers of harmony are overlapped by a harmonizing element without becoming associated (i.e., coupled) with it has important consequences for the behavior of long [o:] and [ɔ:] in non-initial syllables in Baiyina Oroqen. The nonhigh long vowels are not harmony triggers when they occur in initial syllables; however, in non-initial syllables they will propagate harmony that is triggered by a preceding [o] or [ɔ], as in [dʒɔlɔ-xɔ:n-mɔ] ‘stone (dim. def. acc.)’ (cf. [bira-xa:n-ma] ‘river (dim. def. acc.)’). The Gestural Harmony Model predicts this behavior from the non-triggering long nonhigh vowels. In an initial syllable, a long nonhigh vowel is coupled to its own lip protrusion gesture and is thus subject to the constraint SELFDEACTIVATE. This constraint ensures that the long nonhigh vowel will not trigger rounding harmony. However, in a non-initial syllable [o:] and [ɔ:] are round because of overlap by another vowel’s lip protrusion gesture; they are not coupled to their own lip protrusion gestures in this position due to the high ranking of LICENSE(nonhigh round V, first σ) in (81b). This is illustrated by the coupling graph and gestural score for [dʒɔlɔ-xɔ:n-mɔ] ‘stone (dim. def. acc.)’ in (86). For reasons of space and clarity, only the gestures for the vowels are included.

(86) Coupling graph and gestural score for vowels of [dʒɔlɔ-xɔ:n-mɔ] ‘stone (dim. def. acc.)’

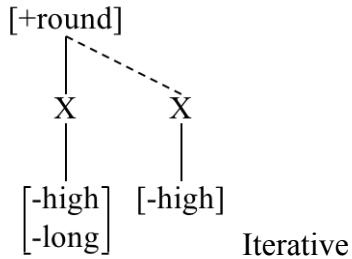


In (86), the initial [ɔ]₁ is coupled to a persistent lip protrusion gesture, which overlaps all other gestures and causes following vowels, including long nonhigh vowels, to surface as rounded. This satisfies high-ranked *COUPLE(short nonhigh V, self-deactivating lip protrusion). Crucially, the single lip protrusion gesture of the triggering initial [ɔ]₁ is the source of rounding for all of the undergoers of harmony; rounding does not spread iteratively from vowel to vowel. Thus, the vowel [ɔ:]₃ is not a source of rounding for the final [ɔ]₄, but rather a fellow undergoer of rounding harmony. The fact that [ɔ:] does not trigger harmony is irrelevant to its ability to propagate harmony to following vowels.

As pointed out by Walker (2014), an alternative analysis that views harmony as a process of local iterative feature spreading faces difficulty in accounting for the patterning of the long nonhigh vowels in Baiyina Oroqen. This difficulty is due to such models' representation of harmony as the step-by-step addition of association lines between segments and a harmonizing

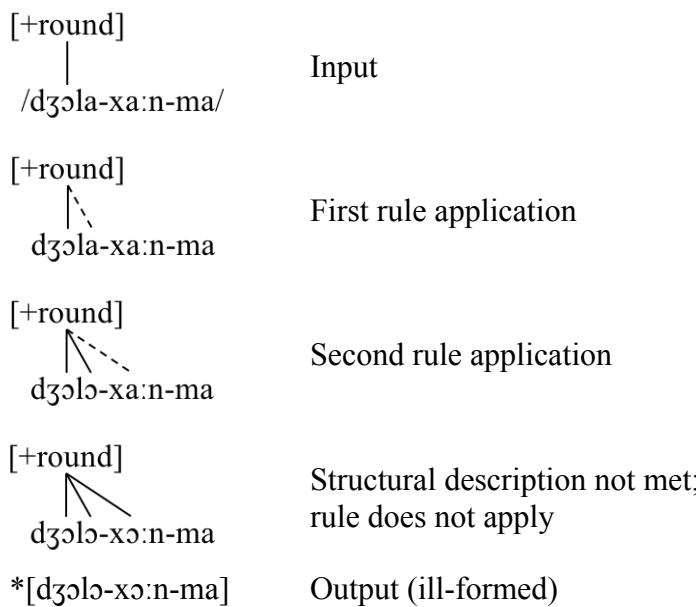
feature in order to satisfy a harmony-driving constraint or due to the application of a feature-spreading rule. In Baiyina Oroqen, such a rule could be defined as in (87).

- (87) Iterative [+round] spreading rule for Baiyina Oroqen



This rule states that the feature [+round] will spread from one nonhigh vowel (the trigger) to another (the undergoer), provided that the trigger is short. Because it is specified as an iterative rule, it may apply to its own output provided the structural description of the rule is met. The derivation for the Baiyina Oroqen form [dʒɔlɔ-xɔ:n-mɔ] ‘stone (dim. def. acc.)’ proceeds according to this rule as in (88).

- (88) Derivation of [dʒɔlɔ-xɔ:n-mɔ] ‘stone (dim. def. acc.)’ via feature spreading rule



At each step of the derivation in (88), the segments that meet the structural description of the rule in (87) change, and a different segment acts as the trigger of harmony. As a result, prohibiting a long nonhigh round vowel from triggering harmony will also prohibit it from propagating harmony that originates from another round vowel, contrary to the observed pattern in Baiyina Oroqen. After the second application of the rule, its structural description is no longer met and it will no longer apply. The iterative spreading rule in (87), then, is unable to produce forms such as [dʒələ-xɔ:n-mɔ] ‘stone (dim. def. acc.)’ in which a non-triggering long nonhigh vowel such as [ɔ:] propagates harmony.

Walker (2014) concludes that harmony should be modeled as the result of relations between a single trigger and multiple undergoers, rather than a sequence of local triggers and targets. The Gestural Harmony Model shares this representation of the relation between triggers and undergoers of harmony, and as a result faces no such trouble in analyzing harmony patterns in which some segment types are capable of undergoing and propagating harmony but are not capable of serving as the initial trigger of harmony, as in Baiyina Oroqen. This is a consequence of the fact that harmony is represented as the overlap of potentially many undergoers by a persistent or an elastic gesture that serves as the singular source of a harmonizing property. According to this representation, a so-called propagator of harmony is not actually the source of a harmonizing property, but rather just another undergoer, and thus its status as a trigger or non-trigger of harmony is irrelevant to the other undergoers around it.

Dresher & Nevins (2017) propose an alternative account of Baiyina Oroqen forms such as [dʒələ-xɔ:n-mɔ] ‘stone (dim. def. acc.)’ that circumvents the difficulty encountered by the rule in (87) while still maintaining a local iterative model of harmony. They propose that in Baiyina Oroqen, stem-internal and suffix-targeting rounding harmony are two distinct processes, and that

suffix-targeting rounding harmony is triggered only by nonhigh round vowels, either short or long, in a non-initial syllable. While this account generates the correct surface forms for Baiyina Oroqen, it relies on a more complicated view of the patterns of vowel alternation observed in the language. The one-to-many relationship between trigger and undergoers adopted by the Gestural Harmony Model and by Walker (2014), on the other hand, is able to avoid such complications, instead maintaining a unified view of Baiyina Oroqen rounding harmony as a single phonological process.

In addition to illustrating the relation between triggers and undergoers assumed within the Gestural Harmony Model, Baiyina Oroqen rounding harmony also provides a good test case for the model's ability to produce an analysis of a more complex pattern of harmony triggering. By appealing to the use of a gestural co-occurrence constraint from the *COUPLE family, the surface inventory of round vowels in Baiyina Oroqen can be shaped such that only the perceptually disadvantaged short nonhigh round vowels /o/ and /ɔ/ include persistent lip protrusion gestures. In addition, the representation of harmony as gestural overlap rather than feature association has proven advantageous in analyzing the distributions of the non-triggering long nonhigh round vowels. Not yet discussed is the role played by high vowels, which block rounding harmony in Baiyina Oroqen; this is taken up in section 4.5.3.

3.4.3 *Revisiting Capanahua: Regressive & Bidirectional Nasal Harmony*

Capanahua nasal harmony (section 2.2.2) presents a particularly interesting case of harmony triggering, as it exhibits harmony that is in some cases purely regressive and in other cases bidirectional. As such, an analysis of Capanahua must make use of constraints on both persistent and anticipatory gestures. In addition, bidirectional nasal harmony in Capanahua exhibits a pattern of harmony triggering that can be described as unconditional in the regressive

direction but conditional in the progressive direction. This pattern is accounted for straightforwardly in the Gestural Harmony Model, in which regressive and progressive harmony are the results of two different types of gestures, persistent and anticipatory, being permitted to surface in a language's phonological output forms.

Recall that in Capanahua, nasal harmony is triggered by the nasal stops /n/ and /m/ and affects preceding vowels, glides, and glottals. The data in (89) is reported by Loos (1967/1969) and is repeated from (34) in section 2.2.2.

- (89) a. [h̄amawu] 'step on it'
 b. [pōjān] 'arm'
 c. [bāwīn] 'catfish'
 d. [cīñīn] 'by fire'
 e. [cipōnki] 'downriver'
 f. [wurānwu] 'push it'
 g. [wurānjasāñnwu] 'push it sometime'
 h. [bānawu] 'plant it'

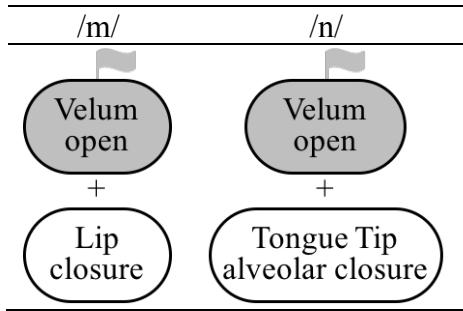
Bidirectional nasal harmony also arises in Capanahua under certain circumstances. In fast or casual speech, a coda nasal consonant's oral closure component is lost, but its nasality remains and triggers nasal harmony, as in (90).¹⁸ In such cases, nasality spreads both regressively and progressively from the original position of the deleted nasal consonant; progressive harmony can be observed in the forms in (90d-e).

- (90) a. [pōjā] 'arm' (cf. [pōjān])
 b. [bāwī] 'catfish' (cf. [bāwīn])
 c. [cīñī] 'by fire' (cf. [cīñīn])
 d. [wurāwū] 'push it' (cf. [wurānwu])
 e. [wurāñasāñwū] 'push it sometime' (cf. [wurānjasāñnwu])

¹⁸ This process, referred to as 'nasal loss' by Loos, does not apply to coda consonants that occur before a stop consonant, either oral or nasal. The details of this process are not a major focus of this section, and are not crucial to the analysis presented here.

Focusing first on the regressive component of this harmony process, in the Gestural Harmony Model this is accounted for by positing a surface phonological inventory in which these triggering nasal stops are accompanied by anticipatory (early-activating) velum opening gestures, as in the inventory in (91), repeated from (39) in section 2.2.2.

(91) Capanahua nasal consonant inventory



The grammar of a language like Capanahua, in which all nasal stops include anticipatory velum opening gestures on the surface, must ensure that even an underlying self-activating velum opening gesture will surface as anticipatory. As already demonstrated for Nandi tongue root harmony in section 3.2.2, this can be achieved by the high ranking of a markedness constraint from the ANTICIPATE(Gest_X) family. With ANTICIPATE(velum opening) ranked above SELFACTIVATE and IDENT(activation)-IO in Capanahua, all velum opening gestures will surface as anticipatory and will trigger regressive (leftward) harmony. The lack of progressive (rightward) harmony in this language, meanwhile, can be attributed to the high ranking of the constraint SELFDEACTIVATE. The full ranking used to generate regressive but not progressive harmony in Capanahua is provided in (92).

(92) Constraint ranking for regressive nasal harmony in Capanahua

- a. ANTICIPATE(velum opening) >> SELFACTIVATE, IDENT(activation)-IO
- b. SELFDEACTIVATE >> PERSIST(velum opening), IDENT(deactivation)-IO

The effect of this ranking is demonstrated by the tableau in (93) for Capanahua [hāmawu] ‘step on it.’ To demonstrate that a velum opening gesture will surface as anticipatory no matter its input activation parameter setting, the hypothetical input in this tableau includes a non-anticipatory velum opening gesture. In addition, to demonstrate that a velum opening gesture will surface as self-deactivating no matter its input deactivation parameter setting, the velum opening gesture in this hypothetical input is persistent.

(93) Tableau for regressive nasal harmony in [h̄amawu] ‘step on it’

Input: / h ₁ a ₂ m ₃ a ₄ w ₅ w ₆ /	Glottis open ₁	Tongue Body pharyng wide ₂	Lip closure ₃	Tongue Body pharyng wide ₃	Lip protr ₅	Tongue Body uvular narrow ₆	ANTICIPATE(velum opening)	SELFACTIVATE	IDENT(anticipation)-IO	SELFDEACTIVATE	PERSIST(velum opening)	IDENT(deactivation)-IO
	Glottis open ₁	Tongue Body pharyng wide ₂	Lip closure ₃	Tongue Body pharyng wide ₃	Lip protr ₅	Tongue Body uvular narrow ₆						
a.	[h ₁ a ₂ m ₃ a ₄ w ₅ w ₆]						*!	*	*	*	*	*
b.	[h̄ ₁ ˜ ₂ m ₃ a ₄ w ₅ w ₆]						*	*	*	*	*	*
c.	[h̄ ₁ ˜ ₂ m ₃ ˜ ₄ ˜ ₅ ˜ ₆]						*	*	*	*	*	*

In (93), candidate (a) [hamawu] surfaces faithfully with a velum opening gesture that is neither anticipatory nor persistent, and therefore triggers no nasal harmony. This fatally violates high-ranked ANTICIPATE(velum opening). Candidate (b) [h̄amawu] and candidate (c) [h̄amāwū]

both satisfy this constraint by surfacing with an anticipatory velum opening gesture that acts as a trigger of regressive harmony. The choice between these two candidates falls to the constraints on persistent gestures. Candidate (c) [hāmāwū], in which nasal harmony is bidirectional, violates high-ranked SELFDEACTIVATE, while winning candidate (b) [hāmawuu], in which harmony is only regressive, satisfies SELFDEACTIVATE. This tableau demonstrates that even when an underlying form contains a non-anticipatory, persistent velum opening gesture, the high ranking of ANTICIPATE(velum opening) and SELFDEACTIVATE in Capanahua ensures that nasal consonants will surface with an anticipatory, self-deactivating velum opening gesture and will therefore trigger regressive (leftward), but not progressive (rightward), nasal harmony.

Because of the high ranking of SELFDEACTIVATE, nasal consonants /n/ and /m/ do not trigger progressive (rightward) nasal harmony. However, as mentioned above, there is one specific instance in which progressive harmony is triggered: when a nasal consonant's primary consonantal gesture is deleted during fast or casual speech, leaving only its velum opening gesture. This stranded velum opening gesture that results from nasal consonant deletion must be coupled to some other gesture in the word in order to be pronounced. I assume that as a result, the velum opening gesture is coupled to the preceding vowel, where it surfaces as persistent, serving as a trigger of progressive nasal harmony.

It takes the addition of only one constraint to successfully account for this pattern of conditional bidirectional harmony. The triggering of progressive nasal harmony only when a velum opening gesture is coupled to a vocalic gesture and not to a consonantal gesture can be analyzed as satisfying a high-ranked *COUPLE constraint that penalizes the co-occurrence of a vocalic gesture with a self-deactivating velum opening gesture. This constraint is defined in (94).

- (94) *COUPLE(vowel, self-deactivating velum opening): Assign a violation mark to a vocalic gesture that is coupled to a self-deactivating velum opening gesture in the output.

Section 3.4.2 introduces the idea that cases of conditional triggering can be accounted for within the Gestural Harmony Model via the use of constraints that prevent perceptually weak bearers of some property from co-occurring with gestures that do not trigger harmony for that property. In the case of nasal harmony, vowels are claimed to be preferred triggers because they are perceptually weak bearers of nasality (Cole & Kisseeberth 1995; Walker 2014). By extending its period of activation, the velum opening gesture of a vowel increases its likelihood of being correctly perceived. As a result of the high ranking of the *COUPLE constraint in (94), in Capanahua a velum opening gesture will only surface as persistent when it is coupled to a vocalic gesture. Therefore, nasal consonants will not serve as triggers of progressive harmony, but vowels that become nasalized due to nasal consonant deletion will trigger progressive harmony. The triggering of regressive nasal harmony, meanwhile, remains unaltered, as it is the result of a distinct set of constraints on gestural anticipation.

The full set of constraints necessary for this analysis of bidirectional nasal harmony in Capanahua is provided in (95).

- (95) Constraint ranking for bidirectional nasal harmony in Capanahua

- a. ANTICIPATE(velum opening) >> SELFACTIVATE, IDENT(anticipation)-IO
- b. *COUPLE(vowel, self-deactivating velum opening) >> SELFDEACTIVATE >> PERSIST(velum opening), IDENT(deactivation)-IO

The interaction of the constraints ANTICIPATE(velum opening), SELFACTIVATE, and IDENT(anticipation)-IO has already been demonstrated by the tableau in (93), and is not affected by any of the constraints in (95b). The workings of the constraints in (95b) are illustrated below for the Capanahua form [wurānwui]~[wurāñwū] ‘push it.’ The tableau in (96) includes a form in

the typical register, in which nasal coda deletion does not take place, and only regressive harmony takes place. For reasons of space, the constraints that select an anticipatory velum opening gesture are not included, and only candidates with anticipatory gestures are considered.

Note also that in this form the tap [ɾ] blocks nasal harmony; this is set aside until section 4.4.4.

(96) Tableau for Capanahua [wurānwu] ‘push it’ (neutral register)

Input: / w ₁ w ₂ f ₃ a ₄ n ₅ w ₆ w̄ ₇ / (neutral register)		*COUPLE(V, self-deact. velum)	SELFDEACTIVATE	PERSIST(velum opening)	IDENT(deactivation)-IO
<p>[w₁ w₂ f₃ ā₄ n₅ w̄₆ w̄₇]</p> <p>a.</p>	*				
<p>[w₁ w₂ f₃ ā₄ n₅ w₆ w̄₇]</p> <p>b.</p>		*	*		

In (96), both candidates contain a velum opening gesture that is coupled to a primary consonantal gesture; therefore, high-ranked *COUPLE(vowel, self-deactivating velum opening) is not relevant. In candidate (a) [wurāñwū] the velum opening gesture is persistent and triggers progressive nasal harmony, satisfying PERSIST(velum opening) but fatally violating higher-ranked SELFDEACTIVATE. In the winning candidate (b) [wurānwū] there is no progressive nasal harmony, as the velum opening gesture is self-deactivating, satisfying SELFDEACTIVATE. This ranking successfully captures the ability of a nasal consonant to trigger regressive, but not progressive, nasal harmony in the neutral register in Capanahua.

When the alveolar closure gesture of coda /n/ is deleted in the fast or casual register, the picture is different. In this case, harmony is both regressive and progressive, as demonstrated by the tableau in (97) for [wurāñwū] ‘push it.’ Here, the alveolar closure gesture of /n/ is deleted in both of the output candidates. As a result, the velum opening gesture of /n/ couples to the gesture of the preceding vowel. As it is not the focus of this analysis, I set aside determining what drives the deletion of nasal consonants in fast and/or casual speech.

(97) Tableau for Capanahua [wurāwū] ‘push it’ (fast/casual register)

Input: / w ₁ w ₂ f ₃ a ₄ n ₅ w ₆ w ₇ / (fast/casual register)							*COUPLE(V, self-deact. velum)	SELFDEACTIVATE	PERSIST(velum opening)	IDENT(deactivation)-IO
Lip protr ₁	TB uvu nar ₂	TT alv tap ₃	TB phar wide ₄	TT alv clo ₅	Lip protr ₆	TB uvu nar ₇				
					Velum open ₅					
w ₁	w ₂	f ₃	ā ₄	w̄ ₆	w̄ ₇		*			
Lip protr ₁	TT alv tap ₃		Velum open ₄							
Tongue Body uvular narrow ₂	Tongue Body pharyngeal wide ₄	Tongue Body uvular narrow ₇								
a.										
w ₁	w ₂	f ₃	ā ₄	w ₆	w ₇		*!	*	*	
Lip protr ₁	TT alv tap ₃		Velum open ₄							
Tongue Body uvular narrow ₂	Tongue Body pharyngeal wide ₄	Tongue Body uvular narrow ₇								
b.										

In (97), high-ranked *COUPLE(vowel, self-deactivating velum opening) is active as the velum opening gesture is coupled to the preceding vowel gesture in both candidates. Now, it is candidate (a) [wurāwū] that is the winner. While this candidate still violates SELFDEACTIVATE, it satisfies high-ranked *COUPLE(vowel, self-deactivating velum opening). Candidate (b) [wurāwū], in which the velum closure gesture is self-deactivating and there is no progressive nasal harmony, fatally violates this high-ranked *COUPLE constraint.

This analysis bears some similarity to Safir's (1982) analysis of Capanahua nasal harmony. He claims that bidirectional nasal harmony is triggered by a vocalic segment immediately preceding a nasal consonant, which optionally deletes only after a process of local nasalization of the vocalic segment. In the gestural analysis proposed here, bidirectional (as opposed to strictly regressive) nasal harmony is triggered when a velum opening gesture is coupled to a vocalic gesture as a result of the deletion of a nasal consonant's oral constriction. In a sense, then, it is the nasalized vocalic element that triggers harmony.¹⁹

Nasal harmony in Capanahua is an interesting example of a system of harmony triggering in which a condition on the identity of a triggering segment is enforced in one direction of harmony but not the other. This is accounted for straightforwardly in the Gestural Harmony Model, in which progressive and regressive harmony are the results of two distinct gestural parameter settings and are therefore subject to different sets of constraints. While these constraints parallel one another in their definitions and in the ways in which they shape phonological inventories to include or exclude gestures with certain parameter settings, the two sets of constraints do not interact with one another. In Capanahua nasal harmony, in which the triggering patterns of regressive and progressive harmony are distinct from one another, this independence of the constraint sets is an asset of the model.

3.5 Conditional and Contrastive Triggering: Tongue Root Harmony in Classical Manchu

Throughout this chapter, the Gestural Harmony Model has proven itself capable of accounting for multiple sources of complexity in patterns of harmony triggering. As discussed in sections 3.3 and 3.4, such complexity includes cases in which conditions are placed on trigger

¹⁹ Trigo (1988) offers a slightly different analysis of the progressive component of Capanhua nasal harmony, proposing that harmony is triggered by a debuccalized nasal consonant that fully deletes later in the derivation.

position and identity, as well as cases of contrastive triggering. Classical Manchu (Tungusic; 17th to 19th century China) provides a unique case of a tongue root harmony system characterized by contrastive triggering, conditional triggering, and restrictions on the position of triggers. This makes it a good case with which to test the claim that within the Gestural Harmony Model even quite complex harmony triggering patterns can be reduced to relatively simple principles of inventory shaping and restrictions on the distributions of certain types of segments or gestures.

While earlier research by Vago (1973), Odden (1978), and others treats the harmony system of Classical Manchu as one based on vowel backness, Zhang (1996) and Li (1996) argue that the assignment of vowels into one of two harmony classes is best understood based on tongue root position. The vowel system of Classical Manchu according to Zhang is provided in (98).

(98) Classical Manchu vowel inventory

	ATR Vowels		non-ATR Vowels	
High	i	u	ø	
Nonhigh	ə		a	ɔ

Classical Manchu has a tongue root harmony system in which non-ATR /ø/ alternates with ATR /u/, and non-ATR /a/ alternates with ATR /ə/.²⁰ As in other Tungusic languages, the tongue root specification of the initial syllable determines whether following vowels in the root and any suffixes are ATR or non-ATR. In an initial syllable, the vowel [ə] always triggers ATR harmony (99a-c); non-ATR [a] and [u] may never follow [ə]. [ə] may never occur in a non-initial syllable except as a product of harmony, i.e., following a harmony-triggering ATR vowel. All data are from Zhang (1996).

²⁰ Classical Manchu also exhibits rounding harmony among nonhigh vowels, causing /a/ to alternate with /ɔ/. However, I set aside discussion of rounding harmony in order to focus on the complexities of the language's patterns of ATR harmony triggering.

- (99) a. [səbjə-ŋə] ‘joyous’ d. [kimu-ŋə] ‘harboring hatred’
 b. [hərə-ku] ‘ladle’ e. [sisə-ku] ‘sieve’
 c. [hətu-kən] ‘somewhat stocky’ f. [ujə-kən] ‘somewhat heavy’

If the non-ATR vowels [a] or [ʊ] occur in an initial syllable, all following nonhigh vowels must surface as non-ATR [a], as in (100). High vowels in non-initial syllables are unrestricted in terms of tongue root specification, with [i], [u], and [ʊ] all occurring in those positions (100c-g). When [i] and [u] occur non-initially, they never trigger ATR harmony in following vowels (100d-g).

- (100) a. [aga-ŋga] ‘of rain’
 b. [hola-ŋga] ‘crying’
 c. [malhu-ŋga] ‘frugal’
 d. [kani-ŋga] ‘agreeing’
 e. [dacu-kan] ‘somewhat sharp’
 f. [goni-ŋga] ‘thoughtful’
 g. [hodu-kan] ‘somewhat fast’

Of particular interest here is the fact that the high ATR vowels [i] and [u] do not uniformly trigger ATR harmony when they occur in an initial syllable, as is the case for non-high [ə]. Instead, harmony is triggered by some high vowels and not others. In (101a-e), [i] and [u] trigger ATR harmony within and across morpheme boundaries, while in (101f-i) ATR harmony is not triggered.

- (101) a. [sitə-ku] ‘bed-wetter’ f. [nimasa-ku] ‘two-man boat’
 b. [cisu-də] ‘act for interest’ g. [nilhə-da] ‘be slick’
 c. [hurə-nə] ‘arch’ h. [tuwa-na] ‘go to look’
 d. [urgu-ŋgə] ‘joyous’ i. [mukə-ha-] ‘held a liquid in the mouth’
 e. [ungi-hə] ‘sent off’

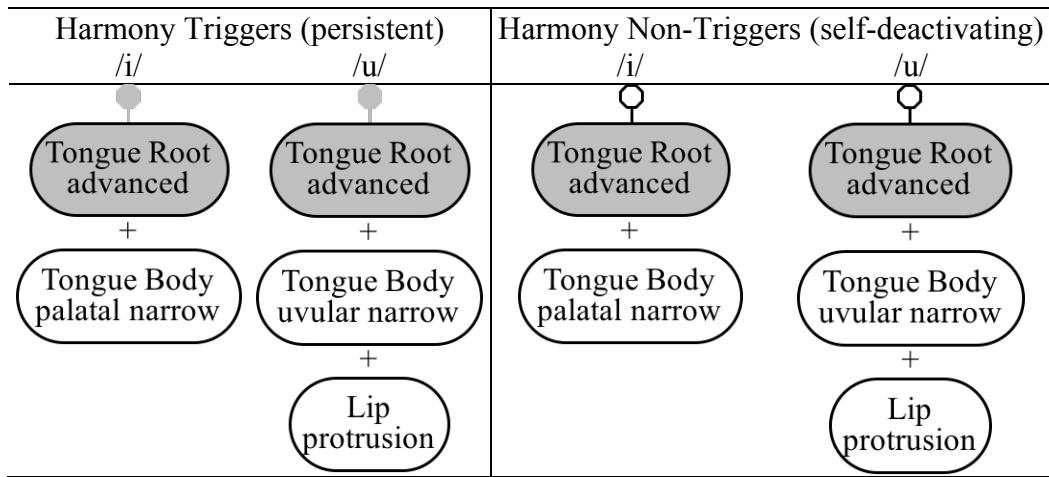
Multiple high ATR vowels may occur in a root without being the product of harmony; these roots will take non-ATR suffixes, as in (102). It is possible for high vowels with independent ATR specifications to surface in a sequence, as in (102a-d), giving the appearance of a harmonizing root while failing to trigger harmony in suffixes. While such a sequence of

ATR vowels may appear to be the result of within-root harmony, there is evidence suggesting that it is not; each high ATR vowel is independently specified as ATR. This is easier to see in (102e-f), whose roots contain multiple high ATR vowels separated by a non-ATR vowel. Since the high ATR vowels in the initial syllables of these forms do not trigger harmony, these roots take non-ATR suffixes.

- (102) a. [sifi-ko] ‘hairpin’
b. [bilu-ŋga] ‘pacified’
c. [fuli-ŋga] ‘lucky’
d. [usu-kan] ‘somewhat fussy’
e. [mijali-ku] ‘measurer’
f. [duwali-ŋga] ‘of the category’

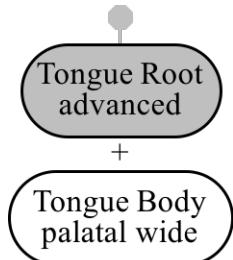
The pattern of harmony triggering exhibited by the high vowels in Classical Manchu represents another case of contrastive triggering similar to those seen in Acehnese and Rejang nasal harmony. Following C. Smith (2017a), I analyze Classical Manchu as having two series of high ATR vowels: one that triggers ATR harmony, and one that does not. The Gestural Harmony Model is able to capture this straightforwardly by allowing these vowels to contrast with respect to the deactivation parameters of their accompanying tongue root advancement gestures. The high ATR vowel inventory of Classical Manchu, which contains both persistent (non-self-deactivating) and self-deactivating tongue root advancement gestures, is provided in (103).

(103) Gestural representation of Classical Manchu high ATR vowel inventory



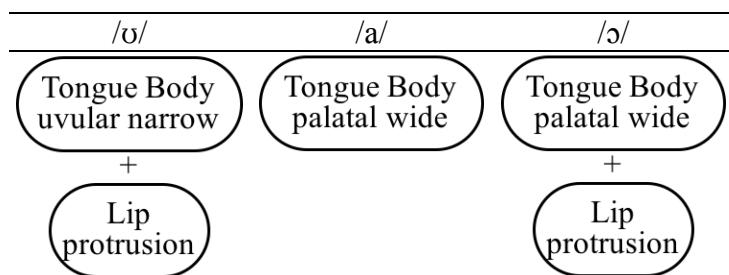
The nonhigh ATR vowel /ə/, on the other hand, is always a trigger of ATR harmony, and shows no such deactivation parameter contrast. This vowel always surfaces with a persistent tongue root advancement gesture, as in (104).

(104) Gestural representation of Classical Manchu /ə/



The non-ATR vowels /o/, /a/, and /ɔ/, meanwhile, are represented by vowel gestures that are not accompanied by tongue root gestures, as in (105).

(105) Gestural representation of Classical Manchu non-ATR vowel inventory



In addition to shaping the surface vowel inventory of Classical Manchu such that it includes the vowels in (103)-(105), the phonological grammar must account for their different distributional restrictions. It is not the case that any vowel may appear in any position in a word. Non-triggering /i/ and /u/ are unrestricted, appearing both in initial and non-initial syllables. Triggering /i/ and /u/, however, are restricted to the initial syllable of a word. As in Acehnese and Rejang nasal harmony, the contrast between self-deactivating and persistent gestures is restricted to a privileged position. In addition, while exhibiting no harmony triggering contrast, the nonhigh ATR /ə/ is also subject to a positional restriction, occurring only in the initial syllable of a word or as a product of ATR harmony. Despite their complexity, the inventory shaping and distributional restrictions exhibited by the Classical Manchu vowel system can be achieved within the Gestural Harmony Model via the interaction of a small set of markedness and faithfulness constraints. These constraints and their interaction are described in the remainder of this section.

Focusing first on non-initial syllables, i.e. non-privileged positions, a high ATR vowel may never trigger harmony and therefore must always surface with a self-deactivating tongue root advancement gesture. Therefore, the constraint SELFDEACTIVATE must be ranked above PERSIST(ATR) and a general version of IDENT(deactivation)-IO. This ranking eliminates the contrast between the self-deactivating and persistent tongue root advancement gesture in Classical Manchu in all positions within a word. To preserve the underlying specification of a gesture's deactivation parameter only in the privileged position of the initial syllable, IDENT(deactivation)_{First σ} , a positional faithfulness constraint (Beckman 1997, 1998), must be ranked above SELFDEACTIVATE. With this ranking, the contrast between self-deactivating and

persistent tongue root advancement gestures will be preserved in the first syllable of a word, and neutralized elsewhere.

Classical Manchu exhibits not only contrastive harmony triggering but a form of conditional triggering as well. Unlike its high ATR counterparts, in an initial syllable the nonhigh ATR /ə/ does not contrast for its ability to trigger harmony, but instead triggers harmony exceptionlessly. It is necessary, then, to restrict /ə/ from being accompanied by a self-deactivating tongue root advancement gesture. As discussed in section 3.4, such a pattern can be achieved via a gestural co-occurrence constraint from the *COUPLE family. In the case of Classical Manchu, this constraint penalizes a nonhigh vowel that is accompanied by a self-deactivating tongue root advancement gesture, as defined in (106).

- (106) *COUPLE(nonhigh vowel, self-deactivating ATR): Assign a violation mark to a nonhigh vowel gesture and a self-deactivating tongue root advancement gesture that are coupled to one another.

This constraint must outrank IDENT(deactivation)-IO_{Firstσ}; even in the privileged position of the initial syllable, triggering is not contrastive for the vowel /ə/ in Classical Manchu.

Finally, recall that [ə] may not occur in a non-initial syllable except as a product of harmony, i.e., except when it is overlapped by the persistent tongue root advancement gesture of a harmony-triggering vowel in an initial syllable. This distributional restriction is achieved via the inclusion of two MAX(gesture)-IO constraints, one general and one position-specific. In a non-initial syllable, only self-deactivating tongue root advancement gestures are permitted due to the ranking of SELFDEACTIVATE over PERSIST(ATR) and the general version of IDENT(deactivation)-IO. As a result, high ATR vowels are non-triggers in these positions. The nonhigh ATR vowel [ə], on the other hand, may never be accompanied by a non-triggering, self-deactivating tongue root gesture due to high-ranked *COUPLE(nonhigh V, self-deact. ATR).

Instead, any nonhigh vowel in a non-initial syllable that is not an undergoer of harmony must surface as non-ATR [a]. The fact that a nonhigh vowel must satisfy both *COUPLE and SELFDEACTIVATE, even if it requires deletion of an underlying tongue root advancement gesture, indicates that both *COUPLE and SELFDEACTIVATE must outrank a constraint from the MAX(gesture)-IO family. This constraint is defined in (107).

- (107) MAX(ATR)-IO: Assign a violation mark to a segment (set of gestures) that includes a tongue root advancement gesture in the input if its output correspondent does not include that gesture.

This constraint must be ranked above IDENT(deactivation)-IO. This ranking will ensure that the tongue root gesture of a high vowel is never deleted in order to satisfy SELFDEACTIVATE; it is only manipulated with respect to its gestural deactivation parameter.

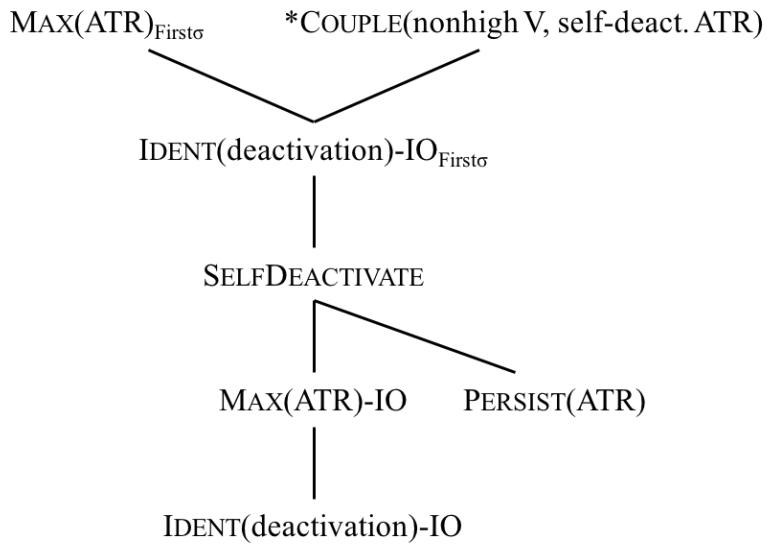
In an initial syllable, however, the tongue root advancement gesture of nonhigh /ə/ is permitted to surface. Therefore, it is necessary to include a position-specific version of MAX(ATR)-IO, defined in (108).

- (108) MAX(ATR)-IO_{Firstσ}: Assign a violation mark to a segment (set of gestures) in an initial syllable that includes a tongue root advancement gesture in the input if its output correspondent does not include that gesture.

With both MAX(ATR)-IO_{Firstσ} and *COUPLE dominating SELFDEACTIVATE, the tongue root advancement gesture of underlying /ə/ will always surface as persistent, and will therefore always trigger ATR harmony. In addition, by ranking MAX(ATR)-IO_{Firstσ} over IDENT(deactivation)-IO_{Firstσ}, the grammar will compel any underlying /ə/ that is in an initial syllable and is accompanied by a self-deactivating tongue root advancement gesture to change the deactivation parameter of that gesture rather than deleting it.

The full ranking of constraints necessary to account for Classical Manchu tongue root harmony is provided in (109).

(109) Constraint ranking for Classical Manchu tongue root harmony



The analysis of the distribution of harmony triggering and non-triggering vowels in Classical Manchu using the constraint ranking in (109) is demonstrated in the following tableaux. The first tableau in (110) is for the form [sisə-ku] ‘sieve,’ in which an /i/ in the initial syllable triggers ATR harmony throughout the rest of the word. For the sake of space and clarity, only the vowel gestures for the input and output candidates are included.

(110) Tableau for Classical Manchu [sisə-ku] ‘sieve’

<p>Input: /s i₁ s a₂ – k u₃ /</p>	MAX(ATR)-IO _{Firstσ} *COUPLE(nonhigh V, self deact. ATR) IDENT(deactivation)-IO _{Firstσ}	SELFDEACTIVATE MAX(ATR)-IO IDENT(deactivation)-IO PERSIST(ATR)
		*
	*!	* * *
	*!	*

The input of the tableau in (110) contains the vowel /i/ with a persistent tongue root advancement gesture. In outputs (a) and (b), this vowel is in the initial syllable. The winning candidate (a) [sisə-ku] surfaces with a faithfully realized persistent tongue root advancement gesture, violating SELFDEACTIVATE but satisfying higher-ranked IDENT(deactivation)_{Firstσ}. In candidate (b) [sisa-ku] the tongue root advancement gesture of [i] is self-deactivating, resulting

in the following vowels surfacing as their non-ATR alternants. This satisfies SELFDEACTIVATE but fatally violates higher-ranked IDENT(deactivation)_{First σ} , as well as the low-ranked general IDENT(deactivation)-IO and PERSIST(ATR). The candidate that is faithful to the input's specified deactivation parameter for tongue root advancement is the winner. Candidate (c) [sisa-kv] vacuously satisfies the markedness constraints and both IDENT(deactivation)-IO constraints by deleting the tongue root advancement gesture altogether. However, in doing so it fatally violates both high-ranked MAX(gesture)-IO_{First σ} as well as general MAX(gesture)-IO.

The faithful candidate is also selected when the input contains a self-deactivating tongue root advancement gesture in an initial syllable. This is demonstrated in the tableau in (111) for [nilhu-da] 'be slick.'

(111) Tableau for Classical Manchu [nilhu-da] ‘be slick’

<p>Input: /n i₁ l h u₂ – d a₃ /</p> <p>Tongue Body palatal narrow₁</p> <p>Tongue Body uvular narrow₂</p> <p>Tongue Body palatal wide₃</p> <p>Tongue Root advanced₁</p>	<p>MAX(ATR)-IO_{Firstσ}</p> <p>*COUPLE(nonhigh V, self deact. ATR)</p> <p>IDENT(deactivation)-IO_{Firstσ}</p> <p>SELFDEACTIVATE</p> <p>MAX(ATR)-IO</p> <p>IDENT(deactivation)-IO</p> <p>PERSIST(ATR)</p>
<p>a. [nilhu-də]</p> <p>[i₁ u₂ a₃]</p> <p>Tongue Root advanced₁</p> <p>Tongue Body palatal narrow₁</p> <p>Tongue Body uvular narrow₂</p> <p>Tongue Body palatal wide₃</p>	<p>*!</p> <p>*</p> <p>*</p>
<p>b. [nilhu-da]</p> <p>[i₁ u₂ a₃]</p> <p>Tongue Root advanced₁</p> <p>Tongue Body palatal narrow₁</p> <p>Tongue Body uvular narrow₂</p> <p>Tongue Body palatal wide₃</p>	<p>*</p>
<p>c. [nilhu-da]</p> <p>[i₁ u₂ a₃]</p> <p>Tongue Body palatal narrow₁</p> <p>Tongue Body uvular narrow₂</p> <p>Tongue Body palatal wide₃</p>	<p>*!</p> <p>*</p> <p>*</p>

In (111), the input contains an /i/ with a self-deactivating tongue root advancement gesture. In candidate (a) [nilhu-də] this gesture surfaces as persistent, violating both IDENT(deactivation)-IO constraints as well as SELFDEACTIVATE. The winning candidate (b) [nilhu-da] faithfully realizes the tongue root advancement gesture as self-deactivating, crucially satisfying high-ranked IDENT(deactivation)_{Firstσ} and violating only low-ranked PERSIST(ATR).

Again, candidate (c) [nilhv̥-da] deletes the tongue root advancement gesture and fatally violates both versions of MAX(gesture)-IO. The ranking in (109), then, has successfully preserved the contrast between self-deactivating and persistent tongue root advancement gestures in an initial syllable.

When a high vowel occurs in a non-initial syllable, it never triggers harmony, regardless of what its input specification for self-deactivation or persistence may be. This is demonstrated by the tableau in (112) for [kani-ŋga] ‘agreeing.’ In order to demonstrate that a tongue root advancement gesture will always surface as self-deactivating in a non-initial syllable, a hypothetical input with a persistent tongue root advancement gesture is posited.

(112) Tableau for Classical Manchu [kani-ŋga] ‘agreeing’

Input: / k a ₁ n i ₂ - ŋ g a ₃ /	Tongue Body palatal wide ₁	Tongue Body palatal narrow ₂	Tongue Body palatal wide ₃	Tongue Root advanced ₂	MAX(ATR)-IO _{Firstσ}	*COUPLE(nonhigh V, self deact. ATR)	IDENT(deactivation)-IO _{Firstσ}	SELFDEACTIVATE	MAX(ATR)-IO	IDENT(deactivation)-IO	PERSIST(ATR)
a. [kani-ŋgə]	[a ₁ i ₂ a ₃]			Tongue Root advanced ₁				*			
b. [kani-ŋga]	[a ₁ i ₂ a ₃]			Tongue Root advanced ₁					*	*	
c. [kani-ŋga]	[a ₁ i ₂ a ₃]			Tongue Body palatal wide ₁ Tongue Body palatal narrow ₂ Tongue Body palatal wide ₃				*			

In (112), IDENT(deactivation)-IO_{Firstσ} is not relevant, as the tongue root advancement gesture of [i] does not occur in the initial syllable of either candidate output. Therefore, in this form the choice between candidates falls to the lower-ranked constraints. Candidate (a) [kani-ŋgə], in which the tongue root advancement gesture of [i] is persistent and therefore a trigger of harmony, fatally violates SELFDEACTIVATE. Winning candidate (b) [kani-ŋga], on the

other hand, satisfies this constraint with its self-deactivating tongue root advancement gesture at the expense of violating the low-ranked general IDENT(deactivation)-IO, as well as PERSIST(ATR). Candidate (c) [kani-ŋga] avoids violation of both the IDENT(deactivation)-IO constraints and SELFDEACTIVATE by deleting the tongue root advancement gesture altogether, but is ruled out by violation of the general version of MAX(gesture)-IO. This tableau demonstrates that no matter a tongue root advancement gesture's input deactivation parameter setting, it will always surface as self-deactivating in a non-initial syllable. This accounts for the inability of vowels to trigger ATR harmony outside of the initial syllable.

Turning now to the pattern of harmony triggering exhibited by nonhigh /ə/, the tableau in (113) demonstrates the evaluation of the form [hərə-ku] ‘ladle.’ In order to show that /ə/ in an initial syllable will always surface with a persistent tongue root advancement gesture and will therefore always trigger harmony, a hypothetical input containing a self-deactivating tongue root advancement gesture is posited.

(113) Tableau for Classical Manchu [hərə-ku] ‘ladle’

<p>Input: / h ə₁ r a₂ – k u₃ /</p>	<p>Tongue Body palatal wide₁</p> <p>Tongue Body palatal wide₂</p> <p>Tongue Body uvular narrow₃</p> <p>Tongue Root advanced₁</p>	<p>MAX(ATR)-IO_{Firstσ}</p> <p>*COUPLE(nonhigh V, self-deact. ATR)</p> <p>IDENT(deactivation)-IO_{Firstσ}</p> <p>SELFDEACTIVATE</p>	<p>MAX(ATR)-IO_{Firstσ}</p> <p>IDENT(deactivation)-IO</p> <p>PERSIST(ATR)</p>
<p>a. [hərə-ku]</p>	<p>[ə₁ ə₂ u₃]</p> <p>Tongue Root advanced₁</p> <p>Tongue Body palatal wide₁ Tongue Body palatal wide₂ Tongue Body uvular narrow₃</p>	<p>*</p> <p>*</p>	<p>*</p>
<p>b. [həra-ku]</p>	<p>[ə₁ a₂ u₃]</p> <p>Tongue Root advanced₁</p> <p>Tongue Body palatal wide₁ Tongue Body palatal wide₂ Tongue Body uvular narrow₃</p>	<p>*!</p>	<p>*</p>
<p>c. [hara-ko]</p>	<p>[a₁ a₂ u₃]</p> <p>Tongue Body palatal wide₁ Tongue Body palatal wide₂ Tongue Body uvular narrow₃</p>	<p>*!</p>	<p>*</p>

In (113), the tongue root advancement gesture in winning candidate (a) [hərə-ku] is persistent and triggers ATR harmony, violating SELFDEACTIVATE as well as both IDENT(deactivation)-IO constraints while satisfying highest-ranked MAX(ATR)-IO_{Firstσ} and *COUPLE. The faithful candidate (b) [həra-ku] surfaces with a self-deactivating tongue root advancement gesture, satisfying all faithfulness constraints but fatally violating high-ranked

*COUPLE(nonhigh vowel, self-deact. ATR). This *COUPLE constraint requires a nonhigh ATR vowel to trigger harmony, regardless of the input specification of its tongue root advancement gesture. Both IDENT(deactivation)-IO constraints are outranked by *COUPLE and therefore are unable to preserve any underlying contrast in triggering ability among nonhigh ATR vowels. MAX(ATR)-IO_{Firstσ} is fatally violated by candidate (c) [hara-ku], demonstrating that in the initial syllable, violation of *COUPLE is avoided by altering a tongue root advancement gesture's deactivation parameter rather than by deleting the offending gesture.

Finally, the tableau in (114) for the word [hula-ŋga] 'crying' includes the hypothetical input /hulə-ŋga/, which contains an ill-formed word-medial /ə/. In the input, its tongue root advancement gesture is self-deactivating, but this is an arbitrary decision and does not affect the outcome of EVAL.

(114) Tableau for [hola-ŋga] ‘crying’

Input: / h u ₁ l ə ₂ - ŋ g a ₃ /	Tongue Body uvular narrow ₁	Tongue Body palatal wide ₂	Tongue Body palatal wide ₃	Tongue Root advanced ₂	MAX(gesture)-IO _{Firstσ} *COUPLE(nonhigh V, self deact. ATR)	IDENT(deactivation)-IO _{Firstσ}	SELFDEACTIVATE	MAX(gesture)-IO	IDENT(deactivation)-IO	PERSIST(ATR)
a. [hulə-ŋgə]	[u ₁ ə ₂ ə ₃]			Tongue Root advanced ₁			*!		*	
b. [holə-ŋga]	[u ₁ ə ₂ a ₃]			Tongue Root advanced ₁			*!			*
c. [hola-ŋga]	[u ₁ a ₂ a ₃]			Tongue Body uvular narrow ₁				*		

Because no tongue root gesture appears in the initial syllable of any of the candidates in (114), MAX(ATR)-IO_{Firstσ} and IDENT(deactivation)-IO_{Firstσ} do no work here. Candidate (a) [hulə-ŋgə] contains a persistent tongue root gesture in a non-initial syllable, fatally violating SELFDEACTIVATE, as well as low-ranked general IDENT(deactivation)-IO. Candidate (b) [holə-ŋga], in which the tongue root gesture is self-deactivating, satisfies SELFDEACTIVATE but

fatally violates *COUPLE, which prohibits self-deactivating tongue root advancement gestures from co-occurring with nonhigh vowel gestures. Winning candidate [hola-ŋga] (c) satisfies both of these constraints by deleting the tongue root gesture, causing underlying /ə/ to surface as [a]. With the ranking of constraints in (109), this analysis is able to account for the distributions of both high and nonhigh vowels in Classical Manchu.

The only exception to the generalization that [ə] does not occur outside of an initial syllable is when it does so as a result of undergoing harmony. The reason for this is apparent in several of the winning candidates already presented. When a nonhigh vowel follows a triggering ATR vowel in an initial syllable, it surfaces as ATR not because it is coupled to its own tongue root advancement gesture, but because it has been overlapped by the tongue root advancement gesture of an ATR vowel in an initial syllable. The same situation arose in the analyses of Kyrgyz rounding harmony (section 3.2.1), in which round vowels may only occur in non-initial syllables as the result of harmony, and Baiyina Oroqen rounding harmony (section 3.4.2), in which the same positional restriction is placed on nonhigh round vowels.

Classical Manchu tongue root harmony presents an exceptionally complex pattern of harmony triggering. High ATR vowels display contrastive triggering of tongue root harmony, while nonhigh ATR vowels are required to always trigger harmony. This is combined with the restriction of harmony triggers to the privileged position of the initial syllable. The Gestural Harmony Model successfully accounts for all of this through the interaction of constraints on a gesture's deactivation parameter (SELFDEACTIVATE), general and positional faithfulness constraints (MAX(ATR)-IO and IDENT(deactivation)-IO), and constraints on gestural co-occurrence (*COUPLE(nonhigh vowel, self-deactivating ATR)). To fully appreciate the complexity of this system, compare it with one of the simple cases of harmony triggering

presented in section 3.2., which rely only on the high ranking of PERSIST(Gest_X) or ANTICIPATE(Gest_X). In Classical Manchu, on the other hand, PERSIST(ATR) occupies the lowest constraint stratum. This is indicative of the importance of viewing the presence of harmony as the result of the interaction between markedness and faithfulness constraints such that they shape phonological inventories to include segments with harmony-triggering gestures, and of restricting those segments to certain positions. A constraint that simply requires harmony, be it PERSIST(Gest_X) in a gestural framework or SPREAD(F) in a featural framework, is unable to capture the full range of complexity exhibited by patterns of harmony triggering.

3.6 Alternative Accounts of Harmony Triggering

The Gestural Harmony Model's characterization of the ability to trigger harmony as a property that is encoded within the representation of a trigger is unique among mainstream approaches to the analysis of harmony. This approach is crucial to its success in capturing complex patterns of harmony triggering, in particular those that involve the idiosyncratic triggering of harmony. In the Gestural Harmony Model, such patterns are analyzed as the result of a language's surface phonological inventory being shaped such that it preserves the contrast between triggering and non-triggering versions of a segment whose gestural makeup may be otherwise identical. This can be achieved via the high ranking of faithfulness that preserves gestures' persistence and/or activation parameters.

In this section I examine several alternative methods of driving harmony, both gesture-based and feature-based, and show that they are unable to account for patterns of contrastive triggering without invoking additional theoretical mechanisms. The alternative gestural model I consider in this section lacks the mechanisms of gestural persistence and anticipation that are crucial to the Gestural Harmony Model's success in accounting for cases of contrastive

triggering. In the case of feature-based theories, meanwhile, commonly used mechanisms for dealing with idiosyncratic or exceptional application of phonological processes including (1) constraint indexation and (2) featural pre- and underspecification make several undesirable typological predictions, both over- and undergenerating patterns of harmony triggering.

3.6.1 Gestural Spreading via Direct Activation Manipulation

In accounting for patterns of contrastive triggering of harmony, the Gestural Harmony Model distinguishes itself from the conception of harmony driving in a similar gestural model proposed by Tejada (2012). In Tejada's theory of gestural spreading based on direct activation manipulation, tone spreading across multiple syllables is proposed to be the result of the failure of a tone gesture to deactivate at a specified phase. This failure of a tone gesture to deactivate itself is enforced by the constraint *SELF-DEACTIVATE-BY-CLOCK,²¹ which penalizes gestural self-deactivation. In contrast, the constraint *SPAN-SYLL penalizes a gesture that extends its period of activation beyond a single syllable. Similar, but not identical, constraints are adopted in the Gestural Harmony Model: PERSIST(Gest_X) penalizes a self-deactivating gesture of type X, while SELFDEACTIVATE penalizes any persistent (non-self-deactivating) gesture. Though these sets of constraints appear quite similar, there are crucial differences in how they are implemented, how they interact, and the typologies they generate. Because Tejada's framework assumes that all regressive (leftward) harmony is the result of movement, the discussion in this section of how her model compares to the Gestural Harmony Model focuses only on progressive harmony.

As discussed throughout this chapter and chapter 2, in the Gestural Harmony Model, gestures may be either self-deactivating or persistent (non-self-deactivating). Progressive

²¹ Gestural planning oscillators are often referred to as ‘clocks.’

(rightward) harmony occurs in languages in which the language's surface phonological inventory includes persistent gestures. A persistent gesture will always surface in a language when PERSIST(Gest_X) outranks both SELFDEACTIVATE and the faithfulness constraint IDENT(deactivation)-IO. Similarly, a self-deactivating gesture will surface in a language with the ranking of SELFDEACTIVATE over PERSIST(Gest_X) and IDENT(deactivation)-IO. A third possibility is that the faithfulness constraint will outrank both SELFDEACTIVATE and PERSIST(Gest_X), allowing both types of gestures to surface and potentially to contrast. This third possible ranking allows the Gestural Harmony Model to account for cases of contrastive harmony triggering, including the nasal harmony systems of Acehnese and Rejang (section 3.3) and ATR harmony in Classical Manchu (section 3.5).

In the direct activation manipulation approach to tone spreading, however, tone gestures are not specified as either persistent or self-deactivating. As a result, the constraints *SELF-DEACTIVATE-BY-CLOCK and *SPAN-SYLL do not evaluate the type of tone gesture present in a form, and there are no faithfulness constraints that preserve a gesture's underlying deactivation specification. Instead, these constraints directly drive gestures to be active for certain periods of time. *SPAN-SYLL is satisfied by a tone gesture whose period of activation is equal in length to that of the vocalic gesture to which it is coupled. It does not matter if this single-syllable activation of the tone gesture is the result of its self-deactivation or the result of blocking by a tone gesture in the following syllable. Likewise, *SELF-DEACTIVATE-BY-CLOCK is satisfied by a tone gesture whose period of activation is equal in length to that of the vowel gesture to which it is coupled, provided that it is immediately followed by a blocking tone gesture in the next syllable. Again, it does not matter if this single-syllable activation of the tone gesture is the result of self-deactivation or of external deactivation; in accordance with *SELF-DEACTIVATE-BY-

CLOCK, it has deactivated in a position adjacent to a blocker. While the Gestural Harmony Model's constraints PERSIST(Gest_X) and SELFDEACTIVATE operate to produce gestures of different types, those either with or without the potential to trigger harmony, the use of *SELF-DEACTIVATE-BY-CLOCK and *SPAN-SYLL represent an analysis in which there is a more direct manipulation of the period of gestural activation within output candidates.

The Gestural Harmony Model's reliance on constraints against certain types of gestures, either self-deactivating or persistent, rather than constraints that directly manipulate a gesture's period of activation, presents significant advantages in analyzing more complex patterns of triggering, especially contrastive triggering. By viewing progressive harmony as the result of the presence of a persistent gesture in a phonological form, the presence or absence of harmony in a language is reduced to the relatively simple matter of inventory shaping via the interaction of markedness and faithfulness constraints that reference a gesture's deactivation parameter. The patterns of harmony triggering that some languages exhibit, then, are the result of constraining the distributions of the self-deactivating and persistent gestures in a language's phonological inventory.

The high ranking of IDENT(deactivation)-IO and/or IDENT(activation)-IO is crucial to building an accurate account of cases of contrastive triggering, including the nasal harmonies of Acehnese and Rejang and the ATR harmony of Classical Manchu. In addition, the ability to relativize this faithfulness constraint to privileged positions accounts for the distinct distributional properties of triggering and non-triggering segments in these languages. Using only the markedness constraints *SELF-DEACTIVATE-BY-CLOCK and *SPAN-SYLL, it is unclear how such attested patterns of triggering could be generated without adopting additional theoretical mechanisms, such as constraint indexation (Pater 2000, 2009a; Flack 2008; Becker

2009; Finley 2010). In doing so, the direct activation manipulation approach to gestural spreading would essentially be duplicating the results of the Gestural Harmony Model with respect to cases of idiosyncratic triggering, albeit via the inclusion of an arbitrary specification of a gesture (whether it bears an index to a harmony-driving constraint) instead of a meaningful gestural parameter (self-(de)activation). Furthermore, it is unclear whether the positional restrictions on the contrast between triggers and non-triggers of harmony, exhibited in Acehnese, Rejang, and Classical Manchu, could be captured by a model that employs constraint indexation.

3.6.2 *Constraint Indexation*

In a feature-based framework, the use of constraint indexation to capture patterns of idiosyncratic triggering of harmony encounters several issues. In harmony, exceptional triggering can be achieved in a feature-based theory via indexation to a harmony driving constraint, such as SPREAD(F) (Padgett 1995; Walker 1998/2000). However, this approach both over- and undergenerates patterns of harmony triggering, rendering it an undesirable alternative to the Gestural Harmony Model. The reasons for this are examined in this section. Though the discussion focuses on the constraint SPREAD(F), it should be noted that these issues extend to all analyses that rely on maximal harmony drivers that favor the association of a harmonizing feature to all segments in a word.

The constraint SPREAD(F), as well as similarly evaluated harmony driving constraints such as EXTEND(F) and ALIGN(F), drives unbounded harmony by penalizing non-undergoers, i.e., those segments that are not associated to a harmonizing feature F. It is defined as in (115).

- (115) SPREAD(F): For each feature F associated to a segment in domain D, assign a violation mark for every segment S in domain D that is not associated to F. (adapted from Walker (1998, p. 47))

If a candidate form contains the feature F, it will be subject to SPREAD(F), and any segments not associated to the feature F in some domain D (often the entire word) will incur a violation. When SPREAD(F) dominates IDENT(F)-IO, which preserves potential undergoers' underlying values for the feature F, harmony results.

In order to capture the patterns of harmony triggering in a language such as Classical Manchu in which only some forms show within- and across-morpheme harmony, constraint indexation can be used to relativize SPREAD(F) such that it does not apply to all forms. Instead, an indexed constraint will only be relevant when a word contains a morpheme that shares its index, and will only be violated if some portion of an indexed morpheme contributes to its violation. In harmony, patterns in which some forms display harmony while others do not can be analyzed by indexing triggering morphemes to a version of SPREAD(F) that outranks IDENT(F)-IO, which in turn outranks a general version of SPREAD(F). This ranking is shown in (116).

- (116) Constraint ranking for idiosyncratic triggering of harmony with indexed constraints

$$\text{SPREAD}(F)_i \gg \text{IDENT}(F)\text{-IO} \gg \text{SPREAD}(F)$$

When the domain of SPREAD(F) is specified to refer to the entire word, the constraint compels both within- and cross-morpheme harmony. This is true of both the general SPREAD(F) constraint and the version that is indexed only to certain morphemes. Crucially, it is not the case that the entire structural description of an indexed constraint must be met only by material from an indexed morpheme. Rather, Pater (2009a) specifies that an indexed constraint is violated if its structural description contains some part of an indexed morpheme.

Tableaux that demonstrate the workings of the ranking in (116) are provided in (117) and (118). Both include forms in which two segments S_1 and S_2 occupy a root while segment S_3 occupies a suffix attached to that root. In (118), the root morpheme is indexed to high-ranked $\text{SPREAD}(F)_i$. In both the input and output, brackets indicate morpheme boundaries.

(117) Tableau with harmony triggered by an indexed morpheme

Input: [S_1 S_2] _i [S_3]	$\text{SPREAD}(F)_i$	$\text{IDENT}(F)\text{-IO}$	$\text{SPREAD}(F)$
 a. [S_1 S_2] _i [S_3]	*!*		**
 b. [S_1 S_2] _i [S_3]		**	

In the tableau in (117), the morpheme containing the potential trigger segment S_1 , which is associated with feature F, is indexed to high-ranking $\text{SPREAD}(F)_i$. Output candidate (a) violates both the indexed and non-indexed versions of $\text{SPREAD}(F)$ due to the lack of association lines between the harmonizing feature F and segments S_2 and S_3 . Winning candidate (b) satisfies both SPREAD constraints but violates $\text{IDENT}(F)\text{-IO}$ due to the added association lines between feature F and segments S_2 and S_3 .

The situation is different in the tableau in (118), in which the morpheme containing the potential trigger segment S_1 bears no index.

(118) Tableau with harmony not triggered by an unindexed morpheme

Input: [S ₁ S ₂] [S ₃]	SPREAD(F) _i	IDENT(F)-IO	SPREAD(F)
 Input: [S ₁ S ₂] [S ₃]			**
 a. [S ₁ S ₂] [S ₃]			
 b. [S ₁ S ₂] [S ₃]		*!*	

In (118), winning candidate (a), which displays no harmony, violates only low-ranked SPREAD(F). This is because the morpheme containing the potential trigger segment S₁ bears no index, and is therefore not subject to high-ranked SPREAD(F)_i. Harmonizing candidate (b) fatally violates IDENT(F) due to the added association lines between feature F and segments S₂ and S₃. With this ranking, then, a system in which only morphemes indexed to a high-ranked version of SPREAD(F) display harmony, while other morphemes do not, can be generated straightforwardly.

However, one major drawback of the constraint indexation approach to idiosyncratic harmony triggering is that it is unable to generate certain aspects of the distributions of triggers and non-triggers of harmony. In Acehnese, Rejang, and Classical Manchu, the contrast between triggering and non-triggering segments that bear a harmonizing property is restricted to a privileged syllable (initial in Classical Manchu, final in Acehnese and Rejang), and neutralized elsewhere. This sort of preservation of phonological contrast only in privileged positions is common, and can be accounted for using positional faithfulness constraints (Beckman 1997, 1998; Hyman 1998; Walker 2005, 2011). The Gestural Harmony Model, with its focus on analyzing harmony triggering patterns as the result of constraints on the positions in which self-

deactivating and persistent (or non-anticipatory and anticipatory) gestures may occur in a word, is well suited to accounting for such patterns.

Indexation of a harmony-driving constraint, on the other hand, encounters difficulty in generating the different distributional patterns of triggering and non-triggering segments. In a framework that assumes that harmony-driving constraints may only be indexed to morphemes (e.g., Pater 2000, 2009a; Becker 2009), this is unsurprising. A segment bearing feature F that occurs in a morpheme indexed to SPREAD(F)_i or some other harmony-driving constraint will trigger harmony no matter its position in the morpheme.

The adoption of segmental rather than morphemic indexation to constraints, as proposed by Temkin Martínez (2010), does not solve this issue. Markedness and faithfulness constraints, whether they are relativized to privileged positions or not, can reference properties of phonological units, such as feature values or gestural parameter settings. For instance, the analysis of Classical Manchu in section 3.5 utilizes the constraint IDENT(deactivation)-IO_{Firstσ} to preserve the contrast between persistent and self-deactivating tongue root advancement gestures only in the first syllable of a word. However, there is no parallel approach that preserves the contrast between segments that are indexed to a harmony driving constraint and those that are not (e.g., /S/ vs. /S_i/). This is because indices to constraints are not objects that can be referenced by constraints in the same way that properties of features or gestures can be referenced. That is, there are no constraints such as IDENT(i)-IO or IDENT(i)-IO_{Firstσ}, where i is an index to a harmony-driving constraint. The index i on a morpheme or segment carries no distinctive information on its own; it is only defined if there is some constraint in the grammar, such as SPREAD(F)_i, that shares that indexation. An index conveys information about the relation between a phonological unit and some element of the phonological grammar, not about the

phonological unit itself. Thus, markedness and faithfulness constraints should not be able to reference any constraint indices a phonological unit might bear, and would therefore be of no use in determining the distribution of exceptional harmony triggers, i.e., segments bearing an index to SPREAD(F)_i. Indexation to standard harmony-driving constraints, therefore, is unable to generate patterns of harmony triggering in which distributional restrictions are placed on triggers and non-triggers of harmony.

The constraint indexation approach also encounters an issue of overgeneration of possible harmony triggering patterns. This issue arises when we consider that it is not only morphemes that contain the trigger of harmony that can be indexed to the constraint SPREAD(F)_i. Because the structural description of the constraint SPREAD(F) may contain segments from two different morphemes when the domain is specified to be the entire word, there are two morphemes that might potentially bear an indexation to the constraint. That is, either the trigger or the undergoer of harmony may be in an indexed morpheme that activates the indexed SPREAD(F)_i constraint. This means that the SPREAD(F) constraint depicted graphically in (119) is relevant when either segment S (either the potential trigger or the potential undergoer) in the structural description is part of an indexed morpheme.

(119) Structural description of SPREAD(F)²²



²² In the following discussion, I assume that the constraint SPREAD(F) assigns violations each time the structure illustrated in (119) is present, i.e. whenever a segment S is unassociated with feature F in domain D. Furthermore, what Pater refers to as the locus of violation I take to mean the structural description. I do not assume, as in McCarthy (2003a), that the structural description of a constraint should be divided into a locus of violation and its context.

The problem arises when a morpheme containing a potential undergoer of harmony is indexed to $\text{SPREAD}(F)_i$ while a morpheme containing a potential trigger of harmony is not indexed. This is demonstrated in the tableau in (120), in which the triggering segment S_1 bearing feature F is still in the root, but the indexation to $\text{SPREAD}(F)_i$ is now borne by the affix containing S_3 . This situation results in harmony across the root, despite the fact that the root would surface as disharmonic if it did not have an indexed affix attached to it, as in the tableau in (118).

(120) Tableau with harmony triggered across an unindexed morpheme due to indexed affix

Input: $[S_1 \quad S_2] [S_3]_i$	$\text{SPREAD}(F)_i$	$\text{IDENT}(F)\text{-IO}$	$\text{SPREAD}(F)$
F Input: $[S_1 \quad S_2] [S_3]_i$			
a. F $[S_1 \quad S_2] [S_3]_i$	*!*		**
b. F ↘ $[S_1 \quad S_2] [S_3]_i$		*!*	

In candidate (a) the lack of harmony for the feature F both within and across the morpheme boundary violates both versions of $\text{SPREAD}(F)$. Most crucially, the high-ranked indexed version of $\text{SPREAD}(F)_i$ is violated because the affix containing S_3 is indexed to it. The winning candidate (b) satisfies high-ranked $\text{SPREAD}(F)_i$ by spreading the feature F across the root and onto S_3 in the indexed affix. In candidate (b), the segment S_1 has triggered harmony in order to satisfy $\text{SPREAD}(F)_i$ despite the fact that S_1 does not even occur in the morpheme bearing the indexation to that constraint. Therefore, while this hypothetical language usually has no within-morpheme harmony (due to the ranking of $\text{IDENT}(F)\text{-IO}$ over the general $\text{SPREAD}(F)$ constraint), within-morpheme harmony has occurred in candidate (b) of (120) so that the feature F can spread to an indexed morpheme, thereby satisfying high-ranked $\text{SPREAD}(F)_i$. Such a pattern is

unattested according to Finley (2010), who claims that even in the presence of an affix that is an exceptional undergoer of harmony, harmony is never induced within an otherwise disharmonic stem. Morpheme indexation to a harmony-driving constraint has therefore generated an unattested, pathological pattern of harmony.

Also working against a morpheme indexation analysis of so-called exceptional triggering of harmony is the fact that in Rejang (section 3.3), triggering and non-triggering nasals may occur in the same morpheme, as in [m̩nae] ‘come here,’ in which the [m] is a triggering nasal and the [n] is a non-triggering nasal. If a morpheme as a whole were indexed to a harmony driving constraint, there would be no way to account for the spreading of nasality from one nasal consonant and not another. Instead, an analysis of Rejang would require some way to index a harmony-driving constraint to a particular triggering [nasal] feature or segment. Temkin Martínez (2010) proposes that certain patterns of phonological idiosyncrasy operate on the segmental rather than the morphemic level, indicating that it is necessary to allow for the possibility of segmental constraint indexation. A segment indexation solution to nasal harmony triggering in Rejang essentially captures the same contrast between triggers and non-triggers as the Gestural Harmony Model. In either case, there is some underlying property of a nasal (either indexation to a harmony-driving constraint or a gestural deactivation parameter) that determines whether or not it triggers harmony. However, this approach generates the same pathology seen in the tableau in (120). If SPREAD(F)_i were indexed to segment S₃ rather than the morpheme that contains S₃, the same pathological pattern of triggering would be generated.

With respect to patterns in which the ability to trigger harmony appears to be a contrastive property, the Gestural Harmony Model successfully avoids the issues that beset analyses based upon mechanisms for exceptionality in feature spreading. Because gestural

representations include parameters for persistence and anticipation, these parameters can be referenced by markedness and faithfulness constraints that determine different gestures' distributions. In particular, these parameters are subject to IDENT(parameter_X)-IO, which allows the persistence and anticipation parameters of a gesture to act as contrastive properties. This is a novel approach to accounting for patterns of harmony triggering that have previously fallen within the realm of phonological exceptionality. Analyses of such apparent exceptionality in harmony triggering that are based in featural frameworks fall short of the success of the Gestural Harmony Model. In particular, analyses that rely on morpheme or segment indexation to harmony-driving constraints suffer from issues of both over- and undergeneration of patterns of harmony triggering.

While the Gestural Harmony Model obviates the need for constraint indexation in accounting for patterns of apparent exceptionality in harmony triggering, I leave open the question of what the general status of such indexation is in the model. At present, it is not clear whether contrasts for gestural parameters that are unavailable within featural representations (such as persistence versus self-deactivation) can wholly replace the results of constraint indexation. However, there are additional cases of apparent exceptionality that can be reanalyzed as cases of phonological contrast for a gestural parameter setting. This subject is discussed further in sections 5.3 and 5.4, in which contrasts based on gestural blending strength are considered.

3.6.3 Pre- and Underspecification

Another approach to idiosyncrasy in the application of phonological processes relies on proposing distinctions in the feature specifications of input forms that are neutralized in output forms. By proposing that segments may be either prespecified or underspecified for a relevant

feature in the input, such theories are able to account for the idiosyncratic undergoing of phonological processes, and also correctly predict that idiosyncratic phonological behavior is granular at the level of the segment, rather than the morpheme. It is also possible to utilize distinctions in input specification to account for the idiosyncratic triggering of harmony; however, such an approach involves the adoption of additional theoretical mechanisms, either within the phonological grammar or the post-phonological mechanism of phonetic implementation.

The underlying specification of segments for a relevant spreading feature have long been used to account for the blocking of feature spreading (see, for example, work in Autosegmental Phonology by Clements (1976a, 1981) and van der Hulst & N. Smith (1982a, 1982b)). Within the study of harmony, underlying feature specification has often been used in analyses of idiosyncratic undergoing and blocking of harmony. Under such analyses, undergoers and blockers of harmony are distinguished based on whether or not they are already specified for the harmonizing feature. These include analyses of Turkish backness harmony (Clements & Sezer 1982), the nasal harmonies of Tucano (Noske 1995) and Tuyuca (Barnes 1996), Kalenjin ATR harmony (Ringen 1988), and others.

Inkelas (1994) and Inkelas, Orgun, & Zoll (1997) propose that this featural pre- and underspecification approach can be adopted within parallel OT in order to account for patterns of apparent exceptionality in the application of phonological processes. Under their analysis, segments may be either pre- or underspecified for a feature in the input, leading to a potential surface contrast in whether they are targeted by a phonological process. Whether this contrast arises is due to the interaction of markedness and faithfulness constraints. When faithfulness constraints referencing some feature specification are ranked high, the featural makeup of

prespecified segments will be preserved, while underspecified segments will be permitted to alternate for that feature specification. Apparently exceptional non-undergoers of phonological processes, then, are those that are prespecified for a relevant feature in the input, and their failure to undergo a process is due to the preservation of that feature specification by faithfulness constraints. The following tableaux demonstrate this approach to apparent exceptionality in undergoing a harmony process.

- (121) Tableau with harmony blocked by a segment prespecified for feature F

	[+F] S ₁	[-F] S ₂ /		
Input: /	S ₁	S ₂ /	FAITH(F)-IO	SPREAD(+F)
a.	[+F] S ₁	[-F] S ₂		*
b.	[+F] S ₁	[-F] S ₂	*!	

In (121), the input contains two segments that are specified as [+F] and [-F], respectively. In the winning candidate (a), no feature spreading occurs, and both segments surface with their underlying feature specifications. This violates SPREAD(+F), but satisfies higher-ranked FAITH(F)-IO. In candidate (b), the feature [+F] spreads onto segment S₂, which loses its underlying [-F] specification in fatal violation of FAITH(F)-IO. When a potential undergoer of harmony is unspecified for the feature F in the input, however, the outcome is different; this is illustrated by the tableau in (122).

(122) Tableau with harmony undergone by a segment unspecified for feature F

[+F]		
Input: / S ₁ S ₂ /	FAITH(F)-IO	SPREAD(+F)
[+F] [-F] a. S ₁ S ₂	*	*!
[+F] b. S ₁ S ₂	*	

In (122), the input contains an S_2 that is unspecified for feature F. In both output candidates, S_2 is specified for F and as a result both violate FAITH(F)-IO. It then falls to the constraint SPREAD(+F) to determine the winner. This winner is spreading candidate (b), as its specification of S_2 satisfies SPREAD(+F). Candidate (a), on the other hand, specifies S_2 for the feature value [-F], violating SPREAD(+F). The tableaux in (121) and (122), then, demonstrate how two segments that are potential undergoers of a feature spreading process can be idiosyncratically targeted by (or can idiosyncratically block) harmony based on whether or not they are specified for some feature in the input.

However, the picture is more complicated when attempting to use the pre- and underspecification of input forms to account for the contrastive triggering of harmony. Within derivational theories of phonology, such as those relying on ordered rules, distinguishing triggers and non-triggers of harmony in this way produces the correct outcome. In Classical Manchu, for instance, ATR harmony would be triggered by underlyingly ATR /i/ and /u/, while unspecified /I/ and /U/ would be unable to trigger ATR harmony. Only after harmony has taken place would /I/ and /U/ become specified as ATR, too late for them to serve as triggers. This is a case of counterfeeding opacity with eventual absolute neutralization of an underlying contrast between

triggering /i/ and /u/ and non-triggering /I/ and /U/. This approach is illustrated in the derivation in (123).

(123) Contrastive triggering of ATR harmony via counterfeeding opacity

Input	/i-a/	/I-a/
ATR Harmony	i-ə	—
High Vowels → [ATR]	—	i-a
Output	[i-ə-ə]	[i-a-a]

These sorts of crucial rule orderings resulting in neutralization of an input contrast are incompatible with output-oriented frameworks such as OT or Harmonic Serialism (McCarthy 2000, 2008a, 2008b; McCarthy & Pater 2016). In both of these frameworks, if a segment [i] is determined by constraint rankings in the grammar to be a trigger of ATR harmony, then that grammar will select a winning output candidate in which [i] triggers harmony, no matter its specification in the input (or in any earlier stage of the derivation in the case of Harmonic Serialism). In their most basic forms, these frameworks do not permit triggering by an [i] that was previously specified as ATR in the input while prohibiting triggering by an [i] that was previously /I/. The tableau in (124) demonstrates.

(124) Tableau with harmony triggered by underlyingly specified or unspecified segment

$[+ATR]$ Input: / i A /		
$[+ATR] [-ATR]$ a. [i a]	*	*!
$[+ATR]$ b. [i ə]	*	
Input: / I A /	FAITH(ATR)-IO	SPREAD(+ATR)
$[+ATR] [-ATR]$ a. [i a]	**	*!
$[+ATR]$ b. [i ə]	**	

In (124), the first input contains a high [+ATR] vowel followed by a low vowel unspecified for [ATR]. Its violation profile parallels that of the tableau in (122). In each output candidate, the low vowel receives specification for [ATR], incurring a violation of FAITH(ATR)-IO. Therefore, the constraint SPREAD(+ATR) determines the winner. In candidate (a), [+ATR] does not spread from the high to the low vowel, violating SPREAD(+ATR). In winning candidate (b), SPREAD(+ATR) is satisfied. The same outcome results for the second input in (124), in which the high and low vowel are both unspecified for [ATR]. Both output candidates, in which these vowels have received specification for [ATR], incur two violations of FAITH(ATR)-IO, and it again falls to the constraint SPREAD(+ATR) to determine the winner. Again, it is candidate (b), in which the high vowel's [+ATR] specification has spread onto the low vowel. This result demonstrates that even when a constraint such as FAITH(ATR)-IO is

ranked high, a surface ATR vowel will be compelled to trigger ATR harmony, regardless of whether it was specified for this feature in the input.

A possible solution to the incompatibility between the counterfeeding opacity account of contrastive triggering in (123) and output-oriented, constraint-based grammars is the adoption of some theoretical mechanism that would prevent harmony that is triggered by a feature that is inserted into an output form. Under such an approach, harmony would be triggered by segments specified for a harmonizing feature in an input form, and would not be triggered by segments unspecified for that feature, even if they came to be specified in the output. One way to achieve this is through constraint conjunction (Smolensky 1993; Smolensky & Legendre 2006). Segments that are underspecified for a harmonizing feature in the input could be prevented from triggering harmony via the conjunction of a constraint that penalizes feature insertion, such as DEP(F)-IO, with a constraint that is violated when harmony takes place, such as IDENT(F)-IO, which would be violated by the undergoers of harmony. With this constraint ranked above a constraint driving harmony, harmony would be triggered only by those segments in an output candidate that do not insert a feature before spreading it.

Another possibility is the adoption of one of the theoretical mechanisms designed specifically to capture cases of apparent derivational opacity within constraint-based frameworks, such as Sympathy Theory (McCarthy 1999) or comparative markedness (McCarthy 2003b). I illustrate this point within comparative markedness theory. Within this theory, violations marks for markedness constraints are assigned to candidates based on whether their violations are old (present in both the input and the output candidate) or new (present in the output candidate only). Markedness constraints come in pairs, with one assigning marks for old violations and one assigning marks for new violations. According to McCarthy, cases of

apparent counterfeeding opacity can be captured by a constraint ranking in which a constraint against old markedness violations is ranked above a relevant faithfulness constraint, which in turn outranks a constraint against new markedness violations. The relevant ranking for deriving harmony that is triggered by a vowel that is underlyingly specified for [ATR] but not an underlyingly unspecified vowel is provided in (125).

- (125) Constraint ranking for idiosyncratic triggering of harmony with comparative markedness
- $$\text{SPREAD(ATR)}_{\text{old}} \gg \text{IDENT(ATR)-IO} \gg \text{SPREAD(ATR)}_{\text{new}}$$

The workings of this constraint ranking are demonstrated in the tableau in (126).

- (126) Contrastive triggering of ATR harmony via input underspecification and comparative markedness

Input: /I-a-a/	SPREAD(ATR) _{old}	IDENT(ATR)-IO	SPREAD(ATR) _{new}
☞ a. [i-a-a]			**
b. [i-ə-ə]		*!*	
Input: /i-a-a/	SPREAD(ATR) _{old}	IDENT(ATR)-IO	SPREAD(ATR) _{new}
a. [i-a-a]	*!*		
☞ b. [i-ə-ə]		**	

In (126), the first input contains a high vowel that is unspecified for the feature [ATR]; both output candidates contain the fully specified vowel [i]. Winning candidate (a), in which [i] does not trigger harmony, incurs two violations of SPREAD(ATR), as it includes an [ATR] feature that is not associated with the two [a] vowels. However, this is a new violation of SPREAD(ATR) that is created by the insertion of [ATR] into the output form; therefore, the violation is incurred by low-ranked SPREAD(ATR)_{new}. Candidate (b), in which harmony does occur, violates higher-ranked IDENT(ATR)-IO by changing the [ATR] values of the /a/ vowels. In contrast, the second input contains an /i/ vowel that is specified as [ATR]. Now, non-triggering candidate (a) violates

high-ranked SPREAD(ATR)_{old}, as the violations of SPREAD(ATR) incurred by the non-undergoing [a] vowels are present in the input as well. As a result, harmonizing candidate (b) is the winner.

The pre- and underspecification of features, then, can be compelled to account for cases of idiosyncratic harmony triggering within output-oriented models of phonology such as OT, provided that additional theoretical architecture is also implemented. This was demonstrated using comparative markedness; however, it is generalizable to approaches utilizing constraint conjunction or Sympathy Theory as well. A major drawback of these approaches, however, is that they are quite powerful and make less constrained typological predictions about patterns of harmony and the application of phonological processes more generally. The ability of independently motivated individual constraints to produce unattested patterns when conjoined, for instance, has been discussed by Itô & Mester (1998), Pater (2009b), and others. Relatedly, the adoption of comparative markedness is accompanied by a doubling of all of the markedness constraints in CON; every markedness constraint M in standard markedness theory corresponds to the constraints M_{old} and M_{new} in comparative markedness theory. The full range of typological predictions made by such an explosion of the constraint set assumed within OT has not been fully explored, though see Lubowicz (2003) and T. Hall (2007) for some discussion of this issue and arguments against comparative markedness based on typological predictions.

In contrast with these approaches that rely on the surface neutralization of an input distinction between segments that are specified versus unspecified for a harmonizing feature, the Gestural Harmony Model's account of idiosyncratic triggering relies on a contrast in the setting of a gestural deactivation and/or activation parameter that persists from input to output. Relying on such a parameter to account for idiosyncratic triggering of harmony is thus entirely

compatible with output-oriented frameworks such as OT without invoking additional theoretical mechanisms such as Sympathy Theory, comparative markedness, or constraint conjunction.

An alternative strategy for deriving idiosyncratic harmony triggering from pre- and underspecified inputs is to assume that a non-triggering segment is not specified for a harmonizing feature in either input or output forms. Underspecification in the phonological output is proposed by, among others, Avery & Rice (1989), Itô, Mester, & Padgett (1995), and Rice (1996). Under this approach, the contrast in Acehnese and Rejang between a harmony-triggering nasal consonant and a non-triggering nasal consonant would be preserved between input and output. Likewise, the contrast in Classical Manchu between a harmony-triggering ATR [i] and a non-triggering [I], and between a triggering ATR [u] and a non-triggering [U], would be preserved. In addition, the contrast between non-triggering [U] and non-ATR [o] in Classical Manchu must also be preserved. This would require that a later grammatical component that derives fully specified output forms and/or the phonetic implementation of the forms output by the phonological grammar, either (1) supply a [+F] specification to any segments unspecified for a harmonizing feature, or (2) automatically produce unspecified segments as [+F]. [+F] corresponds with [+nasal] in the case of Acehnese and Rejang, and with [+ATR] in the case of Classical Manchu.

There are a variety of mechanisms that have been proposed to operate after the phonological grammar has produced an output form. Phonetic implementation models such as those proposed by Keating (1988, 1990) and Cohn (1990) do not fill in or alter output phonological forms, but instead determine the states of the vocal tract required to produce specified segments and interpolate between these specified segments. Other models, such as those proposed by Zsig (1993, 1997, 2000) and Rice (1996), fill in underspecified feature

values to produce fully specified forms. Zsiga's model also involves the translation between feature-based phonological surface forms and gesture-based phonetic forms, as well as language-specific rules that manipulate the coordination relations between gestures. Rice, meanwhile, proposes a phonetic implementation mechanism in which individual languages may choose whether to implement consonants unspecified for place in the phonological output as either coronal or velar. Both proposals are rooted in the idea that rules apply to phonological outputs to provide them with default specifications, but that these defaults are determined on a language-specific basis.

Both Zsiga and Rice propose models of the phonetic implementation mechanism that not only produce a phonetic form from a phonological form, but do so based on the application of language-particular rules. In this sense, each of these mechanisms is akin to a second phonetic grammar that follows the first phonological grammar. Within these theories, the output of phonology is even more abstract than generally assumed; the phonological grammar does not actually produce forms that represent the end state of a derivation, but rather intermediate forms. The adoption of such a stratal framework in order to account for the contrastive triggering of phonological processes, including harmony, thus introduces an additional level of complexity to our theory.

This can be contrasted with the Gestural Harmony Model's account of idiosyncratic harmony triggering via contrastive settings of the parameters of gestural self-activation and self-deactivation. The model relies on a contrast between triggering and non-triggering segments that is present in both input and output phonological forms, obviating the adoption of any sort of multi-step derivational component within the phonological and/or phonetic grammar. As discussed in section 1.2.2, the Gestural Harmony Model does adopt the multi-step process of

speech production assumed within Articulatory Phonology, by which the Coupled Oscillator Model calculates a gestural score from a coupling graph and the Task Dynamic Model calculates articulatory trajectories from a gestural score. However, these later levels of representation are calculated based on crucially language-universal principles, rather than being chosen by a language-specific grammatical component. The only grammar assumed within the Gestural Harmony Model is the Optimality Theoretic phonological grammar that produces the coupling graph. The Coupled Oscillator Model and the Task Dynamic Model are purely extragrammatical mechanisms in the sense that their outputs are calculated from the content of a coupling graph and involve no manipulation of that coupling graph. No additional language-specific, grammatical transformations may occur between coupling graph and gestural score, nor between gestural score and articulatory trajectories. The Gestural Harmony Model therefore avoids the complications that arise when utilizing featural pre- and underspecification to account for patterns of idiosyncratic triggering of harmony. As a result, the Gestural Harmony Model proves itself to be a particularly parsimonious option for accounting for cases of idiosyncratic harmony triggering.

3.7 Summary

This chapter has served as the first introduction to the grammatical component of the Gestural Harmony Model. The grammar of triggering in this model is one based on the shaping of surface phonological inventories such that they contain harmony-triggering gestures, as well as placing distributional restrictions on members of those inventories. This is achieved via the interaction of markedness and faithfulness constraints, both general and position-specific. In reconceptualizing the driving of harmony in this way, the Gestural Harmony Model makes

significant inroads in addressing some of the issues that arise in the analysis of harmony triggering.

The Gestural Harmony Model is able to account for harmony systems in which harmony triggers are restricted to specific positions, as well as those that place conditions on the identities of triggers of harmony. In particular, the Gestural Harmony Model successfully accounts for patterns of contrastive triggering in harmony, including those in which the contrast between triggers and non-triggers is restricted to privileged positions. At the same time, it avoids many of the issues of over- and undergeneration that arise when accounting for patterns of harmony triggering within feature-based frameworks.

Appendix A: Constraint Definitions

This appendix contains definitions for all of the constraints used in the analyses presented in chapter 3.

PERSIST(lip protrusion): Assign a violation mark to a lip protrusion gesture that is self-deactivating.

PERSIST(velum opening): Assign a violation mark to a velum opening gesture that is self-deactivating.

PERSIST(ATR): Assign a violation mark to a tongue root advancement gesture that is self-deactivating.

SELFDEACTIVATE: Assign a violation mark to a gesture that is not self-deactivating.

IDENT(deactivation)-IO: Assign a violation mark to a gesture whose input and output correspondents do not have identical deactivation specifications.

IDENT(deactivation)-IO_{Final}: Assign a violation mark to a gesture in the final syllable of a word whose input and output correspondents do not have identical deactivation specifications.

IDENT(deactivation)-IO_{First_σ}: Assign a violation mark to a gesture in the first syllable of a word whose input and output correspondents do not have identical deactivation specifications.

ANTICIPATE(velum opening): Assign a violation mark to a velum opening gesture that is self-activating.

ANTICIPATE(ATR): Assign a violation mark to a tongue root advancement gesture that is self-activating.

SELFACTIVATE: Assign a violation mark to a gesture that is not self-activating.

IDENT(activation)-IO: Assign a violation mark to a gesture whose input and output correspondents do not have identical deactivation specifications.

*COUPLE(short nonhigh V, self-deactivating lip protrusion): Assign a violation mark to a short nonhigh vocalic gesture and a self-deactivating lip protrusion gesture that are coupled to one another in an output.

*COUPLE(vowel, self-deactivating velum opening): Assign a violation mark to a vocalic gesture that is coupled to a self-deactivating velum opening gesture in the output.

*COUPLE(nonhigh vowel, self-deactivating ATR): Assign a violation mark to a nonhigh vowel gesture and a self-deactivating tongue root advancement gesture that are coupled to one another.

LICENSE(lip protrusion, first σ): Assign a violation mark to a lip protrusion gesture that is not in an initial syllable.

LICENSE(nonhigh round V, first σ): Assign a violation mark to a nonhigh round vowel that is not in an initial syllable.

LICENSE(ATR, first σ): Assign a violation mark to a tongue root advancement gesture that is not in an initial syllable.

MAX(lip protrusion)-IO: Assign a violation mark to a segment (set of gestures) that includes a lip protrusion gesture in the input if its output correspondent does not include that gesture.

MAX(ATR)-IO: Assign a violation mark to a segment (set of gestures) that includes a tongue root advancement gesture in the input if its output correspondent does not include that gesture.

MAX(ATR)-IO_{First σ} : Assign a violation mark to a segment (set of gestures) in an initial syllable that includes a tongue root advancement gesture in the input if its output correspondent does not include that gesture.

INTEGRITY-IO: Assign a violation mark to a primary gesture and a non-primary gesture that are part of the same segment (set of gestures) in the input and are not coupled to one another in the output.

Chapter 4

Patterns of Transparency & Blocking

4.1 Introduction

In many of the harmony systems examined in chapters 2 and 3, harmony proceeds throughout entire words, causing all segments to take on a harmonizing property. In the Gestural Harmony Model, this is represented by a gesture that extends to overlap all other segments (sets of gestures) in a word. In this chapter, I focus on cases of so-called neutrality to harmony, in which one or more segments in a word surface without a harmonizing property. Neutrality is often used as a catchall term to refer to transparency, in which segments are seemingly skipped by a harmony process, and blocking, in which a segment arrests the further spread of a harmonizing property. However, in this chapter I claim that appealing to this unitary concept of neutrality in analyzing attested harmony patterns is neither useful nor accurate, and that transparency and blocking should be treated separately.

One of the principle contributions of the Gestural Harmony Model arises from its representation of transparency and blocking as the results of two distinct theoretical mechanisms. In doing away with the concept of neutrality, the model successfully accounts for the distinct typological patterns that are exhibited by cases of transparency and blocking. C. Smith (2016a) observes that among rounding and nasal harmony systems, the set of attested transparent segments is a proper subset of attested blocking segments. This asymmetry is not predicted by any approach in which segment neutrality to harmony is the result of a single mechanism within the phonological grammar. However, the Gestural Harmony Model successfully accounts for this typological asymmetry by regarding transparency and blocking as the results of distinct

mechanisms at work within the model. Crucially, the mechanism responsible for transparency is available to a limited set of segments, as determined by their gestural makeup. The blocking mechanism, on the other hand, is available to all segment types.

The mechanisms within the Gestural Harmony Model that account for transparency and blocking are based upon two different possible consequences of gestural overlap. When a persistent (non-self-deactivating) or an anticipatory (early-activating) gesture extends to overlap other segments in a word, it will at times result in the concurrent activation of gestures that are *antagonistic* to or *incompatible* with one another. Gestural incompatibility refers to any situation in which the concurrent activation of two gestures is articulatorily or perceptually marked in some way. The phonological grammar assumed by the Gestural Harmony Model determines whether or not the incompatibility that would result from such overlap is permitted to surface. When the grammar does not allow such incompatibility, the result is the blocking of harmony. Because there are many different sources of gestural incompatibility, many different classes of segments are predicted to be able to act as blockers within a given type of harmony.

Gestural antagonism, on the other hand, refers to a specific type of incompatibility in which two concurrently active gestures are specified for directly opposing target articulatory states. I propose that transparency to harmony arises when a harmonizing gesture overlaps another gesture that is antagonistic to it. When this overlap is permitted by the grammar, the target states of these gestures will compete with one another for realization, and the transparent gesture will temporarily mask the effect of a harmonizing gesture. In the Gestural Harmony Model, then, transparent segments are cast as a special type of undergoer of harmony. This mirrors earlier proposals by Clements (1976b), Piggott (1988), Cole & Kisseeberth (1994, 1995),

Walker (1998/2000, 2003), Jurgec (2011), and others that at some level of representation, transparent segments undergo harmony.

By representing transparency as the result of a harmonizing gesture's overlap of an antagonistic gesture, the Gestural Harmony Model makes the claim that only those segments that include an antagonistic gesture are predicted to potentially be transparent to harmony. Because of this, the model is able to successfully account for crosslinguistic patterns of transparency and blocking in which attested classes of transparent segments make up a proper subset of attested classes of blocking segments, as in nasal harmony and in rounding harmony. Analyses of harmony that analyze transparency and blocking together under the banner of neutrality are unable to restrict transparency to a subset of segment classes and are therefore unable to generate these attested typological asymmetries.

By dividing transparency and blocking among two distinct theoretical mechanisms, the Gestural Harmony Model also allows for these mechanisms to operate independently, and in some cases concurrently. As a result, the Gestural Harmony Model successfully accounts for harmony systems in which both transparency and blocking arise. This is illustrated in this chapter with a case from Halk Mongolian rounding harmony (Svantesson 1985; Svantesson, Tsendina, Karlsson, & Franzén 2005), in which high front vowels are transparent to harmony, while high back vowels serve as blockers. Other examples of harmony systems that exhibit both transparency and blocking include Coatzospan Mixtec nasal harmony (Gerfen 1999, 2001) and Menominee tongue root harmony (Cole & Trigo 1988; Archangeli & Pulleyblank 1994; Archangeli & Suzuki 1995; Walker 2009, 2018). The Gestural Harmony Model successfully accounts for such patterns by allowing the two mechanisms responsible for transparency and blocking to operate concurrently within the same language. While some feature-based analyses

of harmony are able to match the success of the Gestural Harmony Model in this regard, many others are unable to generate such patterns.

The chapter is organized as follows. Section 4.2 provides an overview of the typological patterns of transparency and blocking that arise in several different types of harmony. Due to the typological asymmetries in attested transparent and blocking segments described in this section, section 4.3 goes on to demonstrate how both transparency and blocking can be represented as the results of two distinct mechanisms in the Gestural Harmony Model. Sections 4.4, 4.5, and 4.6 show how these mechanisms function in nasal harmony, rounding harmony, and ATR harmony, respectively, and how the phonological grammar generates attested patterns of transparency and blocking. Section 4.7 outlines the strengths of the predictions made by the Gestural Harmony Model with respect to transparency and blocking, and compares these predictions to those of previous feature-based analyses of harmony. An appendix with the definitions of all of the constraints used throughout is included at the end of the chapter.

4.2 Typological Patterns of Transparency and Blocking

This section examines the typological patterns of transparency and blocking in various vowel and vowel-consonant harmonies. For some harmony phenomena, such as those based on tongue root position, the set of crosslinguistically attested classes of transparent and blocking segments are identical. However, for other harmony types, such as those based on nasality and rounding, the set of attested transparent segment types is a proper subset of attested blocking segment types. This section lays out these typological patterns in detail, providing a clear picture of the patterns of transparency and blocking that must be matched by the predictions of a successful model of harmony.

4.2.1 Nasal Harmony

Nasal (vowel-consonant) harmony exhibits a well-known crosslinguistic asymmetry between the sets of attested transparent and blocking segments. Looking across all reported nasal harmony systems, all consonants are attested blockers. While any consonant may act as a blocker of nasal harmony, it is not the case that within a given language any arbitrary set of consonants may be selected as blockers. Rather, the set of blockers of nasal harmony in a language forms an implicational hierarchy roughly approximating the sonority hierarchy. This pattern is reported by Schourup (1972), who notes that blocking of nasal harmony by liquids implies blocking by obstruents in the same language, and that blocking by glides implies blocking by liquids and obstruents. Similar versions of this implicational pattern of nasal harmony blocking are also noted by Pulleyblank (1989), Piggott (1992), Cohn (1993a, 1993b), Hume & Odden (1996), and Walker (1998/2000). Cohn and Hume & Odden consider the likelihood of a segment to block or to undergo nasal harmony to be roughly a function of its sonority.²³ Pulleyblank and Walker, on the other hand, analyze the blocking of nasal harmony as a function of certain segments types' compatibility with nasalization. The implicational hierarchy of blocking effects leads Walker (1998/2000) to posit the harmony scale in (127) based on segmental incompatibility with nasalization.

(127) Harmony scale of nasal (in)compatibility proposed by Walker (1998/2000)

$$\begin{array}{ccccccccc} \text{nasal} & \succ & \text{nasal} & \succ & \text{nasal} & \succ & \text{nasal} & \succ & \text{nasal} \\ \text{sonorant stop} & & \text{vowel} & & \text{glide} & & \text{liquid} & & \text{fricative} & & \text{obstruent stop} \end{array}$$

According to Walker, languages may mark the cutoff between undergoers and blockers of nasal harmony at different points along the scale in (127). Harmony may affect only vowels

²³ Hume & Odden construct their scale based on segmental ‘impedance,’ which is defined as roughly the converse of sonority.

and glottal consonants, as in Sundanese (Robins 1957); vowels, glottals, and glides, as in Capanahua (Loos 1967/1969; Safir 1982); vowels, glottals, glides, and liquids, as in Kayan (Blust 1972); or all segment types, as in Tuyuca (Barnes & Takagi de Silzer 1976; Barnes 1996).

While many different classes of segments may serve as blockers of nasal harmony, it is only obstruents that may be transparent to it, as observed by Piggott (1992) and Walker (1998/2000, 2003). Both also observe that obstruent transparency in nasal harmony only occurs in languages in which no sonorant consonants block harmony. This prompts Walker to propose that transparent segments pattern as undergoers with respect to the harmony scale in (127). In the nasal harmony of Moba Yoruba (Niger-Congo; Nigeria), for instance, vowels, glottals, glides, and liquids all surface as nasalized, while obstruents are transparent to harmony (Ajiboyè 2001; Ajiboyè & Pulleyblank 2008).

It is not uncommon for voiced and voiceless obstruents to pattern distinctly from one another within a nasal harmony system. For instance, it is possible for voiced obstruents to undergo nasal harmony while voiceless obstruents are transparent to it, or for voiced obstruents to undergo nasal harmony while voiceless obstruents block to it. The first of these patterns is exemplified by Tuyuca (Tucanoan; Colombia, Brazil), in which voiceless stops and fricatives are transparent to nasal harmony, while voiced oral stops are in complementary distribution with nasal stops, suggesting that they are targeted by nasal harmony (Barnes & Takagi de Silzer 1976; Barnes 1996). A similar pattern of complementary distribution between voiced oral stops and nasal stops is observed in Orejón (Tucanoan; Peru).²⁴ Pulleyblank (1989), citing an unpublished manuscript by Arnaiz, claims that in Orejón nasal harmony, voiceless obstruents block the spread of nasality, while voiced obstruents show the same kind of complementary distribution

²⁴ Velie Gable (1975) and Pulleyblank (1989) report slightly different nasal harmony patterns in their descriptions of Orejón presumably due to dialectal differences. I adopt Pulleyblank's description here.

with nasal consonants that is seen in Tuyuca. Again, this suggests that voiced obstruents are targeted by nasal harmony, while voiceless obstruents are not.

In sum, a successful analysis of crosslinguistic patterns of transparency and blocking in nasal harmony must account for several typological patterns. They include (1) the implicational hierarchy of blocking behaviors by glides, liquids, and obstruents; (2) the fact that only obstruents may be transparent to nasal harmony; and (3) the variable susceptibility of voiced obstruents to nasal harmony.

4.2.2 *Rounding Harmony*

An asymmetry between attested transparent and blocking segment types is also observed across rounding harmony systems. Kaun's (1995, 2004) surveys of rounding harmony show that all vowels are attested as blockers in some rounding harmony pattern. According to Kaun, the driving factors behind the various patterns of blocking are the avoidance of cross-height harmony, non-high round vowels, and front round vowels. Kaun describes a number of rounding harmony blocking patterns built around these three considerations. In some languages, only high vowels undergo rounding harmony, while nonhigh vowels serve as blockers. This is the case in a number of Turkic languages. It is also possible for rounding harmony to hold only among nonhigh vowels, while high vowels serve as blockers; this is exemplified by Baiyina Oroqen (sections 3.4.2 and 4.5.3).

In some rounding harmony systems, whether or not a vowel of a certain quality blocks rounding harmony is dependent upon the quality of the trigger. In many languages, the sets of triggers, undergoers, and blockers of rounding harmony are determined by a restriction on cross-height harmony. Combined with height-specific requirements on triggers of rounding harmony, this cross-height harmony restriction generates a number of blocking patterns. Perhaps the most

straightforward example comes from Yokuts: harmony triggered by nonhigh vowels is blocked by high vowels, and harmony triggered by high vowels is blocked by nonhigh vowels. In other languages, bans on both cross-height harmony and nonhigh round vowels result in rounding harmony that holds only among high vowels, as in Kachin Khakhas, Hixkaryana, and Tsou. Kaun (1995, 2004) also reports that the markedness of front round vowels affects patterns of triggering and blocking, resulting in rounding harmony systems in which only back vowels may undergo harmony, while front vowels act as blockers.

While there are many attested patterns of blocking among rounding harmony systems, transparency in rounding harmony is quite restricted. The only attested transparent segments are high front vowels. This is observed in the rounding harmony systems of various Mongolic languages, such as Halh Mongolian and Šuluun Höh (also known as Chakhar Mongolian), in which [i] and [ɪ] are transparent (Svantesson 1985; Svantesson et al. 2005).

Two apparent exceptions to this generalization come from Buriat (Mongolic; Russia, Mongolia, China) and Mari (also known as Cheremis; Uralic; Mari Republic, Russia). However, in both of these cases the transparent vowels in question are reported to be reduced vowels, rendering their quality indeterminate. Sebeok & Ingemann (1961) and Odden (1991) report that Mari displays rounding and backness harmonies, and that the reduced vowel [ə] is transparent to both of them. Likewise, Svantesson, Tsendina, Karlsson, & Franzén (2005) claim that the vowel transcribed as short [e] in Buriat is actually pronounced as a short, reduced vowel akin to schwa, and that this vowel is transparent to rounding harmony. However, it is possible that the apparently transparent vowels in Mari and Buriat are so reduced that any round vowel quality they would take on as a result of harmony would not be perceivable. It is plausible that neither of these languages exhibit true transparency, but are instead cases of apparent or perceptual

transparency. Such cases are not unheard of; there are other languages in which vowels that were reported to be transparent to some harmony process were found through instrumental study to actually be undergoers of harmony. See, for example, work by Gick, Pulleyblank, Campbell, & Mutaka (2006) on the so-called transparent low vowel in Kinande ATR harmony, Benus & Gafos (2007) on the transparency of the front vowels /i/, /i:/, and /e:/ in Hungarian backness harmony, and Ritchart & Rose (2017) on the status of schwa in Moro height harmony.

A final possible counterexample to the generalization that only high front vowels are transparent to rounding harmony comes from Tutrugbu (also known as Nyangbo; Niger-Congo, Kwa; Ghana).²⁵ According to Essegbe & McCollum (2017), Tutrugbu has both rounding and tongue root harmony processes, though rounding harmony is considerably more limited in its application. Rounding spreads from word-initial second person pronominal prefixes [o-]~[ɔ-] (2.sg.) and [no-]~[nɔ-] (2.pl.) onto following prefixes containing nonhigh vowels, but never affects roots. When a word includes either of the non-initial prefixes [-gi-]~[-gɛ-] (neg. pst.) or [-ti-]~[-tɛ-] (neg.), they do not undergo harmony but do not prevent following prefixes from undergoing rounding harmony triggered by word-initial second person pronominal prefixes. The transparency of [i]-containing prefixes does not affect the generalization that high front vowels are the only vowels attested as transparent in rounding harmony. However, these prefixes are also transparent to rounding harmony when they surface as their RTR variants [-gɛ-] and [-tɛ-] as the result of tongue root harmony with a following root.

While the transparency of [ɛ] may appear to represent a counterexample to the claim that only high front vowels are transparent to rounding harmony, this transparency is unsurprising given Essegbe & McCollum's analysis of the Tutrugbu vowel inventory. They claim that the

²⁵ Thanks to Adam McCollum for bringing this language to my attention, and for his detailed descriptions of its harmony systems.

RTR vowels [ɛ] and [ɔ] are phonologically high vowels, having been derived from a recent historical process of lowering from *ɪ and *ʊ, respectively. From this insight, there are two possible explanations for the apparent transparency of [ɛ] in Tutrugbu rounding harmony. The first possibility is that [ɛ] is transparent to rounding harmony because it is actually a phonologically high vowel, derived from /i/ via the language's tongue root harmony process. As an allophone of /i/, high [ɛ] could be expected to be transparent to rounding harmony just as [i] would be. A second possibility lies in the historical development of [ɛ] from *ɪ. As a reflex of *ɪ, [ɛ] has retained its phonological distribution with respect to rounding harmony, at least for the time being. In any case, the status of [ɛ] as transparent to Tutrugbu rounding harmony does not provide a strong counterargument to the generalization that high front vowels are the only ones that are transparent to rounding harmony.

4.2.3 *Tongue Root and Postvelar Harmonies*

Tongue root harmony does not show the same sort of typological asymmetry in attested transparent and blocking segment classes that is seen in nasal harmony and rounding harmony. Instead, the sets of attested blockers and transparent segments overlap entirely. In ATR harmony, it is not uncommon for the low vowel /a/ to lack an ATR counterpart. When this is the case, it may be either a blocker, as in Akan (Clements 1981), or transparent, as in Budu (Kutsch Lojenga 1994). There are no cases in which high vowels fail to undergo ATR harmony, and cases in which mid vowels lack ATR counterparts are very rare. Even in such cases, mid vowels re-pair with other vowels in the inventory, surfacing as high ATR vowels instead of mid ATR vowels. This is the case in Fur (Kutsch Lojenga & Waag 2004).

In Casali's (2008) survey of tongue root harmony systems, transparency of the low RTR vowel /a/ to ATR harmony is attested in several languages, including Bila, Budu, Ngiti, and

Talinga-Bwisi. However, the case of apparent transparency of /a/ in Kinande may cast some doubt on these cases. Kinande was long reported to have a tongue root harmony system in which the low vowel /a/ is transparent to the spread of ATR. However, an ultrasound study conducted by Gick et al. (2006) found that /a/ is actually produced with an advanced tongue root in ATR words, surfacing as [ə]. In other words, this vowel is an undergoer of ATR harmony, despite the lack of acoustic cues. This calls the transparent status of /a/ in other languages with ATR harmony into question; the matter is worthy of further study.

In other tongue root harmony systems in which active retraction of the tongue root is the harmonizing property, it is the high vowels that are transparent or block. In many languages, /i/ and /u/ block the spread of RTR harmony. A well known case of such a system comes from the standard variety of Yoruba (Pulleyblank 1988; Archangeli & Pulleyblank 1989, 1994). It is also possible for /i/ and /u/ to be transparent to RTR harmony. Perhaps the most well-known examples of high vowel transparency to RTR harmony come from Ife Yoruba (Ola Orie 2001, 2003) and Wolof (Pulleyblank 1996). However, given the new understanding of vowel articulation in Kinande, there are also cases in which high vowels are reported as being transparent to RTR harmony when instrumental study shows that are not. For instance, while /i/ has been described as transparent to RTR harmony in Halk Mongolian, acoustic data collected by Svantesson et al. (2005) show that /i/ is actually produced as [ɪ] in RTR forms.

Interestingly, a similar pattern of transparency and blocking effects appears to hold across RTR vowel harmonies and vowel-consonant postvelar harmonies, which also involve retraction of the tongue body and/or root. In Flathead Montana Salish, /i/ is transparent to a process of faecal (uvularization or pharyngealization) harmony (Doak 1992; Bessell 1998), which is triggered by uvular and pharyngeal consonants. The related Coeur d'Alene Salish displays a

similar process in which /i/ in some words appears to partially undergo harmony and partially remain transparent to it (Doak 1992; Bessell 1998); this is discussed in greater detail in section 5.3.

In addition, many varieties of Arabic have a process of emphasis (uvularization/pharyngealization) harmony that interacts in interesting ways with palatal consonants and high vowels. In Arabic, coronal consonants may be either plain or emphatic, i.e. produced with concurrent tongue body retraction. Emphasis harmony spreads this tongue body retraction from a triggering coronal consonant onto surrounding consonants and vowels (for an overview, see Watson (2002)). In many varieties of Arabic, palatal consonants and the vowel /i/ block emphasis harmony; this is the case in Palestinian Arabic (Younes 1982, 1993; Herzallah 1990; Davis 1995; Shahin 1997). In other varieties, such as Cairene Arabic, the set of blockers is expanded to include the high back vowel /u/ (Watson 2002).

4.2.4 *Vowel Place Harmonies*

The other two properties upon which harmony is commonly based are vowel height and backness. The most well-known cases of transparency and blocking in backness harmony come from the Uralic languages, especially Hungarian and Finnish, in which front unround vowels fail to participate in the progressive spread of backness. Often, these languages show a distinction in the behavior of front vowels with respect to rounding, with round front vowels frequently harmonizing while unround front vowels are neutral to harmony. Many analyses focus on whether these front unround vowels are transparent to harmony, allowing a preceding vowel to spread its [+back] feature onto a following vowel, or whether they trigger their own harmony based on the feature [-back]. In Finnish, the front unround vowels /i/ and /e/ lack back counterparts and are transparent to backness harmony when they occur in suffixes. A similar

case comes from Votic backness harmony, in which high /i/ is transparent and /e/ is sometimes transparent (Blumenfeld & Toivonen 2016). A great deal of research on Hungarian has focused on the relative likelihood of front unround vowels of different heights and lengths to be transparent or to block harmony (e.g., Vago 1976; Ringen & Vago 1998; Siptár & Törkenczy 2000; Gafos & Beňuš 2006; Hayes & Londe 2006). Work on this language has established a continuum of likelihood of a vowel to be transparent to backness harmony: [i] and [i:] are most likely to be transparent, followed by [e:], followed by [ɛ]. Other sources of the patterns of backness harmony neutrality in Hungarian include vowel length, as well as statistical patterns over the lexicon; see Hayes & Londe (2006) for an overview.

Backness harmony is also common among languages with rounding harmony, especially within the Turkic language family. However, backness harmony in these languages usually proceeds uninterrupted, with no vowels being either transparent to or blocking harmony. However, there are reported cases of consonants blocking backness harmony. One example of this comes from Turkish. In Turkish, all vowels participate in backness harmony; rounding harmony only holds among high vowels, while nonhigh vowels act as blockers. Interestingly, while backness harmony is not blocked by any vowels in the Turkish inventory, it is blocked in some cases by palatalized consonants (Clements & Sezer 1982).

Among height harmonies, it is common for the low vowel /a/ to block processes that result in either vowel raising or vowel lowering. Parkinson (1996) lists many cases of height harmony involving stepwise vowel raising. While some of these height harmonies target all vowels in a language's inventory, others do not affect the low vowel /a/. One example comes from Kikuria, in which /a/ blocks raising that is triggered by a high vowel in a suffix from affecting preceding prefixes. Low /a/ also blocks height harmony in Shona, in which vowel

lowering is triggered by mid vowels but not the low vowel /a/; furthermore, /a/ blocks vowel lowering from spreading further (Beckman 1997, 1998). This is similar to the situation in some rounding harmony systems, in which non-triggering round vowels also block harmony.

There do not appear to be any instances of transparency in unbounded height harmony. A classic case of height harmony which has been described as displaying both transparency and blocking comes from Menominee (Cole & Trigo 1988). However, this harmony system has been reanalyzed by Archangeli & Pulleyblank (1994) and others as involving tongue root position rather than height. On the other hand, there are cases of metaphony, a type of bounded harmony, in which /a/ is transparent to harmony involving raising. In Lena Asturian, high vowels in inflectional suffixes cause raising of a stressed vowel in the root. When an unstressed [a] intervenes, it is not affected by harmony (Hualde 1989). However, Walker (2011) suggests that there is reason to believe that this and other metaphony patterns should not be analyzed as feature spreading, but as long-distance agreement of some kind. In Lena Asturian, /a/ is a target of harmony when it is in a stressed syllable, raising to [e] when it precedes a triggering inflectional suffix with a high vowel. However, /a/ is transparent to harmony, surfacing faithfully as [a], when it is in a syllable between the stressed syllable and the inflectional suffix.

Harmony systems based on vowel height and backness will be discussed in section 6.2.1. Currently, there are no direct analogs for vowel height and backness within any theories of gesture-based phonology. This means that while it is possible within gestural phonology to represent front and back vowels of all heights, there is at present no way to represent the spread of height and backness. The representation of such harmonies within the Gestural Harmony Model requires a substantial modification to the representation of vowel place within gestural phonology.

4.2.5 *Summary*

For all vowel and vowel-consonant harmonies, with the possible exception of unbounded height harmony, both transparency and blocking are attested. Of particular interest is the fact that blocking and transparency show different patterns of attestation in nasal and rounding harmonies, with the ability to surface as transparent limited to significantly smaller classes of segments. In nasal harmony, all segment types are attested as blockers, while only obstruents are attested as transparent. In rounding harmony, all vowels are attested as blockers, while only high front vowels are attested as transparent. In other types of harmony, including those based on tongue root position, no much asymmetry exists; the sets of attested blocking and transparent segments are identical. A successful model of harmony must be able to limit the ability to be transparent to smaller segment classes in nasal and rounding harmonies, but not in other types of harmony.

In addition, it is possible for transparent and blocking segments to exist within a single harmony system. This occurs in some rounding harmony systems (e.g., Halk Mongolian), nasal harmony systems (e.g., Coatzospan Mixtec), and in tongue root harmony systems (e.g., Menominee). A successful model of harmony must be able to generate such systems.

The typological patterns of transparency and blocking in nasal harmony and rounding harmony are of interest because they are not predicted by standard approached to neutrality in harmony, in which neutral segments are the result of a single mechanism within the phonological grammar. The Gestural Harmony Model accounts for both the subset asymmetry among transparent and blocking segments and the ability of a harmony system to exhibit both transparency and blocking by analyzing them as the results of distinct theoretical mechanisms. The following section introduces these two mechanisms in turn.

4.3 Gestural Antagonism and Gestural Inhibition

Rather than treating transparency and blocking as two different manifestations of the singular concept of neutrality, the Gestural Harmony Model provides two distinct mechanisms with which to drive and represent transparency and blocking. Crucially, the mechanism responsible for transparency in the Gestural Harmony Model is available to a limited set of segments, accounting for the fact that transparent segments make up a proper subset of blocking segments in nasal harmony and rounding harmony. The blocking mechanism, on the other hand, is available to all segment types. These two mechanisms are based on the notions of gestural *incompatibility* and gestural *antagonism*.

In the Gestural Harmony Model, harmony is the result of a gesture that potentially overlaps all segments (sets of gestures) in a word, causing them to undergo harmony. However, at times this sort of overlap may result in the concurrent activation of gestures that are either *antagonistic* to or *incompatible* with one another. These two possible consequences of gestural overlap are the motivators of the two distinct mechanisms that generate transparency and blocking within the Gestural Harmony Model.

I propose that in the Gestural Harmony Model, transparent segments are not neutral to harmony, but instead that they are overlapped by a harmonizing gesture. Transparent segments, then, are just a special type of undergoer. In this model, transparency to harmony is the result of the concurrent activation of a harmonizing gesture and a gesture that is antagonistic to it. Two gestures are antagonistic if they have directly opposing target articulatory states that strive to pull an active articulator in opposite directions. For example, a velum opening and a velum closure gesture are antagonistic when active at the same time. During this period of concurrent activation, the velum receives conflicting instructions from the two active gestures; these target articulatory states cannot both be achieved. Instead, resolution of this competition is calculated

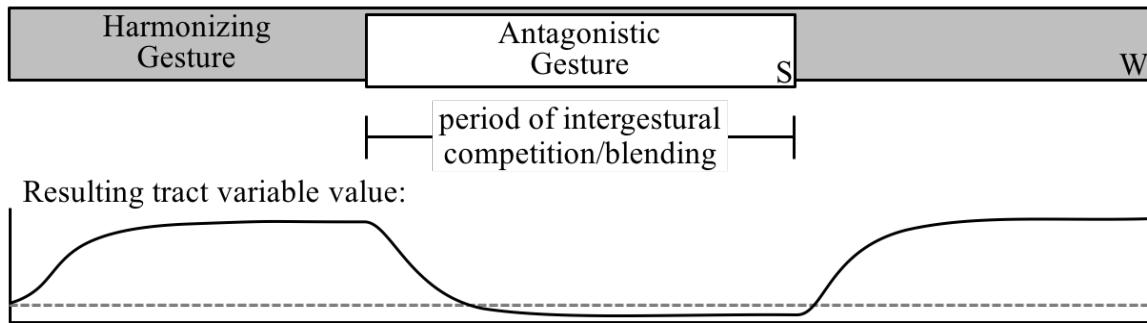
according to the Task Dynamic Model of speech production (Saltzman & Munhall 1989). According to the Task Dynamic Model, concurrently active gestures with non-identical target articulatory states undergo gestural blending, or averaging, as discussed in section 1.2.1. During the period of their concurrent activation, the composite target articulatory state of two or more blended gestures is the weighted average of their individual target states, with each gesture's specified strength parameter contributing the weights. As a result of this blending, one or both of the antagonistic gestures will not fully achieve its target articulatory state. This is discussed in further detail in section 5.2.1

The Gestural Harmony Model recruits this mechanism of gestural competition and blending to account for transparency to harmony. When a harmonizing gesture overlaps another gesture that is antagonistic to it, competition arises and gestural blending occurs. If the gesture that is overlapped by the harmonizing gesture is sufficiently strong, its target articulatory state will be favored by gestural blending, and it will counteract the effect of the harmonizing gesture throughout its period of activation. The result is transparency to harmony.

This is represented schematically in the gestural score in (128). In this gestural score, a harmonizing gesture extends to overlap a gesture that is antagonistic to it. During the period of their concurrent activation, these gestures undergo blending. Because the antagonistic gesture is specified for a high gestural strength (denoted by 'S' for strong) while the harmonizing gesture is specified for a relatively lower gestural strength (denoted by 'W' for weak), blending of these antagonistic gestures is resolved in favor of the target articulatory state of the antagonistic gesture. As a result, the active articulator is pulled away from the position specified by the still-active harmonizing gesture during the production of the antagonistic gesture. When the

antagonistic gesture deactivates, the articulator is free to return to the position required by the harmonizing gesture.

(128) Schematic gestural score showing coactivation transparency due to gestural antagonism



In the Gestural Harmony Model, there is no need for the phonological grammar to be involved in driving transparency to harmony. Instead, transparency follows directly from the concurrent activation of antagonistic gestures and the calculations of the Task Dynamic Model of speech production. The analysis of transparency in the Gestural Harmony Model takes advantage of the dynamical, goal-based nature of gestures. Cast in this way, transparency is a consequence not of the work of the phonological grammar, but of the gestural representations themselves. Therefore, the account of transparency based on intergestural competition predicts that only certain configurations of gestural overlap can result in transparency. Specifically, only those segments bearing gestures that are antagonistic to a harmonizing gesture can surface as transparent to harmony. Because of this, the Gestural Harmony Model is able to account for the limited sets of possible transparent segments in rounding harmony and nasal harmony.

This representation of transparent segments as a special type of undergoer of harmony is in keeping with previous work by Clements (1976b), Piggott (1988), Walker (1998/2000, 2003), Jurgec (2011), and others claiming that transparent segments are more closely related to undergoers of harmony than blockers of harmony. Walker (2003) refers to transparent segments

and undergoers together as *permeable* segments. Both Clements and Piggott analyze transparency to harmony as the result of a derivationally opaque process by which both undergoers and transparent segments are targeted by a feature-spreading rule. Afterward, transparent segments undergo a repair rule that returns them to their original feature specifications. Walker (1998/2000, 2003) analyzes transparency to nasal harmony using Harmonic Sympathy, an extension of Sympathy Theory (McCarthy 1999) in order to mimic this effect of derivational opacity within OT. In the Gestural Harmony Model, by contrast, neither a repair rule nor the additional grammatical architecture of Sympathy Theory are necessary in order to generate transparency to harmony. Instead, transparency will result automatically from the overlap and subsequent blending of antagonistic gestures, as calculated by the Task Dynamic Model.

While gestural antagonism refers to a specific case of overlap in which two gestural have directly opposing target articulatory states, gestural *incompatibility* refers to any situation in which the concurrent activation of two or more gestures is marked in some way (including the special case of gestural antagonism). The overlapping of two incompatible results in the production of a segment that is either articulatorily or perceptually difficult. For example, the concurrent activation of a velum opening gesture with the lingual gestures making up a liquid is marked for perceptual reasons (Walker 1998/2000). A language's phonological grammar may either allow the marked structure caused by this gestural overlap, or ban it and prevent the overlap of these incompatible gestures.

I analyze blocking of harmony as the result of a language banning the concurrent activation of a harmonizing gesture and the gestures of a blocking segment with which it is incompatible. Blockers of harmony are distinct from transparent segments in this way; while

transparent segments are undergoers of harmony, blocking segments are not. This appeal to markedness and restrictions on co-occurrence is akin to most feature-based analyses of blocking in harmony. Where the Gestural Harmony Model differs from these analyses is in the application of these restrictions on gestural co-occurrence only to cases of blocking and not to both blocking and transparency. This is the source of the different typological predictions made by the Gestural Harmony Model and many feature-based analyses of harmony with respect to which segment types are attested as transparent and blocking segments. This is discussed in detail in section 4.7.2.

A gestural analysis of blocking must account for the fact that in some systems, a harmony-triggering gesture may extend to overlap some gestures and not others. Furthermore, it must do so without directly manipulating a gesture's period of activation, which is not included within a coupling graph representation. Instead, some relation between a harmonizing gesture and a blocking gesture (or set of gestures) must be specified in the coupling graph and must result in no overlap between these gestures. The generalization that seems to be at the heart of this blocking behavior is that the activation of a blocking gesture prevents the activation of a harmonizing gesture. In the case of progressive harmony, a blocking gesture causes deactivation of a persistent (non-self-deactivating) gesture, while in the case of regressive harmony, a blocking gesture prevents an anticipatory (early-activating) gesture from activating even earlier.

I propose that this inhibitory relation between incompatible gestures is what must be represented in the coupling graph. *Inhibition* refers to a relation between two units in which the activation level of one unit detracts from the activation level of the other. Within the Gestural Harmony Model, I assume this inhibition relation to be unidirectional, with the activation of the inhibiting gesture determining the activation of the inhibited gesture. In a coupling graph, an

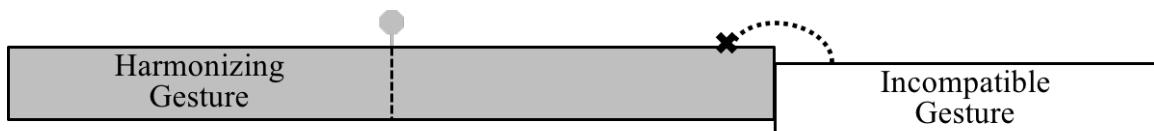
inhibitory relation between two gestures can be represented as in (129) for a case of progressive harmony. In this figure, the inhibitory relation is represented by the dotted line between the two gestures, and the X indicates the gesture which is being inhibited.

(129) Intergestural inhibition relation between incompatible gestures



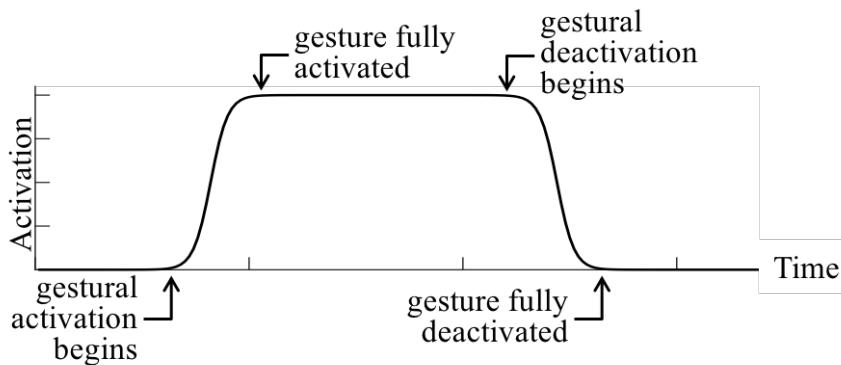
In the case of progressive harmony, the potential for a persistent gesture to extend its period of activation is represented by the gesture's setting of its deactivation parameter such that it will not self-deactivate upon reaching its target articulatory state. Its precise end time is not specified, but is rather calculated by the augmented version of the Coupled Oscillator Model described in section 2.2. The inclusion of an inhibition relation between a persistent gesture and a following blocking gesture specifies that whenever a blocking gesture is activated, the harmonizing gesture will deactivate. In (129), the activation periods of the inhibited and inhibiting gestures are not represented; however, this figure still represents the fact that the inhibited gesture will deactivate whenever the inhibiting gesture activates. When a coupling graph that includes an inhibition relation between a harmonizing gesture and a blocking gesture is input to the Coupled Oscillator Model, the result will be a gestural score in which the harmonizing gesture extends only partially through a word. This is illustrated in the schematic gestural score in (130).

(130) Schematic gestural score showing intergestural inhibition due to gestural incompatibility



Early work in Articulatory Phonology (e.g., Browman & Goldstein 1986, 1989) assumes that gestures are either active (with an activation level equal to one) or inactive (with an activation level equal to zero). In this view, the transition from inactive to active and vice versa is instantaneous. If this is the case, at the moment when a blocking gesture goes from fully inactive to fully active, an inhibited persistent gesture will go from fully active to fully inactive. More recent work in Articulatory Phonology, such as that reported by Byrd & Saltzman (2003), assumes a ramped representation of gestural activation and deactivation, in which a gesture's transition between activity and inactivity is rapid but not instantaneous, as in (131).

(131) Timecourse of ramped activation and deactivation of a gesture



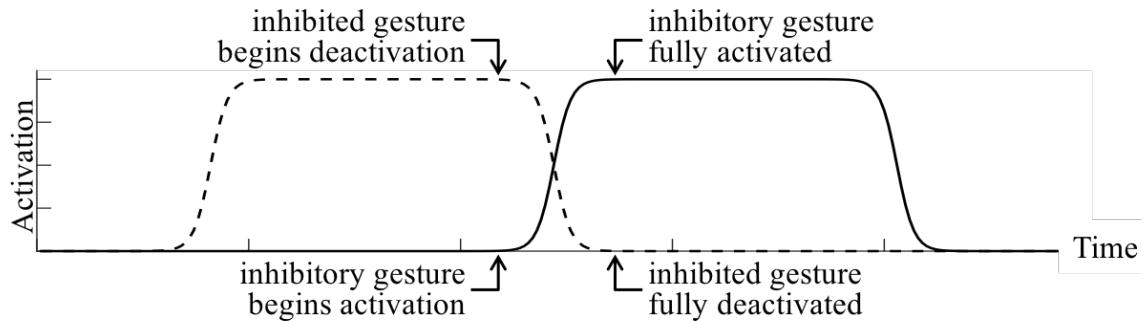
Intergestural inhibition can be implemented in a gestural framework that assumes ramped activation as well. As a working hypothesis I assume that the calculation of the activation levels of gestures that are in an inhibitory relationship is fairly simple (though see section 6.2.2 for further discussion). When two gestures are in an inhibitory relationship and are simultaneously active, the activation of the inhibited gesture is calculated as the difference between 1 and the activation level of an inhibitory gesture, as in (132). When an inhibitory gesture is not activated, it has no effect on the activation of the inhibited gesture and the equation in (132) does not hold.

(132) Equation for gestural inhibition

$$\text{Activation Level of Inhibited Gesture} = 1 - \frac{\text{Activation Level of Inhibitory Gesture}}{\text{Activation Level of Inhibited Gesture}}$$

That the activation level of the blocking gesture determines the sum total activation of the two gestures is captured by the asymmetric nature of the inhibitory relation between them. As the activation of the inhibitory gesture approaches 1, the activation of the inhibited gesture must fall to zero. I assume that once a gesture's activation reaches 0, it remains there; gestures cannot be reactivated at a later time. The figure in (133) shows the time course of activation of two gestures in an inhibitory relationship.

(133) Persistent gesture (dashed) is inhibited and deactivated by a following blocking gesture (solid)



This inhibition mechanism can also be used to represent blocking in regressive harmony systems, in which a blocker precedes a harmony triggering anticipatory gesture. In this case, rather than deactivating a harmonizing gesture, inhibition by a blocking gesture prevents the Coupled Oscillator Model from activating an anticipatory gesture even earlier and extending that gesture's activation even further in the regressive (leftward) direction. This is illustrated in the schematic gestural score in (134).

(134) Schematic gestural score showing intergestural inhibition due to gestural incompatibility



The presence of an inhibition relation between a harmonizing gesture and an incompatible blocking gesture can be attributed to the need to satisfy a constraint within the phonological grammar. Note that this contrasts with the analysis of transparency via the concurrent activation of antagonistic gestures, in which transparency results directly from the representational units themselves and not as the result of any grammatical mechanism. I propose that blocking via intergestural inhibition is enforced by constraints from the *OVERLAP family, the schematic definitions of which are repeated in (135) from (19) in section 1.2.2.

(135) Schemas for *OVERLAP constraints

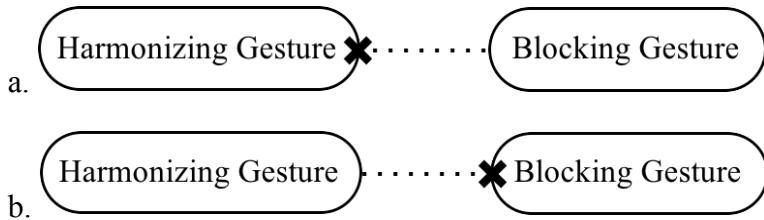
- a. *OVERLAP(Gest_X, Gest_Y): Assign a violation mark for a pair of gestures of type X and type Y that are concurrently active.
- b. *OVERLAP(Gest_X, Gest_Y, Gest_Z): Assign a violation mark for a gesture of type X that is concurrently active with a gesture of type Y and with a gesture of type Z.

The marked temporal overlap between a harmonizing gesture and a gesture or set of gestures with which it is incompatible is prevented when these gestures enter into an inhibition relation with one another, such that the blocking gesture deactivates the harmonizing gesture. The overlap of incompatible gestures is not prevented by simply stating the starting point or end point of the harmonizing gesture within the gestural score, but by altering the coupling graph (via the inclusion of an inhibition relation) such that the desired gestural score is produced from it by the Coupled Oscillator Model.

This alteration of the coupling graph involves not only the inclusion of an inhibition relation, but also the proper setting of the directionality of the asymmetric inhibition relation.

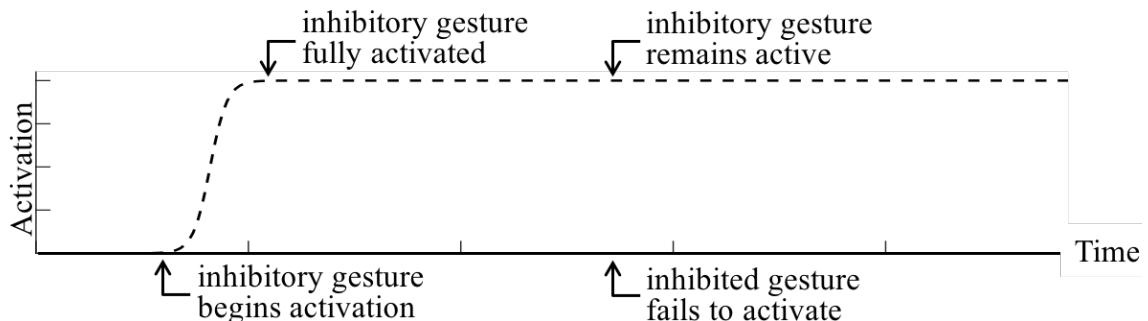
*OVERLAP constraints do not specify the direction of intergestural inhibition. Instead, the desired directionality of inhibition, by which a blocking gesture inhibits a harmonizing gesture (and not vice versa), will arise automatically for both persistent and anticipatory gestures. Looking first at progressive (rightward) harmony, consider the two possible directions of asymmetric inhibition between a persistent (non-self-deactivating) gesture and a following blocking gesture in (136).

- (136) Inhibition relations between harmonizing persistent gesture and blocking gesture



The relation shown in (136a), in which the intended blocking gesture inhibits the persistent harmonizing gesture, produces the desired time course of gestural activation shown in (133) above. With this inhibition relation in place, the harmonizing gesture activates itself, and deactivates when the inhibitory blocking gesture activates itself. The relation shown in (136b), on the other hand, produces the undesired time course of gestural activation in (137).

- (137) Persistent gesture (dashed) inhibits following blocking gesture (solid), preventing its activation (not produced by GEN)



Again, the persistent harmonizing gesture activates itself, but now it is this harmonizing gesture that inhibits the intended blocking gesture. Because the summed activations of two

gestures in an inhibition relation must equal one, and the fully active velum opening gesture already has an activation of one, the blocking gesture will be prevented from activating at the 0° phase of its planning oscillator as specified in the coupling graph. Meanwhile, the harmonizing gesture will remain active. This directionality of inhibition has produced two undesirable outcomes: the persistent gesture has not been deactivated by its intended blocker, and the blocking gesture has failed to activate at all.

The inhibition relation in (136b) produces a scenario in which a gesture that is present in the coupling graph fails to ever activate. The Gestural Harmony Model must ban such a configuration from ever being generated by the phonological grammar. This can be achieved by stating that it is a property of GEN that it will not produce candidate output forms that do not allow for the activation all gestures present in the coupling graph. By ruling out the inhibition relation in (136b) in which the harmonizing persistent gesture inhibits its intended blocking gesture, only one possibility remains. When an inhibition relation is added to a coupling graph between a harmonizing gesture and a blocking gesture, it will always be the case that the blocking gesture inhibits the harmonizing gesture. There is no need to stipulate this directionality in the definition of a constraint like *OVERLAP.

The same reasoning holds true of regressive (leftward) harmony, in which a blocking gesture precedes a harmonizing anticipatory (early-activating) gesture. The desired directionality of inhibition, by which a blocking gesture inhibits a following harmonizing anticipatory gesture as in (136a), will arise automatically in candidate coupling graphs. If a harmonizing anticipatory gesture were to instead inhibit a preceding blocking gesture, it would be permitted to activate as early as possible in a word and would extend to overlap the blocking gesture, thus preventing it from ever activating. The time course of activation for such a configuration would be identical to

that in (137). This configuration is also assumed to be universally banned from being generated by the phonological grammar.

In order to account for patterns of blocking across harmony systems, the phonological grammar must include some constraint that conflicts with the family of *OVERLAP constraints. Otherwise, harmony will be predicted never to proceed past a segment that is subject to some *OVERLAP constraint, i.e. any segment that is attested as a blocker of harmony in any language. In many analyses of harmony, this is achieved by ranking a harmony-driving constraint over the constraint that is responsible for blocking. However, the Gestural Harmony Model does not make use of any explicit harmony driver, instead relying on a property of the harmonizing gesture, its persistence and/or early activation, to motivate the temporal extension of a gesture. Rather than using a harmony driver to counter *OVERLAP, I propose the addition of a constraint that penalizes inhibition relations generally, as defined in (138).

- (138) *INHIBIT: Assign a violation mark to an inhibition relation between gestures in a coupling graph.

When a *OVERLAP constraint is ranked above *INHIBIT, the gestures that are named as the arguments of the *OVERLAP constraint are allowed to enter into an inhibition relation in order to prevent the overlap of incompatible gestures. This results in the blocking of harmony. When *INHIBIT is ranked above *OVERLAP, the overlap of incompatible gestures will be permitted, and harmony will not be blocked. This interaction between *OVERLAP and *INHIBIT constraints is illustrated by the tableau in (139). In candidate (a), two incompatible gestures overlap one another, violating *OVERLAP(Gest_X, Gest_Y) but satisfying *INHIBIT. In candidate (b), Gesture Y inhibits Gesture X, violating *INHIBIT but satisfying *OVERLAP(Gest_X, Gest_Y). The candidate that surfaces as the winner is determined by the relative ranking of these two constraints.

(139) Tableau illustrating violation profiles for *OVERLAP and *INHIBIT

Input:	*OVERLAP (Gest _X , Gest _Y)	*INHIBIT
 a.	*	
 b.		*

In closing, it should be reiterated that while gestural antagonism and gestural incompatibility are distinct concepts whose effects are manifested in the Gestural Harmony Model in different ways, gestural antagonism is a form of gestural incompatibility. When two concurrently active gestures have conflicting target articulatory states, they are both antagonistic to and incompatible with one another. However, it is not the case that incompatibility between gestures entails gestural antagonism. Gestures may be incompatible with one another for a variety of reasons, both articulatory and perceptual, that do not necessarily have to do with gestural antagonism. Because of this, the ability to induce transparency to a given type of harmony is restricted to the specific set of segments that include a gesture that is antagonistic to a harmonizing gesture, while any incompatible gesture is capable of blocking harmony. By splitting the motivations and theoretical mechanisms responsible for transparency and blocking within the Gestural Harmony Model, distinct sets of predictions are made with respect to which types of segments can be transparent to harmony, and which can block it. This is essential to accurately capturing the fact that in nasal and rounding harmonies the sets of attested transparent and blocking segments are in a subset-superset relation.

Now that the theoretical mechanisms responsible for transparency and blocking in the Gestural Harmony Model have been introduced, the following sections examine how they can be implemented within nasal harmony, rounding harmony, and tongue root harmony. For each type of harmony, it is necessary to determine what gestural representations are necessary to produce transparency via intergestural competition and blending, and which constraints must be present in the phonological grammar to induce intergestural inhibition relations and produce attested patterns of blocking.

4.4 Transparency and Blocking in Nasal Harmony

This section focuses on transparency and blocking in nasal harmony, in which all consonant types are attested as blockers, while only obstruents are attested as being transparent to harmony. This section begins by examining the gestural representations and constraints necessary to successfully produce the attested patterns of transparency and blocking in nasal harmony. The proposals made here are then illustrated by analyses of transparency in Tuyuca, as well as blocking in several languages, including Orejón and Capanhua.

4.4.1 Sources of Antagonism and Incompatibility

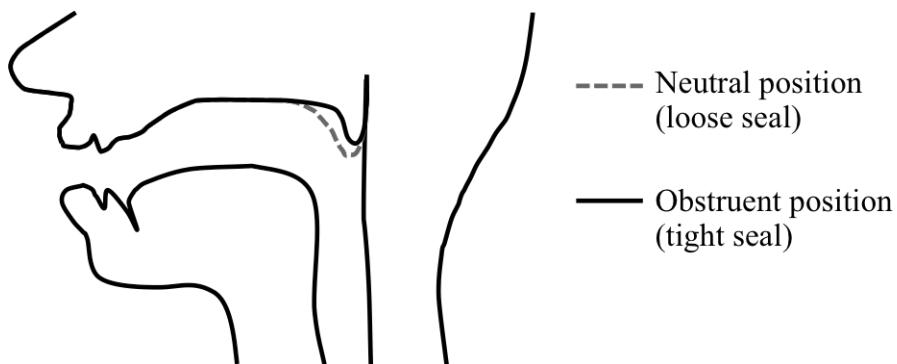
As discussed in section 4.2.1, Piggott (1992) and Walker (1998/2000, 2003) claim that obstruents are the only consonants attested to be transparent to nasal harmony. The particularly strong ban on the co-occurrence of obstruency and nasality is well established within both phonetics and phonology. An oral stop is characterized by a buildup of air pressure during its closure phase, which then leads to an audible burst upon release. Fricatives depend on sufficient airflow through a narrow channel formed at some point along the vocal tract in order to produce the turbulence necessary for friction. Both of these acoustic events are dependent upon precise aerodynamic conditions of the vocal tract, conditions that are significantly disrupted by the

opening of the velum. These aerodynamic factors lead Ohala & Ohala (1993) to posit the theorem in (140) with respect to obstruents and velum position.

- (140) Theorem A: The velic valve must be closed (i.e., the soft palate must be elevated) for an obstruent articulated further forward than the point where the velic valve joins the nasal cavity and the oral cavity. (p. 227)

Following the lead of Theorem A, some representations of obstruents in Articulatory Phonology include both an oral constriction gesture (full closure for stops and critical constriction for fricatives) and a velum closure gesture. I adopt this representation of obstruents. The inclusion of a velum closure gesture in the representation of an obstruent will ensure that there is a tight seal of the velopharyngeal port that will prevent the escape of air through the nasal cavity. While the neutral position of the velum (the position it assumes when not engaged by an active gesture) is assumed to be high enough to close the velopharyngeal port, the seal is presumably not sufficiently tight for the production of obstruents. Thus, tighter closure between the velum and pharyngeal wall must be achieved by an active velum closure gesture that raises the velum relative to its neutral position. These velum positions are illustrated in the figure in (141).

- (141) Vocal tract with velum in neutral, loosely sealed position (dashed line) and in actively raised, tightly sealed position (solid line)



Articulatory data supports the claim that the gestural representation of an obstruent should include a velum closure gesture. Numerous studies, including those by Lubker (1968), Bell-Berti & Hirose (1975), and Bell-Berti (1976) report raising of the velum during the production of oral stops relative to the height achieved during the production of oral vowels (which are assumed to represent the lower neutral position of the velum), as well as during the production of nasal consonants.

The presence of a velum closure gesture in the representation of obstruents is crucial to the analysis of their transparency to nasal harmony within the Gestural Harmony Model. A velum closure gesture is directly antagonistic to a harmonizing velum opening gesture, and is the source of obstruents' resistance to nasalization. When an obstruent is overlapped by a velum opening gesture, its antagonistic velum closure gesture will ensure that the obstruent is not nasalized. In contrast, a loose seal of the velopharyngeal port is sufficient to achieve the less stringent oral airflow goals of liquids, glides, and vowels. Thus, these sounds are not represented with an accompanying velum closure gesture. Because of this lack of a velum closure gesture, the Gestural Harmony Model accurately predicts that these segments are unable to surface as transparent to nasal harmony, and will always surface as nasalized when they are overlapped by a harmonizing velum opening gesture.

Complicating the picture slightly is the status of fricatives and of voiced obstruents, which appear to vary across languages with respect to whether they are classified as obstruents or as sonorants. In some nasal harmony systems, both fricatives and oral stops are transparent to nasal harmony, suggesting that they are specified for active velum closure in that language. An example of such a nasal harmony system comes from Moba Yoruba (Ajiboyè 2001; Ajiboyè & Pulleyblank 2008). In other nasal harmony systems, however, fricatives appear to pattern with

sonorants in surfacing as nasalized. An example of such a system comes from Applecross Scottish Gaelic (Ternes 1973; Warner, Brenner, Schertz, Fisher, & Hammond 2015). There also appears to be variability across languages as to whether the voicing of a fricative or oral stop determines its status as a sonorant or an obstruent. In Tuyuca nasal harmony, for instance, voiceless fricatives and stops are transparent to nasal harmony, while voiced stops surface as nasalized (Barnes & Takagi de Silzer 1976; Barnes 1996).²⁶

The Gestural Harmony Model's account of the variable behavior of voiced and voiceless obstruents in nasal harmony adopts the proposals by Rice & Avery (1989), Piggott (1992), Rice (1993), Botma (2004), and Botma & N. Smith (2007) that voiced obstruents that undergo nasalization are represented in a way that is similar to the representation of sonorants. Rice (1993) uses the term 'sonorant obstruents' to refer to voiced fricatives and stops that surface as oral in oral environments but are susceptible to nasalization in the same way that sonorants are. Within gestural phonology, I propose that the class of obstruents be defined as those fricatives and stops that are accompanied by a velum closure gesture. The class of sonorants, then, encompasses any segment that does not include a velum closure gesture. Languages appear to vary as to whether their fricatives and voiced oral stops are accompanied by a velum closure gesture, rendering them obstruents, or whether they lack a velum closure, rendering them sonorants. As a result of this lack of a velum closure gesture, both true sonorants and 'sonorant obstruents' (fricatives and oral stops without a velum closure gesture) are predicted to be unable to surface as transparent to nasal harmony.

While transparency to nasal harmony is limited to the class of obstruents, all classes of consonants (and in rarer cases vowels) are able to block harmony on a language-specific basis. The propensity of different consonant types to block harmony follows the implicational

²⁶ Tuyuca has no voiced fricatives.

hierarchy observed by Schourup (1972), Pulleyblank (1989), Piggott (1992), Cohn (1993a, 1993b), Hume & Odden (1996), and Walker (1998/2000). In particular, I follow the proposals of Pulleyblank and Walker that this implicational hierarchy is based on different types of segments' incompatibility with nasalization. However, I propose that this implicational hierarchy need not distinguish between fricatives and oral stops in terms of their incompatibility with nasalization. Instead, whether fricatives pattern with liquids or with obstruents is determined by the presence or absence of a velum closure gesture in their representations; the same holds true of voiced fricatives and stops. The revised scale of nasal incompatibility that I assume is provided in (123).

(123) Proposed harmony scale of nasal (in)compatibility

$$\begin{array}{ccccccc} \text{nasal} & > & \text{nasal} & > & \text{nasal} & > & \text{nasal} \\ \text{sonorant stop} & > & \text{vowel} & > & \text{glide} & > & \text{liquid} & > & \text{obstruent} \end{array}$$

The blocking of nasal harmony can be captured within the Gestural Harmony Model by the interaction of constraints from the *OVERLAP and *INHIBIT families. In order to account for the patterning of different types of consonants as either undergoers or blockers of nasal harmony, it is necessary to first explicitly define consonantal types in gestural terms. I assume the definitions of different segment types provided in (124), and the use of these terms in the constraint definitions that follow can be considered shorthand for these definitions.

(124) Gestural definitions of segment types

- a. Vowel: a segment whose primary gesture is a low-stiffness vocalic gesture
- b. Glide: a segment whose primary gesture is a high-stiffness vocalic gesture with narrow constriction degree
- c. Liquid: a segment that includes a consonantal tongue tip gesture and not a velum gesture
- d. Consonant: a segment whose primary gesture is a consonantal gesture or a high-stiffness vocalic gesture with narrow constriction degree

- e. Sonorant: a segment that does not include a velum closure gesture
- f. Obstruent: a segment that includes a velum closure gesture
- g. Oral consonant: a consonantal segment that does not include a velum opening gesture

Having defined these terms for referring to different types of consonants, the constraints that make reference to them can now be defined as well. First, a *OVERLAP constraint penalizes the concurrent activation of any oral consonant and a velum opening gesture. This constraint is defined in (125).

- (125) *OVERLAP(oral C, velum opening): Assign a violation mark to the gesture(s) of an oral consonant that is/are active concurrently with a velum opening gesture.

This constraint is violated by any oral consonant (as defined in (124g)) that undergoes nasal harmony. It conflicts with constraints from the *INHIBIT family by motivating forms to surface with an inhibition relation between the gestures of an oral consonant and a velum opening gesture.

The implicational hierarchy of nasal harmony blockers can be captured by a set of stringent constraints (de Lacy 2002) requiring that a constraint that penalizes a marked structure must also penalize any other structure that is considered more marked by some harmony scale. The constraint *INHIBIT is defined stringently in order to capture the implicational hierarchy of nasal harmony blockers. The set of *INHIBIT constraints will capture this hierarchy by most harshly penalizing the poorest blockers of nasal harmony. In order to do this, the stringency relation must run from the least to the most incompatible with nasality: glides are the least likely to block nasal harmony, followed by liquids, followed finally by obstruents. The set of stringently defined *INHIBIT constraints that reflect this implicational hierarchy are defined in (126). These *INHIBIT constraints can be ranked relative to the general *OVERLAP(oral C, velum opening) constraint in order to capture attested patterns of blocking of nasal harmony.

(126) Constraints against velum gesture inhibition by consonant type

- a. *INHIBIT(glide, velum opening): Assign a violation mark for an inhibition relation between a glide and a velum opening gesture.
- b. *INHIBIT(sonorant C, velum opening): Assign a violation mark for an inhibition relation between a sonorant consonant and a velum opening gesture.
- c. *INHIBIT(oral C, velum opening): Assign a violation mark for an inhibition relation between an oral consonant and a velum opening gesture.

Many analyses of harmony focus on defining the class of blockers of a certain harmony process. In the Gestural Harmony Model's analysis of nasal harmony, the *INHIBIT constraints achieve this by determining which class or classes of segments may not block harmony in some language. The family of *INHIBIT constraints can be thought of as favoring the spreading of nasalization through various classes of segments. *INHIBIT(glide, velum opening) prevents blocking of nasal harmony by glides; in other words, it drives glides to be permeable to nasal harmony. *INHIBIT(sonorant C, velum opening) similarly drives glides and liquids to be permeable to nasal harmony, and *INHIBIT(oral C, velum opening) drives all oral consonants to be permeable to nasal harmony rather than blocking it (with obstruents surfacing as transparent due to their gestural makeup). It should be noted that harmony is still the result of the presence of a persistent or an anticipatory gesture in a coupling graph and resulting gestural score, and not of a constraint explicitly requiring that a harmonizing gesture remain active for a longer period of time. The *INHIBIT constraints only serve to ensure that when a persistent or an anticipatory gesture does extend its period of activation, that it is not prevented from extending as far as possible by a weak blocker.

Typology calculation using OT-Help 2 (Potts, Pater, Jesney, Bhatt, & Becker 2010) verifies that the relative ranking of the set of *INHIBIT constraints ranked relative to *OVERLAP(oral C, velum opening) generates the attested patterns of transparency and blocking

in nasal harmony listed in (127). The variable patterning of fricatives and voiced obstruents within each of these generated blocking patterns is determined by whether they include a velum closure gesture in their gestural representations.

(127) Predicted nasal harmony blocking patterns

Ranking	Result	Attested in
*OVERLAP(oral C) >> *INHIBIT(glide) *INHIBIT(sonorant C) *INHIBIT(oral C)	Glides, liquids, fricatives, and stops block nasal harmony.	Sundanese (Robins 1957)
*INHIBIT(glide) >> *OVERLAP(oral C)	Glides undergo nasal harmony; liquids, fricatives, and stops block.	Capanahua (Loos 1967; Safir 1982)
*INHIBIT(sonorant C) >> *OVERLAP(oral C)	Sonorants undergo nasal harmony; obstruents block.	
	All fricatives and stops pattern as obstruents.	Kayan (Blust 1972)
	Voiced fricatives and stops pattern as sonorants; voiceless fricatives and stops pattern as obstruents.	Orejón (Pulleyblank 1989, citing Arnaiz 1988)
	Fricatives pattern as sonorants; stops pattern as obstruents.	Applecross Scottish Gaelic (Ternes 1973)

Ranking	Result	Attested in
*INHIBIT(oral C) >> *OVERLAP(oral C)	All segments undergo nasal harmony; obstruents surface as transparent.	
	All fricatives and stops pattern as obstruents.	Moba Yoruba (Ajiboyè 2001; Ajiboyè & Pulleyblank 2008)
	Voiceless fricatives and stops pattern as sonorants; voiceless fricatives and stops pattern as obstruents.	Guaraní (Gregores & Suárez 1967)
	Fricatives pattern as sonorants; stops pattern as obstruents.	

It should be noted that while most of the patterns of transparency and blocking in nasal harmony generated by the constraint set are attested, there is one gap in the table in (127). As yet I have been unable to find a clear-cut case of a nasal harmony system in which fricatives surface as nasalized while stops surface as transparent to harmony. This is likely due to the relative rarity of distinctions between the patterning of stops and fricatives within nasal harmony systems generally. Based on the database of nasal harmony systems provided by Walker (1998/2000), nasal harmonies are much more likely to distinguish between voiced and voiceless obstruents than they are to distinguish between stops and fricatives.

The remainder of this section presents analyses of several of these nasal harmony systems, from Tuyuca, Orejón, and Capanahua. First to be examined is Tuyuca, exemplifying a process of nasal harmony in which all segments undergo nasal harmony and voiceless obstruents surface as transparent.

4.4.2 *Tuyuca: Voiceless Obstruent Transparency*

The nasal harmony of Tuyuca (Tucanoan; Colombia, Brazil; Barnes & Takagi de Silzer (1976), Barnes (1996), Walker (1998/2000)) represents a system in which all segments may undergo harmony, and in which voiceless obstruents surface as transparent. The phonological inventory in (128) is reported by Barnes & Takagi de Silzer (1976).

(128) Tuyuca phonological inventory

Consonants				Vowels		
p	t	k	?	i	i	u
b	d	g		e		o
s					a	
f						
j	w					
		h				

In Tuyuca, nasality is a property of an entire morpheme; morphemes may be either oral or nasal. In oral morphemes, both voiced and voiceless stops and fricatives may appear, as well as sonorant consonants, as in (129). All data come from Barnes & Takagi de Silzer (1976) and Barnes (1996).

- (129) a. [japa] ‘point’
 b. [ete] ‘parakeet’
 c. [juka] ‘falcon’
 d. [sobo] ‘foam’
 e. [buueda] ‘rainbow’
 f. [hooga] ‘banana flower’

In nasal morphemes, nasality is expressed on all segments except voiceless obstruents, which neither undergo nasal harmony nor block it from spreading further (130a-d). Voiced stops, on the other hand, do not appear in nasal morphemes, instead surfacing as their nasal stop counterparts (130e-h). (There are no voiced fricatives in Tuyuca.)

- | | |
|---------------------------|-----------------------------|
| (130) a. [m̩ip̩] ‘badger’ | e. [ʃ̩am̩] ‘night’ |
| b. [w̩at̩] ‘demon’ | f. [w̩in̩o] ‘wind’ |
| c. [ʃ̩uk̩a] ‘yucca soup’ | g. [t̩iŋ̩o] ‘Yapara rapids’ |
| d. [ʃ̩os̩o] ‘bird’ | h. [ʃ̩ɔře] ‘small hen’ |

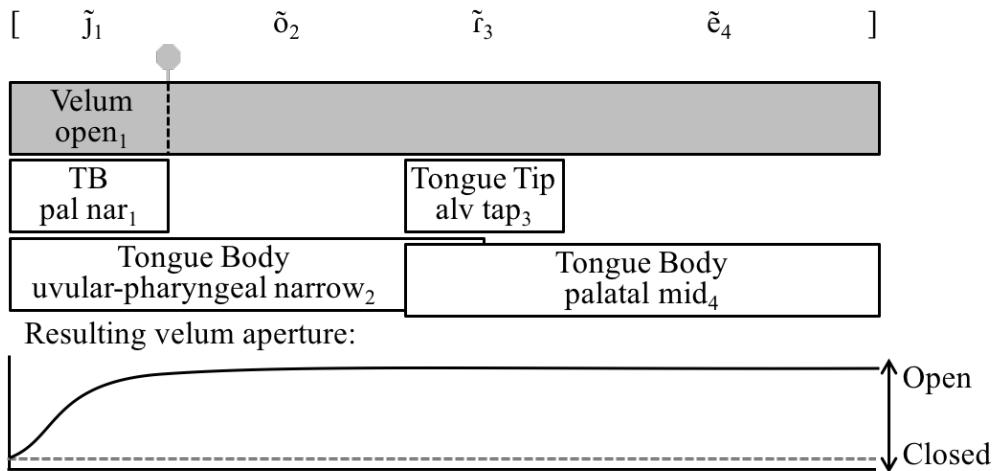
Across morpheme boundaries, the picture is slightly different. Some Tuyuca suffixes undergo nasal harmony that is triggered by a nasal root, as in [h̩iññ-ři] ‘burn (imperative of warning)’ (cf. [tuti-ri] ‘scold (imperative of warning)'). Other suffixes may idiosyncratically block nasal harmony, and will surface as oral even when followed by a nasal root, as in [māmā-wi] ‘new (vehicle classifier).’ When a suffix begins with an obstruent, either voiced or voiceless, the suffix will always block nasal harmony from a root, as in [w̩ākā-go] ‘wake up (evidential).’ I focus in this section on an analysis of within-morpheme nasal harmony in Tuyuca, setting aside a possible avenue for analysis of across-morpheme harmony until section 6.2.2.

Nasal harmony in Tuyuca can be attributed to the presence of a root-initial persistent (non-self-deactivating) velum opening gesture that extends to overlap the gestures of following segments. As proposed in section 3.2, persistent gestures will surface when a constraint of the type PERSIST(Gest_X) is ranked high; in Tuyuca, this constraint is PERSIST(velum opening). The positioning of the persistent velum opening gesture at the beginning of a word in Tuyuca can be attributed to the high ranking of a constraint from the LICENSE family, paralleling the analysis of initial-syllable triggering of rounding harmony in Kyrgyz (section 3.2.1). I will not focus on an analysis of triggering in Tuyuca nasal harmony, and will instead only consider output forms in which a persistent velum opening gesture is coupled to the first segment in a word.

The absence of within-morpheme blocking of nasal harmony can be captured within the Gestural Harmony Model by the ranking of *INHIBIT(oral C) over *OVERLAP(oral C). This will ensure that any oral consonant overlapped by a harmonizing velum opening gesture will be

prevented from inhibiting it, despite the resulting incompatibility. For any segments that do not include a velum closure gesture, this will result in their surfacing as nasalized. This is the case for the Tuyuca word [jõrẽ] ‘small hen,’ in which all consonants and vowels surface as nasalized. The gestural score and resulting velum aperture time course in (131) illustrates. The dashed line in the portion of the figure showing resulting velum aperture represents the neutral position of the velum.

(131) Gestural score for Tuyuca [jõrẽ] ‘small hen’

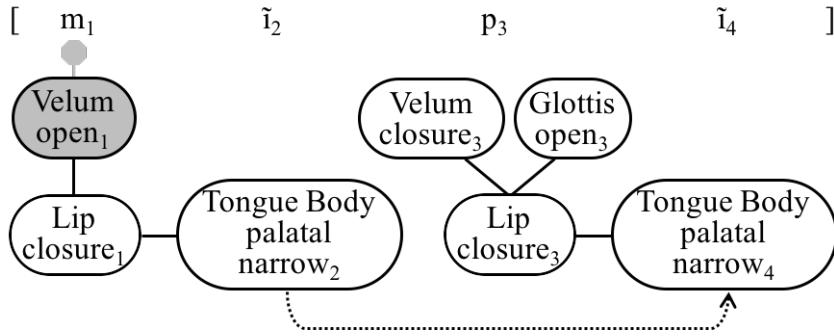


In (131), the persistent velum opening gesture remains active throughout the word, resulting in the nasalization of all consonants and vowels that it overlaps. Because none of these sonorant segments includes a velum closure gesture, they surface as nasalized rather than as transparent when they are overlapped by the velum opening gesture.

A voiceless obstruent, on the other hand, will surface as transparent to nasal harmony when it is overlapped by a velum opening gesture due to the inclusion in its gestural representation of an antagonistic velum closure gesture. This voiceless obstruent transparency is demonstrated in the following coupling graph and resulting gestural score for the Tuyuca word

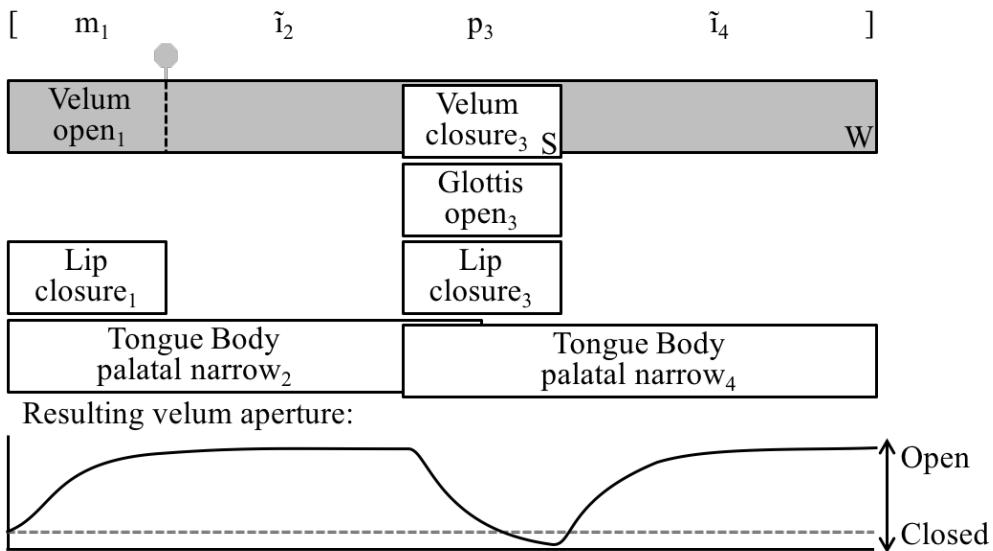
[m̩p̩i] ‘badger,’ in which the voiceless [p] surfaces in a nasal morpheme. The coupling graph for this form is shown in (132).

(132) Coupling graph for [m̩p̩i] ‘badger’



The transparency of obstruent [p] will obtain directly from the content of this coupling graph when it is input to the Coupled Oscillator Model and the Task Dynamic Model. Unlike in many other analyses of transparency in harmony, no additional repair mechanism is necessary to ensure that the [p] of [m̩p̩i] is produced as oral rather than nasal. The coupling graph is specified such that when the gestural score and articulatory trajectories for this word are calculated, nasal harmony with a transparent obstruent will result. This is illustrated in the gestural score in (133), which is output by the Coupled Oscillator Model for the coupling graph in (132).

(133) Gestural score and resulting velum aperture for [m̩íp̩í] ‘badger’



In (133), a persistent velum opening gesture overlaps all other gestures in the word. The initial consonant and the vowels surface as nasalized, but the voiceless obstruent [p], also overlapped by the velum opening gesture, surfaces as oral. This is due to its antagonistic velum closure gesture. This velum closure gesture is specified for a high gestural strength, allowing it to overpower the effect of the velum opening gesture during the period of their concurrent activation. This overpowering is formalized within the Task Dynamic Model of speech production as the result of weighted averaging of the target articulatory states of the two velum gestures such that the target state of the strong velum closure gesture is favored over that of the velum opening gesture. Once the production of the obstruent has concluded and the velum closure gesture deactivates, there is no longer an active gesture that is antagonistic to the velum opening gesture, and the velum opens once again. The validity of this analysis of obstruent transparency in Tuyuca nasal harmony is tested via computational modeling within the Task Dynamic Model of speech production in section 5.2.2.

This representation of transparency as the result of intergestural competition in the Gestural Harmony Model successfully accounts for obstruent transparency in Tuyuca nasal

harmony while maintaining a local representation of the harmonizing element. It also successfully accounts for the ability of voiceless obstruents to surface as transparent to harmony while other segments that are overlapped by a harmonizing velum opening gesture surface as nasalized. The distinction lies in the gestural makeup of these different segment classes, and the analysis of obstruents as consonants that are accompanied by velum closure gestures.

Unlike their voiceless counterparts, voiced obstruents surface as nasalized in the domain of nasal harmony rather than transparent. I analyze this as being due to the surface representations of these segments lacking a velum closure gesture that is necessary to generate transparency. In the form [jäm̩] ‘night,’ for instance, the underlying segment /b/ is proposed to surface as [m] in a nasal morpheme, having undergone nasalization rather than surfacing as transparent. The /b/ in this form surfaces without a velum closure gesture, whether it was accompanied by such a gesture in the input or not. If this form were to surface with a velum opening gesture accompanying /b/, it would be incorrectly produced as *[jäb̩], with a transparent voiced obstruent.

A successful analysis of nasal harmony in Tuyuca and other languages in which only voiceless obstruents are transparent must account for the fact that retention of an obstruent’s velum closure gesture is enforced only when that obstruent is voiceless. That is, a consonant may only retain a velum closure gesture when it is also accompanied by a glottal opening gesture. This can be accomplished by a constraint from the LICENSE family (section 1.2.2) that licenses a velum closure gesture only when it is accompanied by a glottal opening gesture. The constraint is defined as in (134).

- (134) LICENSE(velum closure, glottis open): Assign a violation mark to a velum closure gesture that is not active concurrently with glottal opening gesture.

This licensing constraint is defined negatively, such that an obstruent that is not accompanied by a glottal opening gesture (i.e., a voiced obstruent) violates it, but an obstruent that is accompanied by a glottal opening gesture (i.e., a voiceless obstruent) satisfies it. It can be viewed as the gestural equivalent of the well-established constraint *VOICEDOBSTRUENT, whose phonetic grounding lies in the aerodynamic factors necessary for voicing.

In order to satisfy this LICENSE constraint, an underlying voiced obstruent will deobstruentize by deleting its velum closure gesture. The deletion of the velum closure gesture of a voiceless consonant, on the other hand, is not motivated by this LICENSE constraint, as the presence of the velum closure gesture is licensed by its accompanying glottal opening gesture. Therefore, when LICENSE outranks MAX(velum closure)-IO, voiced obstruency is penalized, while voiceless obstruency is not.

Note that the definition of LICENSE does not penalize voiced obstruency only in a nasalizing context; voiced obstruency is penalized in all contexts. Even in forms without nasal harmony, the velum closure gesture of an underlying voiced obstruent will delete when LICENSE(velum closure, glottis open) outranks MAX(velum closure)-IO. In oral environments, these consonants will still surface as oral, though with only a loose seal between the velum and pharyngeal wall rather than the tight seal that is characteristic of obstruents that include a velum closure gesture. When overlapped with a velum opening gesture, these consonants will surface as nasalized. A possible alternative analysis of the status of voiced obstruents in Tuyuca is discussed in section 5.2.2.

The result of ranking LICENSE(velum closure, glottis open) over MAX(velum closure)-IO is illustrated in the tableau in (135) for the Tuyuca form [m̩p̩] ‘badger,’ in which the

hypothetical word-initial consonant /b/ has surfaced as [m] (despite the inclusion of a velum closure gesture in its underlying representation) while the word-medial voiceless /p/ surfaces as transparent to nasal harmony.

(135) Tableau for Tuyuca [m̩p̩í] ‘badger’

Input: / [nasal] ₁ b ₁ i ₂ p ₃ i ₄ /		LICENSE(velum closure)	MAX(velum closure)-IO
[b ₁ i ₂ p ₃ i ₄] 	a.	*!	
[m ₁ i ₂ p ₃ i ₄] 	b.	*	
[m ₁ i ₂ m ₃ i ₄] 	c.	**!	

In (135), candidate (a) [b̩p̩] retains the underlying velum closure gestures for both the voiced and voiceless underlying obstruents, satisfying MAX(velum closure)-IO and resulting in both obstruents surfacing as transparent to nasal harmony. However, the unlicensed velum closure gesture accompanying voiced [b] fatally violates high-ranked LICENSE(velum closure, glottis open). Winning candidate (b) [m̩p̩] deletes the unlicensed velum closure gesture of voiced /b/ while retaining the velum closure gesture of voiceless /p/, violating MAX(gesture)-IO once but fully satisfying LICENSE(velum closure, glottis open). Candidate (c) [m̩m̩] goes a step further by deleting both velum closure gestures, resulting in both consonants surfacing as nasalized. This candidate incurs a second violation of MAX(velum closure)-IO while not improving upon its performance with respect to LICENSE(velum closure, glottis open); it is harmonically bounded.

The ranking of LICENSE(velum closure, glottis open) over MAX(velum closure)-IO, then, ensures that in Tuyuca voiced obstruents nasalize when overlapped by a harmonizing velum opening gesture while voiceless obstruents surface as transparent to it. The reverse ranking, in which MAX(gesture)-IO dominates LICENSE(velum closure, glottis open), results in a pattern in which velum closure gestures are retained for both voiced and voiceless obstruents, and both are transparent to nasal harmony. This pattern is less common than the Tuyuca-type pattern, but is attested in Moba Yoruba (Ajiboyè 2001; Ajiboyè & Pulleyblank 2008).

The constraint LICENSE(velum closure, glottis open) causes underlying voiced obstruents to de-obstruentize, rendering them susceptible to nasalization. This constraint can be used to straightforwardly account for patterns of voiced and voiceless obstruent transparency in nasal harmony, as demonstrated by the case of transparency in Tuyuca nasal harmony. The disparate

patterning of voiced and voiceless obstruents also arises in the blocking of nasal harmony in Orejón, to be taken up in the next section.

4.4.3 *Orejón: Obstruent Voicing and Blocking*

Orejón presents a case similar to Tuyuca, in which voiced and voiceless obstruents differ in how they pattern with respect to nasal harmony. However, unlike in Tuyuca, the nasal harmony system in Orejón exhibits blocking, making it an interesting case in which the implicational hierarchy of blockers of nasal harmony (section 4.4.1) interacts with the classification of stops and fricatives as either sonorants or obstruents based on their voicing specifications. Orejón nasal harmony exemplifies a system in which voiced obstruents undergo nasal harmony while voiceless obstruents block it. This is illustrated by the data in (136), provided by Pulleyblank (1989).²⁷ In (136a-c), nasal harmony does not extend beyond a voiceless obstruent. In (136d-f), all sonorant stops are nasalized, and voiced obstruents are disallowed in such forms.

- | | | | |
|-------|-----------------------|---------------------------------|------------------------|
| (136) | a. [nāso?] ‘crab’ | d. [? ² mōn̩] ‘come’ | *[? ² bōd̩] |
| | b. [jāko?] ‘eye’ | e. [jēn̩] ‘flow’ | *[jēd̩] |
| | c. [mīte?] ‘mosquito’ | f. [ŋānā] ‘fly’ | *[gādā] |

Following Pulleyblank (1989), I analyze morphemes in Orejón as being specified as either oral or nasal. As such, nasal morphemes are analyzed as having a morpheme-initial persistent (non-self-deactivating) velum opening gesture, as in Tuyuca (section 4.4.2). This persistent velum opening gesture extends to overlap following vowels, glottals, glides, and liquids. As discussed in section 4.4.1, this pattern of blocking can be generated in the Gestural Harmony Model by the ranking in (137).

²⁷ Velie Gable (1975) and Cole & Kisseeberth (1995) provide a different description of nasal harmony in what is presumably another dialect of Orejón in which both voiced and voiceless obstruents act as blockers of nasal harmony. In this section I follow Pulleyblank’s description of Orejón nasal harmony, which is in turn based on an unpublished manuscript by Arnaiz.

(137) Constraint ranking for blocking of Orejón nasal harmony

*INHIBIT(sonorant C, velum opening) >> *OVERLAP(oral C, velum opening) >>
*INHIBIT(oral C, velum opening)

In addition, it appears that voiced stops also undergo nasal harmony; they never occur in nasal morphemes, while their nasal counterparts do. This necessitates the inclusion of the constraint ranking LICENSE(velum closure, glottis open) >> MAX(gesture)-IO. As demonstrated by the case of Tuyuca nasal harmony (section 4.4.2), this ranking will ensure that an underlying voiced obstruent will delete its unlicensed velum opening gesture, rendering it a sonorant according to the definition provided in section 4.4.1. As a result, this de-obstruentized consonant will be susceptible to nasalization when the ranking *INHIBIT(sonorant C) >> *OVERLAP(oral C) holds.

The undergoing, rather than blocking, of nasal harmony by voiced obstruents in Orejón is demonstrated in the tableau in (138) for the form [jẽnĩ] ‘flow.’

(138) Tableau for Orejón [jẽñ] ‘flow’

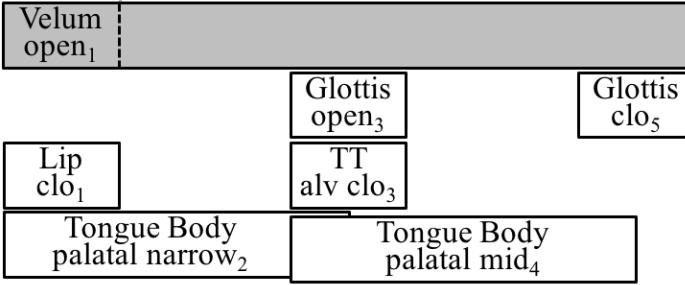
Input: / j ₁ e ₂ d ₃ i ₄ /	Tongue Body pal nar ₁	Tongue Body palatal mid ₂	Tongue Tip alv clo ₃	Tongue Body pal nar ₄	Velum closure ₃	LICENSE(velum,glo) MAX(gesture)-IO *INHIBIT(sonorant C) *OVERLAP(oral C) *INHIBIT(oral C)			
a.	[j ₁ ē ₂ d ₃ i ₄]	Velum open ₁	Velum closed ₃	TT alv clo ₃	Tongue Body palatal mid ₂	Tongue Body palatal narrow ₄			
b.	[j ₁ ē ₂ d ₃ ī ₄]	Velum open ₁	Velum closed ₃	TT alv clo ₃	Tongue Body palatal mid ₂	Tongue Body palatal narrow ₄			
c.	[j ₁ ē ₂ d ₃ i ₄]	Velum open ₁	TT alv clo ₃	Tongue Body palatal mid ₂	Tongue Body palatal narrow ₄	*	*!	*	*
d.	[j ₁ ē ₂ n ₃ ī ₄]	Velum open ₁	TT alv clo ₃	Tongue Body palatal mid ₂	Tongue Body palatal narrow ₄	*		**	

In (138), candidates (a) [j̩edi], with blocking of nasal harmony by [d], and (b) [j̩edɪ], with transparent obstruent [d], each preserve the velum closure gesture of the underlying voiced obstruent, fatally violating high-ranked LICENSE(velum closure, glottis open). Candidates (c) and (d) delete this velum closure gesture, effectively becoming be-obstruentized. This violates MAX(gesture)-IO in favor of satisfying higher-ranked LICENSE(velum closure, glottis open). Candidates (c) [j̩edi] and (d) [j̩enɪ] differ only in whether this sonorant obstruent blocks nasal harmony. In (c), harmony is blocked via an inhibition relation between the tongue tip gesture of [d] and the velum opening gesture. Because this [d] is de-obstruentized, its inhibition of the velum opening gesture violates *INHIBIT(sonorant C). Winning candidate (d), however, includes no such inhibition relation, and the sonorant obstruent undergoes harmony, surfacing as [n].

Blocking by a voiceless obstruent is demonstrated in the tableau in (139) for the Orejón form [m̩ite?] ‘mosquito.’

(139) Tableau for Orejón [m̩íte?] ‘mosquito’

Input: / m ₁ i ₂ t ₃ e ₄ ? ₅ / 	LICENSE(Velum, glottis) MAX(gesture)-IO *INHIBIT(sonorant C) *OVERLAP(oral C) *INHIBIT(oral C)
 a.	*
 b.	*!*
 c.	*! *

	LICENSE(velum, glottis)	MAX(gesture)-IO	*INHIBIT(sonorant C)	*OVERLAP(oral C)	*INHIBIT(oral C)
[m ₁ ū ₂ n̊ ₃ ē ₄ ṳ̄ ₅] d. 		*!		**	

In (139), none of the candidates violate LICENSE(velum closure, glottis open), as they all include a glottal opening gesture accompanying the medial consonant. Therefore, this constraint will not favor any de-obstruentized candidates. As a result, candidates (c) [mūtē?] and (d) [mūn̊ē?], which both delete the velum closure gesture of the medial consonant, are ruled out due to their extraneous violations of MAX(gesture)-IO. Candidates (a) [mūtē?] and (b) [mūtēṳ̄] both contain an obstruent [t]; as a result, *INHIBIT(sonorant C) is irrelevant and it falls to *OVERLAP(oral C) to decide between the candidates. The winning candidate (a) [mūtē?], in which the voiceless obstruent [t] blocks nasal harmony by inhibiting the velum opening gesture, eliminates a violation of *OVERLAP(oral C) at the expense of violating lower-ranked *INHIBIT(oral C). Candidate (b) allows [t] and [?] to be overlapped, fatally violating *OVERLAP(oral C).

The tableau in (138) demonstrates that even when a voiced obstruent includes a velum closure gesture underlyingly, it is lost when LICENSE is ranked high, resulting in de-obstruentization. The same result is seen in the analysis of Tuyuca in section 4.4.2. The only

difference between the nasal harmony systems of Tuyuca and Orejón lies in the behavior of voiceless obstruents. In Tuyuca, they are transparent due to the high ranking of *INHIBIT(oral C), which prevents the blocking of nasal harmony entirely. In Orejón, on the other hand, it is the less stringent *INHIBIT(sonorant C) that outranks *OVERLAP(oral C), leading to blocking by voiceless obstruents, as demonstrated by the tableau in (139). In both languages, voiceless obstruents are the only true obstruents, while voiced obstruents are what Rice & Avery (1989), Piggott (1992), and Rice (1993) call sonorant obstruents. In the Gestural Harmony Model, this distinction between obstruent and sonorant is represented by the presence or absence of a velum closure gesture in the representation of a segment. This determines whether a consonant is able to surface as transparent to nasal harmony due to antagonism with a harmonizing velum opening gesture, as exemplified by Tuyuca nasal harmony. It can also determine whether a consonant undergoes or blocks harmony by determining whether that consonant is under the purview of *INHIBIT(sonorant C), as exemplified by nasal harmony in Orejón.

4.4.4 Revisiting Capanahua: Blocking by Obstruents and Liquids

The final case of nasal harmony examined here comes from the familiar case of Capanahua, whose harmony system was previously discussed in sections 2.2.2 and 3.4.3. In these earlier discussions of nasal harmony in Capanahua, it is mentioned that when a liquid or obstruent occurs in a word with a harmony-triggering nasal, it blocks the spread of nasality. This section provides an analysis of this pattern of blocking, and demonstrates how the use of increasingly less stringent *INHIBIT constraints generates patterns of harmony with fewer types of segments designated as undergoers. For the sake of simplicity, I focus only on regressive harmony in Capanahua, though the pattern of blocking is identical for both regressive and bidirectional nasal harmony.

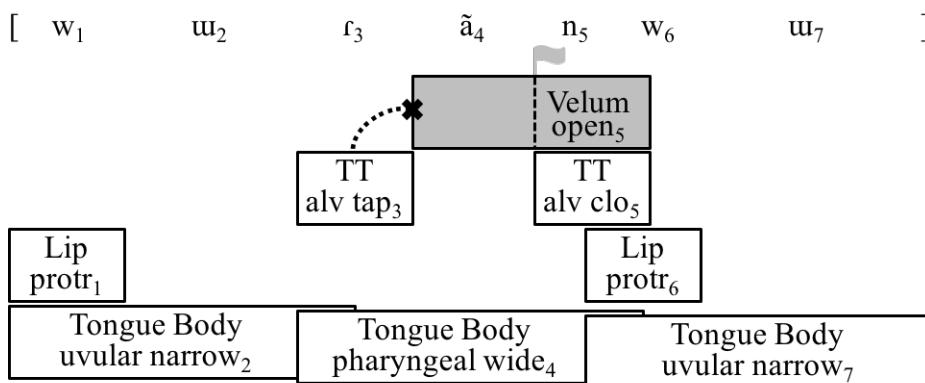
Recall that regressive nasal harmony in Capanahua is triggered by nasal consonants and affects surrounding vowels, glides, and glottals, as in (140) (repeated from (34) in section 2.2.2).

Nasal harmony is blocked by obstruents and the liquid [f].

- (140) a. [h̃āmawu] ‘step on it’
 b. [pōjān] ‘arm’
 c. [bāwīn] ‘catfish’
 d. [cīfīn] ‘by fire’
 e. [cipōnki] ‘downriver’
 f. [wurānwu] ‘push it’
 g. [wurānjasāñnwu] ‘push it sometime’
 h. [bānawu] ‘plant it’

This blocking by liquids and obstruents can now be accounted for within the Gestural Harmony Model by assuming an inhibition relation between the blocking gestures of liquids and obstruents and the anticipatory velum opening gesture responsible for regressive nasal harmony. In the case of [wurānwu] ‘push it,’ for example, the velum opening gesture of [n] and the gesture of the blocking tap [t] must be in an inhibitory relationship. The result of this intergestural inhibition is illustrated in the gestural score in (141).

- (141) Gestural score for Capanahua [wurānwu] ‘push it’



The pattern of blocking in Capanahua nasal harmony, in which vowels, glides, and glottals are undergoers while liquids and obstruents are blockers, can be generated by the ranking in (142).

(142) Constraint ranking for blocking in Capanahua nasal harmony

*INHIBIT(glide) >> *OVERLAP(oral C) >> *INHIBIT(sonorant C), *INHIBIT(oral C)

This ranking ensures that vowels, glottals, and glides will not inhibit an anticipatory velum opening gesture and will therefore not block harmony, while liquids and obstruents will act as blockers. The tableau in (143) demonstrates this for the Capanahua form [wuiɾãnwu] ‘push it.’ In order to focus solely on the issue of blocking, only candidates with anticipatory, self-deactivating gestures are considered here.

(143) Tableau for Capanahua [wurānwu] ‘push it’

Input: / w ₁ w ₂ f ₃ a ₄ n ₅ w ₆ w ₇ /							*INHIBIT(glide)	*OVERLAP(oral C)	*INHIBIT(sonorant C)	*INHIBIT(oral C)	
Lip protr ₁	TB uvu nar ₂	TT alv tap ₃	TB phar wide ₄	TT alv clo ₅	Lip protr ₆	TB uvu nar ₇					
				Velum open ₅							
[~w ₁ ~w ₂ ~f ₃ ~a ₄ n ₅ w ₆ w ₇]							*!*				
a.	Lip protr ₁	TT alv tap ₃	Velum open ₅	TT alv clo ₅	Lip protr ₆	Tongue Body uvular narrow ₂	Tongue Body pharyngeal wide ₄	Tongue Body uvular narrow ₇			
b.	Lip protr ₁	TT alv tap ₃	Velum open ₅	TT alv clo ₅	Lip protr ₆	Tongue Body uvular narrow ₂	Tongue Body pharyngeal wide ₄	Tongue Body uvular narrow ₇	*	*	

In (143), candidate (a) [~w~w~f~a~n~w~w] includes a velum opening gesture that has extended to the beginning of the word, satisfying all of the *INHIBIT constraints but fatally violating high-ranked *OVERLAP(oral C) twice. The winning candidate (b) [wu~f~a~n~w~w] violates the low-ranked *INHIBIT(sonorant C) and *INHIBIT(oral C) and avoids violation of *OVERLAP(oral C) by including an inhibition relation between the tap gesture of [f] and the velum opening gesture. The result of this inhibition relation is the blocking of regressive nasal harmony.

This ranking of the *INHIBIT constraints relative to *OVERLAP(oral C, velum opening) also accounts for the status of obstruents as blockers and of glides as undergoers of nasal harmony in Capanahua. This is illustrated by the tableau in (144) for the form [pōjān] ‘arm.’

(144) Tableau for blocking of nasal harmony in Capanahua [pōjān] ‘arm’

Input: / p ₁ o ₂ j ₃ a ₄ n ₅ /	*INHIBIT(glide)	*OVERLAP(sonorant C)	*INHIBIT(oral C)
<p>[p₁ o₂ j₃ a₄ n₅]</p>	*!	*	*
<p>[p₁ ō₂ ĥ₃ a₄ n₅]</p>	*		*

In (144), candidate (a) [pojān] includes an inhibition relation between the glide [j] and the anticipatory velum opening gesture of word-final [n], blocking the spread of nasality beyond the vowel of the second syllable. While this inhibition relation results in satisfaction of

*OVERLAP(oral C), it incurs violations of all three *INHIBIT constraints, including a fatal violation of high-ranked *INHIBIT(glide). In winning candidate (b), [pōjān] ‘arm’ the anticipatory velum opening gesture extends to overlap the glide [j], resulting in a violation of *OVERLAP(oral C). However, it satisfies higher-ranked *INHIBIT(glide). Instead, this form includes an inhibition relation between the gestures of [p] and the velum opening gesture of [n], resulting in a violation of low-ranked *INHIBIT(oral C).

This ranking of constraints is thus able to capture the undergoing of nasal harmony by glides and the blocking of harmony by liquids and obstruents in Capanahua. It also demonstrates that the mechanism of blocking via intergestural inhibition in nasal harmony is available not just to obstruents, but to sonorants as well.

4.4.5 *Summary*

This section has demonstrated the Gestural Harmony Model’s ability to use the dual mechanisms of transparency via intergestural competition and blending and blocking via intergestural inhibition to account for crosslinguistic patterns of transparency and blocking in nasal harmony. The constraint set outlined for nasal harmony in section 4.4.1, which includes a set of stringently defined *INHIBIT constraints, accurately captures the implicational hierarchy of blocking observed across nasal harmony systems.

In addition, the gestural framework develops a classification of obstruent segments as those whose gestural representations include a velum closure gesture. In the Gestural Harmony Model, this representation of obstruents accurately predicts that they are the only class of segments that possess the gestural makeup necessary to surface as transparent to harmony, in keeping with previous typological observations by Piggott (1992) and Walker (1998/2000). This is due to the model’s representation of a transparent obstruent as an undergoer of harmony that

includes a velum closure gesture that is antagonistic to the harmonizing velum opening gesture. The variable representation of fricatives and voiced obstruents with respect to the inclusion of a velum closure gesture also correctly predicts that these segment classes should vary as to whether they pattern as obstruents or as sonorants in a given harmony system.

The adoption of both gestural antagonism and gestural inhibition by the Gestural Harmony Model is crucial to its success in capturing typological asymmetries that arise among nasal harmony systems. Such asymmetries are also attested in rounding harmony, and thus also benefit from analysis within the Gestural Harmony Model. This is the subject of section 4.5

4.5 Transparency and Blocking in Rounding Harmony

4.5.1 Sources of Antagonism and Incompatibility

As discussed in section 4.2.2, rounding harmony displays a typological asymmetry in attested patterns of transparency and blocking. In rounding harmony, the set of attested transparent segment types is smaller than the set of attested blocking segment types. As in the case of nasal harmony, I propose that within the Gestural Harmony Model this asymmetry is due to the existence of two distinct theoretical mechanisms that are driven by related but distinct consequences of gestural overlap. While the mechanism of transparency to rounding harmony via intergestural competition is available to a small set of vowels due to their gestural makeup, a wide range of vowels may block rounding harmony on the basis of several phonetically grounded conditions proposed by Hong (1994) and Kaun (1995, 2004).

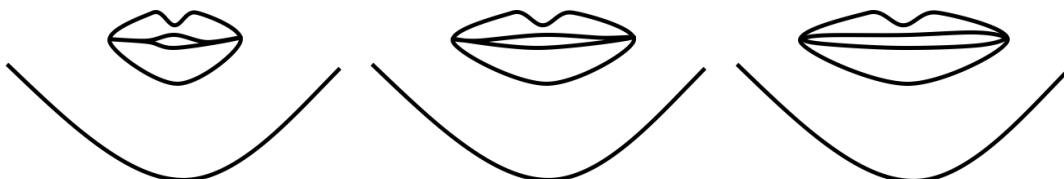
Recall from section 4.2.2 that while all vowels are attested as blockers in some rounding harmony system, the only vowels that are attested as being transparent to rounding harmony are the high front vowels /i/ and /ɪ/. Again, this restriction of the ability to surface as transparent to a small class of segments is made possible by modeling transparency as a direct consequence of

overlap by a harmonizing gesture. I claim that in the Gestural Harmony Model, the transparency of high front vowels in rounding harmony is a direct consequence of their gestural makeup. A high front vowel is represented by a palatal constriction gesture of the tongue body; this alone is insufficient to account for its transparency to rounding harmony. However, there is evidence that the production of high front vowels is also characterized by active lip spreading, posited as a means of raising the second formant of high front vowels in order to maximize their perceptual distance from back vowels. The presence of active lip spreading during the production of high front vowels is supported by the findings of several articulatory studies, including those conducted by Hadding, Hirose, & Harris (1976), Sussman & Westbury (1981), and Goldstein (1991). These findings suggest that the representation of high front vowels should include a lip spreading gesture in addition to a palatal tongue body gesture.

The articulatory effects of active lip protrusion and active lip spreading are illustrated in (145). A gesture for lip protrusion is responsible for rounding harmony, as proposed in section 2.2.1; its effect is illustrated in (145a). In addition, I propose that the set of assumed gestural representations should include a gesture for lip spreading, as in (145c), characteristic of the production of some high front vowels.

(145) Active and neutral lip positions

- a. Active Lip Protrusion b. Neutral Lip Position c. Active Lip Spreading



In comparing the position of the lips in (145a) and (145c), it is apparent that the lip spreading gesture of a high front vowel is antagonistic to the lip protrusion gesture that is

responsible for rounding harmony. As a result, high front vowels whose representations include a lip spreading gesture are predicted to be transparent to rounding harmony. No other vowels include this gesture in their representations, and thus are unable to surface as transparent to rounding harmony when overlapped by a lip protrusion gesture.

In many languages there is evidence that high front vowels are produced with active lip spreading and that a lip spreading gesture should therefore be included in their phonological representations. However, there are also languages in which high front vowels surface as rounded in the domain of rounding harmony, suggesting that they are not accompanied by a lip spreading gesture. Kyrgyz rounding harmony (sections 2.2.1 and 3.2.1) represents one such case. It appears, then, that high front vowels vary across languages as to whether they are accompanied by lip spreading gestures that result in transparency to rounding harmony. This parallels the crosslinguistic variability in the inclusion of a velum closure gesture in the proposed representations of fricatives and voiced obstruents in section 4.4.1.

With respect to blocking patterns in rounding harmony, Kaun (1995, 2004) proposes a set of three markedness restrictions on round vowels whose interactions generate the rather complex typology of blocking in rounding harmony. The first is a restriction on nonhigh round vowels, motivated primarily by the findings of Linker (1982) that nonhigh vowels tend to be produced with less rounding and are therefore marked for perceptual reasons. Hong (1994) proposes a similar restriction on vowel height and rounding, drawing on additional evidence relating jaw height to lip rounding presented by Lindblom & Sundberg (1971). While few languages ban nonhigh round vowels altogether, many languages place restrictions on where these vowels are allowed to occur in a word, and whether they may be derived as a result of vowel harmony.

As a precursor to defining the constraints necessary for an account of blocking in rounding harmony, which must reference vowels according to their height and backness, I provide the gestural definitions of vowel height and backness in (146). These definitions are revisited in section 6.2.1.

(146) Gestural definitions of vowel place

- a. High vowel: a segment whose primary vocalic tongue body gesture is specified for narrow constriction degree in the palatal or uvular region
- b. Nonhigh vowel: a segment whose primary vocalic tongue body gesture is not specified for narrow constriction degree in the palatal or uvular region
- c. Front vowel: a segment whose primary vocalic tongue body gesture is specified for constriction in the palatal region
- d. Back vowel: a segment whose primary vocalic tongue body gesture is specified for constriction in the uvular or pharyngeal region

The restriction on the co-occurrence of a nonhigh vowel with lip rounding can be accounted for within the Gestural Harmony Model using a constraint from the *OVERLAP family. It is defined in (147).

(147) *OVERLAP(nonhigh vowel, lip protrusion): Assign a violation mark to a nonhigh vowel gesture and a lip protrusion gesture that are concurrently active.

When this constraint outranks the anti-blocking constraint *INHIBIT, nonhigh vowels will block rounding harmony rather than undergoing it. A similar restriction proposed by Kaun (1995, 2004) that affects the typology of blocking in rounding harmony is a restriction on front round vowels. Front vowels are also perceptually disadvantaged bearers of rounding, as rounding renders them less acoustically distinct from back vowels. In this case, some languages do impose a total ban on front round vowels in surface forms. Similar to (147), the avoidance of front round vowels is accounted for by a *OVERLAP constraint, defined in (148).

- (148) *OVERLAP(front vowel, lip protrusion): Assign a violation mark to a front vowel gesture and a lip protrusion gesture that are concurrently active.

Finally, many rounding harmony patterns are governed by a principle which Kaun (1995, 2004) refers to as Gestural Uniformity. According to this principle, the span of a single [round] autosegment must be realized uniformly with respect to jaw height; sequence such as [u-o] or [o-u] in which both vowels are linked to the same instance of the feature [round] are ill-formed. Complicating matters somewhat is the fact that Gestural Uniformity is often used by Kaun in tandem with constraints on harmony trigger conditions in order to account for cases in which [o-u] sequences are permitted while [u-o] sequences are not. This strategy for accounting for the directional asymmetry in the effect of Gestural Uniformity is not available to the Gestural Harmony Model; the reason for this and the modifications necessary to adapt Gestural Uniformity for use within the Gestural Harmony Model is discussed in greater detail in the examination of Yakut rounding harmony in section 4.5.5.

The remainder of this section demonstrates the workings of each of these markedness constraints in shaping the patterns of blocking of rounding harmony by gestures that are incompatible with rounding, as well as the representation of transparency resulting from the antagonism of lip protrusion and lip spreading gestures. These are illustrated with examinations of the rounding harmony systems of Halk Mongolian, Baiyina Oroqen (first introduced in section 3.4.2), Tuvan, and Yakut.

4.5.2 Halk Mongolian: Transparency and Blocking by High Vowels

Halk Mongolian (Mongolic; Mongolia; Svartesson (1985), Steriade (1987), van der Hulst & N. Smith (1987), Svartesson et al. (2005)) presents an especially interesting case of rounding harmony that exhibits both transparency and blocking. While high back round vowels block harmony, high front vowels are transparent to it. In Gestural Harmony Model, blocking and

transparency are the products of two distinct theoretical mechanisms that are able to operate independently of one another, and can even operate concurrently. As a result, the Gestural Harmony Model is particularly well suited to analyzing the pattern of transparency and blocking exhibited by Halk Mongolian rounding harmony.

Halk Mongolian has the vowel inventory in (149), as reported by Svantesson et al. (2005).²⁸

(149) Halk Mongolian vowel inventory

	Non-Pharyngeal		Pharyngeal	
High	i	u	I	o
Nonhigh	(e)	ø	a	ɔ

Halk has two processes of vowel harmony, one based on tongue root position and one based on rounding. Tongue root harmony divides the vowel inventory into two classes, pharyngeal (RTR) and non-pharyngeal (non-RTR). Words may contain vowels from only one of these classes, as in (150).²⁹

- | | |
|--|---|
| (150) a. [xeɛl-ʊl-ʃɛ] ‘to decorate (caus. past)’ | e. [jaw-ʊl-ʃɑ] ‘to go (caus. past)’ |
| b. [pi:r-ɪg-e] ‘brush (acc. refl.)’ | f. [mu:r-ɪg-a] ‘cat (acc. refl.)’ |
| c. [su:l-ɪg-e] ‘tail (acc. refl.)’ | g. [xunl-ʊl-ʃɑ] ‘to pleat (caus. past)’ |
| d. [pe:r-ø] ‘kidney (refl.)’ | h. [xɔ:l-ɔ] ‘food (refl.)’ |

Halk also has a process of rounding harmony that holds only among nonhigh vowels, with [e] alternating with [ø] and [a] alternating with [ɔ]. It is triggered by a nonhigh round vowel in the initial syllable of a word. The data in (151) illustrate; compare the rounded vowels of the past suffix in (151) to their unrounded variants in (150a,e,g).

²⁸ Svantesson et al. (2005) transcribe the nonhigh non-pharyngeal round vowel as [o] but state that its pronunciation is closer to central [ø]. Their acoustic data confirms that this vowel is central, and it is transcribed as such here. The vowels in parentheses occur only in non-initial syllables.

²⁹ The high front vowel is often claimed to be transparent to tongue root harmony and transcribed as [i] even in RTR (pharyngeal) words. However, the acoustic data reported by Svantesson et al. indicate that this vowel undergoes tongue root harmony just as the other vowels in the inventory do, surfacing as [i] in RTR words. Therefore, this vowel will be transcribed as [i] here.

- (151) a. [eg-^hʒə] ‘to give (past)’
 b. [c^he:r- ʒə] ‘to decrease (past)’
 c. [ɔr-ʒə] ‘to enter (past)’
 d. [c^hɔ:r- ʒə] ‘to be pierced (past)’

The high vowels do not participate in rounding harmony. High front [i] and [ɪ] are transparent to rounding harmony, neither undergoing it nor blocking it from spreading further, as in the data in (152).

- (152) a. [pə:r-ig-ə] ‘kidney (acc. refl.)’
 b. [e:r-ig-ə] ‘self (acc. refl.)’
 c. [xɔ:j-ig-ɔ] ‘food (refl.)’
 d. [ɔk'j-i-ʒə] ‘to squint (past)’

As in Baiyina Oroqen (sections 3.4.2 and 4.5.3), the high round vowels /u/ and /ø/ pattern quite differently from the nonhigh round vowels. The vowels /u/ and /ø/ do not trigger rounding harmony (153a-d), and are unrestricted in their distribution (153e-f), surfacing in initial and non-initial syllables. In contrast, the nonhigh round vowels /ə/ and /ɔ/ may only occur in an initial syllable, or in a non-initial syllable as the product of rounding harmony. When the high round vowels occur after triggering nonhigh vowels, they block rounding harmony despite being round themselves (153g-h).

- | | |
|--|--|
| <p>(153) a. [uc-ʒe] ‘jump (past)’
 b. [su:ʒ-e] ‘tail (refl.)’
 c. [xun^j-ʒa] ‘to pleat past)’
 d. [mɔ:r-a] ‘cat (refl.)’</p> | <p>e. [it-uʒ-ʒe] ‘to eat (caus. past)’
 f. [jaw-uʒ-ʒa] ‘to go (caus. past)’
 g. [əg-uʒ-ʒe] ‘to give (caus. past)’
 h. [ɔr-uʒ-ʒa] ‘to enter (caus. past)’</p> |
|--|--|

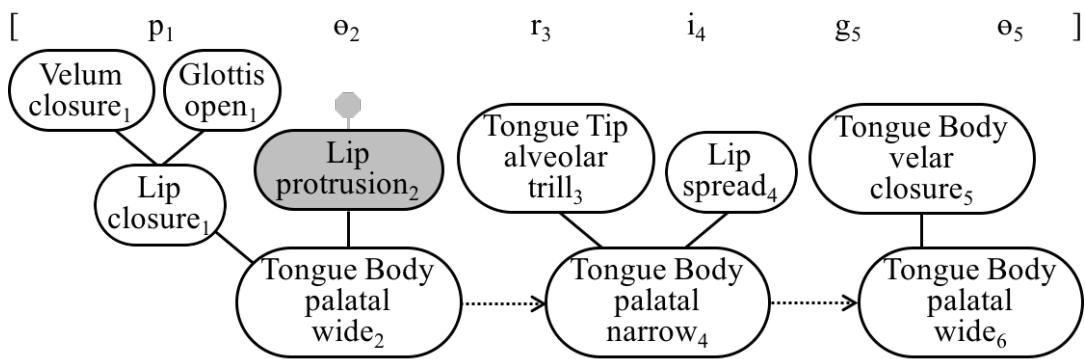
Halk Mongolian is an example of a harmony system that exhibits both transparency and blocking; while high front vowels are transparent to rounding harmony, high back vowels serve as blockers. It is also a case in which non-triggering bearers of a harmonizing property, the high back round vowels, block harmony from spreading further. The Gestural Harmony Model is able to account for all of this straightforwardly due to its reliance on two distinct mechanisms for analyzing transparency and blocking: competition between antagonistic gestures and inhibition

between incompatible gestures. In Halk Mongolian, both mechanisms play an active role in shaping the patterns of transparency and blocking of rounding harmony among the high vowels.

The transparency of high front /i/ and /ɪ/ can be attributed to their inclusion of both a tongue body gesture specified for narrow palatal constriction as well as a lip spreading gesture. (RTR /ɪ/ also includes a tongue root retraction gesture.) These vowels' lip spreading gestures are antagonistic to the lip protrusion gesture responsible for rounding harmony in this language. When a persistent (non-self-deactivating) lip protrusion gesture overlaps a following high front vowel, it results not in rounding of that vowel, but in transparency to the rounding harmony process.

The coupling graph in (154) for [pə:r-ɪg-ə] 'kidney (acc. refl.)' includes a lip spreading gesture in the representation of /i/, which is responsible for its transparency in rounding harmony. When this coupling graph is input to the Coupled Oscillator Model and the Task Dynamic Model to calculate the gestural score and the articulatory trajectories for this form, transparency will result directly from the gestural makeup of transparent /i/. There is no need for the phonological grammar to independently enforce transparency.

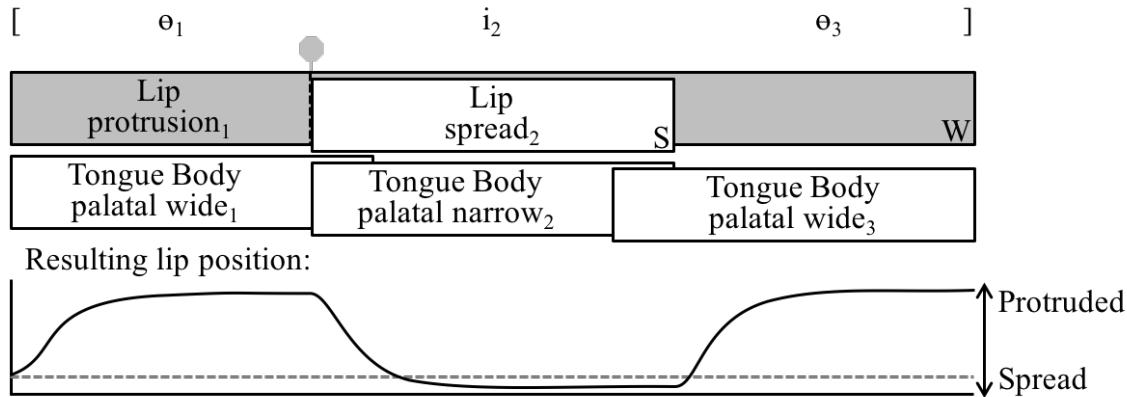
(154) Coupling graph for [pə:r-ɪg-ə] 'kidney (acc. refl.)'



The gestural score in (155) depicts the vocalic portion of the Halk word [pə:r-ɪg-ə] 'kidney (acc. refl.)' that is constructed from the coupling graph in (154). The persistent lip

protrusion gesture extends throughout the word, resulting in rounding harmony. However, here its overlap with the gestures of /i/ results not in rounding of the vowel, but in transparency. The lip spreading gesture included in the representation of /i/ is antagonistic to the lip protrusion gesture that overlaps it. Because the lip spreading gesture is specified for a high gestural strength while the harmonizing lip protrusion gesture is specified for a relatively lower strength, blending of their antagonistic target articulatory states during the period of their concurrent activation is resolved in favor of the lip spreading gesture of /i/. When the production of /i/ ceases, the lips are free to return to the protruded position required by the lip protrusion gesture. The dashed line represents the neutral value for lip protrusion.

(155) Gestural score for vocalic portion of Halk Mongolian [pe:r-ig-e] ‘kidney (acc. refl.)’



Despite the temporary lack of rounding during the production of the vowel [i], the harmonizing lip protrusion gesture is active throughout the entire word. It is simply prevented from achieving its target articulatory state during the production of the high front vowel as a result of that vowel's inclusion of an antagonistic lip spreading gesture in its gestural representation. The phonological grammar's only role here is in allowing the transparent vowel to be overlapped by the harmonizing lip protrusion gesture; the Coupled Oscillator Model and the Task Dynamic Model of speech production do the rest.

However, the phonological grammar does play a role in enforcing the blocking of rounding harmony in Halk Mongolian. In this rounding harmony system, the blockers of harmony are precisely those vowels that do not serve as triggers, despite being round vowels. Within the Gestural Harmony Model, this can be accounted for with a single *OVERLAP constraint that penalizes the overlap of a high back vowel with a persistent lip protrusion gesture. This constraint will account for both the non-triggering and blocking properties of high back round vowels /u/ and /o/.

In the analysis of trigger conditions in Baiyina Oroqen rounding harmony (section 3.4.2), the status of nonhigh round vowels as triggers of harmony is accounted for with a *COUPLE constraint that penalizes the coupling of a nonhigh vowel gesture to a self-deactivating lip protrusion gesture. A similar tactic can be used to account for non-triggers of harmony in Halk Mongolian by penalizing the co-occurrence of a high back vowel gesture with a persistent (non-self-deactivating) lip protrusion gesture. However, rather than using a constraint from the *COUPLE family, I employ a *OVERLAP constraint in order to simultaneously account for both the non-triggering and blocking exhibited by high back vowels. This constraint is defined in (156).

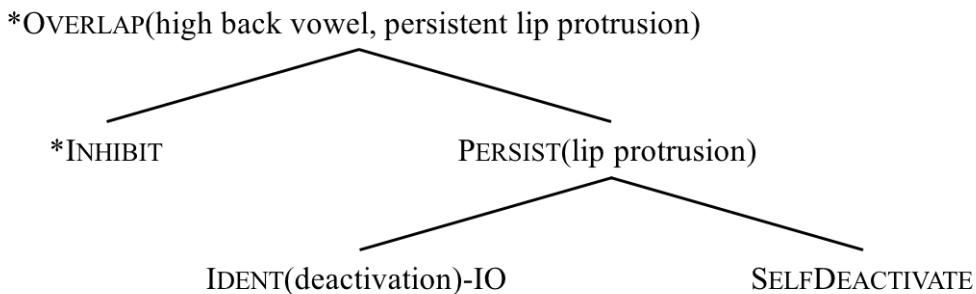
- (156) *OVERLAP(high back vowel, persistent lip protrusion): Assign a violation mark to a high back vowel gesture that is active concurrently with a persistent lip protrusion gesture.

As discussed in section 1.2.2, *OVERLAP constraints are stricter than *COUPLE constraints in that they penalize any co-occurrence of two gestures, whether they are coupled to one another or whether they are concurrently active due to one of the gestures extending to overlap the other. In the case of Halk Mongolian rounding harmony, the stricter of these two constraints is necessary to explain both the non-triggering and blocking of high back round vowels. The effect of the *OVERLAP constraint in (156) is twofold. First, it will prevent high back vowels /u/ and /o/.

from surfacing with a persistent lip protrusion gesture, rendering them non-triggers of rounding harmony. Second, it will prevent them from being overlapped by a persistent gesture that is coupled to another vowel that triggers harmony, rendering them blockers of rounding harmony.

In Halk Mongolian, /u/ and /o/ never trigger rounding harmony, indicating that *OVERLAP(high back vowel, persistent lip protrusion) is never violated. It must therefore be ranked above IDENT(deactivation)-IO and PERSIST(lip protrusion). It must also be ranked above *INHIBIT in order to capture the fact that /u/ and /o/ block rounding harmony. The triggering of rounding harmony by nonhigh vowels is achieved by ranking PERSIST(lip protrusion) above IDENT(deactivation)-IO and SELFDEACTIVATE. This ranking is summarized in the Hasse diagram in (157).

(157) Constraint ranking for triggering and blocking of Halk Mongolian rounding harmony



With the constraint ranking in (157), the status of high back vowels as non-triggers of rounding harmony is demonstrated in the tableau in (158) for the Halk Mongolian word [uc-ł̥e] ‘jump (past).’ It includes a hypothetical input with a persistent lip protrusion gesture to demonstrate the effect of high-ranked *OVERLAP. For reasons of space and clarity, only the vocalic portions of output candidates are included, and candidates are represented in gestural score form.

(158) Tableau for Halh Mongolian [uc-łʒe] ‘jump (past)’

Input: / u ₁ c - ɿ e ₂ /	Tongue Body uvular narrow ₁	Tongue Body palatal wide ₂	Lip protrusion ₁	*OVERLAP(high back V, persist. LP)	PERSIST(lip protrusion)	IDENT(deactivation)-IO	SELFDEACTIVATE	*INHIBIT
a. [uc-łʒə]	[u ₁ e ₂]	Lip protrusion ₁	Tongue Body uvular narrow ₁ Tongue Body palatal wide ₂	*!			*	
b. [uc-łʒe]	[u ₁ e ₂]	Lip protrusion ₁	Tongue Body uvular narrow ₁ Tongue Body palatal wide ₂	*	*			

In candidate (a) [uc-łʒə], the [u] in the initial syllable triggers harmony, satisfying PERSIST(lip protrusion) but violating higher-ranked *OVERLAP(high back vowel, persistent lip protrusion). In the winning candidate (b) [uc-łʒe], the initial /u/ surfaces with a self-deactivating lip protrusion gesture, satisfying *OVERLAP(high back vowel, persistent lip protrusion) at the expense of lower-ranked PERSIST(lip protrusion) and IDENT(deactivation)-IO.

The effect of the *OVERLAP constraint in casting the high back vowels as both non-triggers and blockers of rounding harmony is demonstrated in the tableau in (159) for [og-ʊłʒ-łʒe] ‘to give (caus. past).’ In this form, nonhigh /ø/ in the initial syllable triggers rounding harmony,

and high /u/ blocks it. A hypothetical input in which /θ/ is self-deactivating is considered here in order to demonstrate that PERSIST(lip protrusion) must dominate IDENT(deactivation)-IO.

(159) Tableau for [θg-ulʒ-ʒe] ‘to give (caus. past)’

Input: / θ ₁ g - u ₂ ʃ - ʃ e ₃ /	*OVERLAP(high back V, persist. LP)	PERSIST(lip protrusion)	IDENT(deactivation)-IO	SELFDEACTIVATE	*INHIBIT
<p>The diagram shows the following articulator states:</p> <ul style="list-style-type: none"> Tongue Body palatal wide₁ Tongue Body uvular narrow₂ Tongue Body palatal wide₃ Lip protrusion₁ Lip protrusion₂ 					
<p>Candidate (a) [θg-ulʒ-ʒe]. The timeline shows the sequence of events:</p> <ul style="list-style-type: none"> Initial state: Lip protrusion₁ (shaded gray). At u₂: Lip protrusion₂ appears (shaded gray). At ʃ: Lip protrusion₁ disappears. At e₃: Lip protrusion₂ disappears. <p>Below the timeline, the articulator states are shown:</p> <ul style="list-style-type: none"> Lip protrusion₁ (shaded gray) Lip protrusion₂ (shaded gray) Tongue Body palatal wide₁ Tongue Body uvular narrow₂ Tongue Body palatal wide₃ 	*!	*	*	*	
<p>Candidate (b) [θg-ulʒ-ʒe]. The timeline shows the sequence of events:</p> <ul style="list-style-type: none"> Initial state: Lip protrusion₁ (shaded gray). At u₂: Lip protrusion₂ appears (shaded gray). At ʃ: Lip protrusion₁ disappears. At e₃: Lip protrusion₂ disappears. <p>Below the timeline, the articulator states are shown:</p> <ul style="list-style-type: none"> Lip protrusion₁ (shaded gray) Lip protrusion₂ (shaded gray) Tongue Body palatal wide₁ Tongue Body uvular narrow₂ Tongue Body palatal wide₃ 		**!			
<p>Candidate (c) [θg-ulʒ-ʒe]. The timeline shows the sequence of events:</p> <ul style="list-style-type: none"> Initial state: Lip protrusion₁ (shaded gray). At u₂: Lip protrusion₂ appears (shaded gray). At ʃ: Lip protrusion₁ disappears. At e₃: Lip protrusion₂ disappears. <p>Below the timeline, the articulator states are shown:</p> <ul style="list-style-type: none"> Lip protrusion₁ (shaded gray) Lip protrusion₂ (shaded gray) Tongue Body palatal wide₁ Tongue Body uvular narrow₂ Tongue Body palatal wide₃ 		*	*	*	*

In (159), the lip protrusion gesture of initial /θ/ is self-deactivating in the input. All candidates incur one violation of PERSIST(lip protrusion) for the self-deactivating lip protrusion gesture of [u]. Candidate (a) [θg-ulʒ-ʒe] surfaces with a persistent lip protrusion gesture

accompanying [ø], violating low-ranked IDENT(deactivation)-IO and SELFDEACTIVATE but avoiding additional violation of higher-ranked PERSIST(lip protrusion). However, this candidate fatally violates highest-ranked *OVERLAP(high back vowel, persistent lip protrusion) because the harmonizing lip protrusion gesture overlaps the following [u]. In candidate (b) [øg-ulʒ-łe], /ø/ surfaces faithfully with a self-deactivating lip protrusion gesture, failing to trigger rounding harmony and incurring a second violation of PERSIST(lip protrusion). The winning candidate (c) [eg-ulʒ-łe] surfaces with a persistent lip protrusion gesture accompanying [ø]; however, harmony is blocked by the following [u] via an inhibition relation between the tongue body gesture of [u] and the lip protrusion gesture of triggering [ø]. While this candidate violates low-ranked constraints IDENT(deactivation)-IO, SELFDEACTIVATE, and *INHIBIT, it satisfies the high-ranked constraints *OVERLAP(high back vowel, persistent lip protrusion) (via blocking by [u]) and PERSIST(lip protrusion) (via triggering).

In the Gestural Harmony Model's analysis of Halk Mongolian rounding harmony, the blocking and non-triggering of round harmony exhibited by the back round vowels /u/ and /ø/ is given a unified explanation. The constraint *OVERLAP(high back vowel, persistent lip protrusion) prevents the co-occurrence of high back vowels and persistent lip protrusion gestures, whether they are part of the same segment in the input or whether they come into contact with one another due to rounding harmony. This *OVERLAP constraint is able to shape the surface phonological inventory of Halk Mongolian such that a triggering /u/ or /ø/ will never surface. It can also motivate the inclusion of an inhibition relation between a high back vowel gesture and a preceding persistent lip protrusion gesture, resulting in the blocking of rounding harmony.

The transparency of high front vowels, on the other hand, is due not to any constraints in the grammar but rather to their gestural makeup. High front /i/ and /ɪ/ are accompanied by lip

spreading gestures, which are antagonistic to harmonizing lip protrusion gestures. Because transparency to rounding harmony is restricted only to those vowels that include a lip protrusion gesture in their gestural representations, the Gestural Harmony Model predicts that the high front vowels /i/ and /ɪ/ are the only vowels that may be transparent to rounding harmony. This is a major advantage of the Gestural Harmony Model, as this prediction matches the crosslinguistic typology of attested transparency in rounding harmony outlined in section 4.2.2.

Another important aspect of the Gestural Harmony Model's analysis of Halk Mongolian rounding harmony is that the two mechanisms responsible for transparency and blocking may operate concurrently. Transparency of the high front vowels is the result of competition and blending of antagonistic gestures, and has no basis in constraint interaction. The constraints necessary to account for the blocking and non-triggering of rounding harmony exhibited by back vowels will apply only to those back vowels, and will not affect the transparency of high front vowels in any way. This separation of the analyses of transparency and blocking is crucial to the Gestural Harmony Model's success in accounting for Halk Mongolian rounding harmony, in which both transparent and blocking segments occur.

The use of a *OVERLAP constraint to account for both blocking and non-triggering by bearers of a harmonizing property can be applied to several other cases of Tungusic rounding harmony as well. A similar pattern is found in Baiyina Oroqen. An analysis of nonhigh vowels' participation in this rounding harmony system was presented in section 3.4.2; the following section revisits Baiyina Oroqen and completes the analysis of its rounding harmony system.

4.5.3 *Revisiting Baiyina Oroqen: Non-Triggers as Blockers and Undergoers*

This section returns to the analysis of rounding harmony in Baiyina Oroqen (Li 1996; Kaun 2004; Walker 2014; Dresher & Nevins 2017), previously taken up in section 3.4.2. As in

the case of Halk Mongolian rounding harmony discussed in the previous section, in Baiyina Oroqen only a subset of round vowels trigger rounding harmony. What distinguishes Baiyina Oroqen rounding harmony as a particularly interesting case is that some non-triggering round vowels propagate rounding harmony, while others block it. The Gestural Harmony Model is able to account for these complex patterns of triggering, non-triggering, undergoing, and blocking straightforwardly via the use of constraints from both the *COUPLE and *OVERLAP families.

Recall that Baiyina Oroqen exhibits harmony for both tongue root position and rounding. The vowel inventory in (160), reported by Li (1996), is repeated from (76) in section 3.4.2.

(160) Baiyina Oroqen vowel inventory

	ATR Vowels		RTR Vowels	
High	i i:	u u:	I I:	ʊ ʊ:
Nonhigh	ie	ə ə:	o o:	ɛ ɛ:

While there are a number of round vowels in the language's inventory, rounding harmony in Baiyina Oroqen holds only among the set of non-high back vowels. Harmony is triggered only by the nonhigh short vowels /o/ and /ɔ/ in an initial syllable, as in (161).

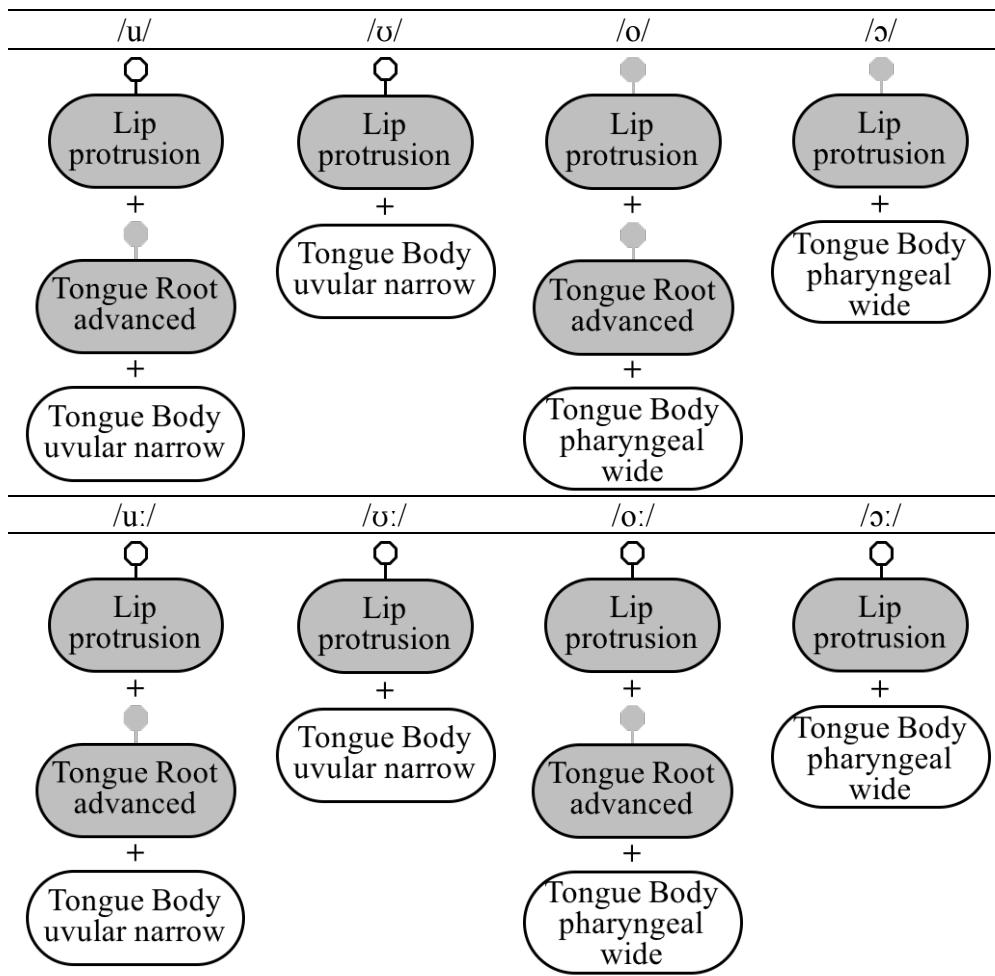
- (161) a. [tʃolpon] ‘morning star’
b. [somsok-jo] ‘pasture (indef. acc.)’
c. [ɔrɔktɔ] ‘hay’
d. [ələ-ja] ‘fish (indef. acc.)’

Long vowels /o:/ and /ɔ:/ never trigger rounding harmony in an initial syllable (162a-d), but may surface as the products of harmony and propagate that harmony onto following nonhigh vowels (162e-h).

- (162) a. [ko:məχə] 'windpipe'
 b. [bo:l-jə] 'slave (indef. acc.)'
 c. [kɔ:nakta] 'handbell'
 d. [gɔ:l-ja] 'policy (indef. acc.)'
 e. [nono-xo:n-mo] 'bear (dim. def. acc.)'
 f. [olo:-wko:n-no] 'to cook (caus. pres.)'
 g. [dʒələ-xɔ:n-mo] 'stone (dim. def. acc.)'
 h. [bɔdɔ-kwo:n-no] 'to think (caus. pres.)'

The patterning of nonhigh vowels in Baiyina Oroqen rounding harmony is accounted for in section 3.4.2 by proposing an inventory in which only underlyingly short nonhigh round vowels are accompanied by persistent lip protrusion gestures. This is accomplished by ranking the constraint *COUPLE(short nonhigh vowel, self-deactivating lip protrusion), which penalizes non-triggering /o/ and /ɔ/, above the constraint SELFDEACTIVATE. Under this ranking, short /o/ and /ɔ/ will be compelled to surface with persistent lip protrusion gestures, and will therefore trigger harmony. Meanwhile, the ranking of SELFDEACTIVATE over PERSIST(lip protrusion) compels long /o:/ and /ɔ:/ to surface with self-deactivating lip protrusion gestures, rendering them non-triggers of harmony. However, none of these constraints prevents long nonhigh vowels from undergoing harmony, or from propagating it to following nonhigh vowels. In a non-initial syllable, /o:/ and /ɔ:/ are round due to overlap by the lip protrusion gesture of a triggering vowel in an initial syllable. They are not coupled to their own lip protrusion gestures, and they do not deactivate the lip protrusion gestures of other round vowels. The surface phonological inventory generated by this constraint ranking is provided in (163), repeated from (79) in section 3.4.2.

(163) Baiyina Oroqen round vowel inventory represented gesturally



Not yet accounted for is the distribution of the high round vowels /u/, /u:/, /ʊ/, and /ʊ:/, and their patterning with respect to rounding harmony. In both respects, the high round vowels are markedly different from the nonhigh round vowels. While nonhigh round vowels are restricted to the initial syllable (unless they are derived by rounding harmony), high round vowels may occur in any position in the word, as in (164).

- (164) a. [bəjun] ‘elk’
 b. [pəntu:] ‘pilose antler’
 c. [talʊ] ‘birch bark’
 d. [akku:] ‘filled, solid’

Also unlike nonhigh round vowels /o/ and /ɔ/, the high round vowels never act as triggers of rounding harmony. The data in (165) illustrates this.

- (165) a. [urə-jə] ‘mountain (indef. acc.)’
 b. [bu:-wkə:n-nə-] ‘to give (caus. pres.)’
 c. [luxi-xə:n-mə] ‘arrow (dim. def. acc.)’
 d. [onta] ‘leather shoe’
 e. [tʃʊ:xa] ‘grass’
 f. [morin-a] ‘horse (indef. acc.)’

Finally, when high round vowels occur following triggering /o/ or /ɔ/, these high round vowels block rounding harmony rather than propagating it, as in (166).

- (166) a. [owon-dulə:] ‘pancake (destin.)’
 b. [ɔrɔn-dula:] ‘reindeer (destin.)’

This blocking of rounding harmony extends to high vowels more generally. Following triggering /o/ or /ɔ/, the high front vowels /i/ and /ɪ/, as well as the diphthongs /ie/ and /ɪɛ/, also block rounding harmony, as in (167).

- (167) a. [moliktə] ‘kind of wild fruit’
 b. [bolboxi-wə] ‘wild duck (def. acc.)’
 c. [omboŋkie-wə] ‘Shaman’s hat (def. acc.)’
 d. [ɔxixan] ‘flame’
 e. [ɔmɔlɪɛ-xal] ‘grandson (pl.)’
 (c.f. [bɔdɔ-xɔl] ‘to think (int. imp. 2sg.)’)
 f. [tʃlik-pa] ‘cloud-shaped design (def. acc.)’

A successful account of Baiyina Oroqen rounding harmony must account for the following observations. (1) A condition is placed on which round vowels may be triggers of harmony. (2) There are two disparate distributional patterns for non-triggers. On the one hand, long nonhigh /o:/ and /ɔ:/ fail to trigger harmony, but will propagate it; on the other hand, high /u/, /u:/, /o/, and /o:/ fail to trigger harmony and block it from spreading any further. The Gestural Harmony Model is able to account for such a pattern due to having two different types of gestural co-occurrence constraints at its disposal: *COUPLE and *OVERLAP.

I interpret the patterns of non-triggering of rounding harmony in Baiyina Oroqen as follows. Non-triggering long nonhigh /o:/ and /ɔ:/ may not be coupled to a persistent lip protrusion gesture, though they are not prohibited from being overlapped by the lip protrusion gesture of another vowel. The result of this coupling-based restriction is that these vowels will neither trigger nor block harmony. However, high vowels are entirely prohibited from being concurrently active with a persistent lip protrusion gesture. The result of this stricter co-occurrence restriction is that a high vowel may neither be coupled to a persistent lip protrusion gesture, nor may it be overlapped by a lip protrusion gesture as a result of harmony.

The patterning of the high back vowels as non-triggers and blockers of harmony in Baiyina Oroqen parallels the role of the high back vowels in the rounding harmony of Halk Mongolian (section 4.5.2). The only difference is that in Baiyina Oroqen the high front vowels also block rounding harmony. From this perspective, the non-triggering and blocking behavior of high vowels in Baiyina Oroqen can be analyzed in a similar way, via the high ranking of a constraint from the *OVERLAP family.³⁰ The constraint necessary for the analysis of Baiyina Oroqen is defined in (168).

- (168) *OVERLAP(high vowel, persistent lip protrusion): Assign a violation mark to a high vowel gesture and a persistent lip protrusion gesture that are concurrently active.

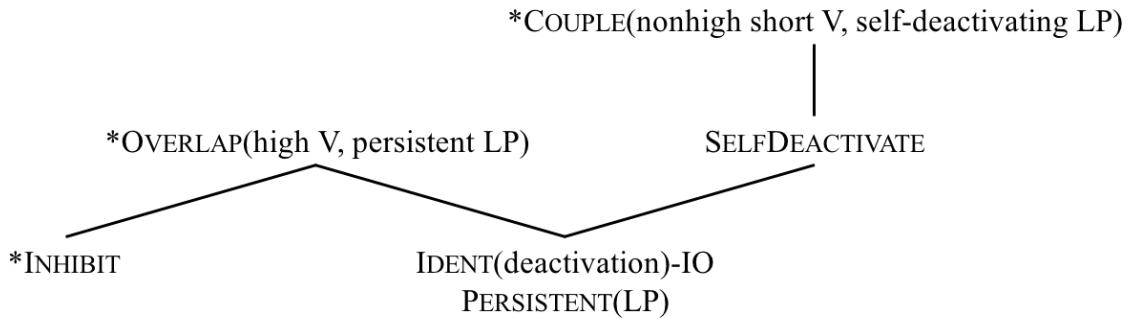
The constraint in (168) disallows the concurrent activation of a high vowel gesture (either back or front) and a persistent lip protrusion gesture. When this constraint is ranked above *INHIBIT, an inhibition relation will be included in a coupling graph such that the concurrent

³⁰ It is also possible that two separate *OVERLAP constraints are responsible for blocking by high vowels in Baiyina Oroqen, one for front vowels and one for back vowels. While the high back vowels are prohibited from co-occurring with persistent lip protrusion gestures, it appears that the high front vowels are prohibited from co-occurring with lip protrusion gestures of any kind, as evidenced by the complete lack of high front round vowels in the language. While the use of one versus two *OVERLAP constraints has consequences for shaping the phonological inventory of the language, it is not crucial to the analysis of blocking laid out here. To simplify the analysis, I assume a single *OVERLAP constraint.

activation of a persistent lip protrusion gesture and a high vowel gesture is avoided. This applies whether the high vowel is round or unround. Because the nonhigh front vowels are diphthongized and include a high vowel portion, they are also rendered blockers by *OVERLAP(high vowel, persistent lip protrusion). In addition, this constraint ensures that any high round vowels do not trigger rounding harmony, as they are prohibited from surfacing with a persistent lip protrusion gesture.

The full ranking of constraints necessary to generate the pattern of triggering, non-triggering, blocking, and undergoing in Baiyina Oroqen is provided in the Hasse diagram in (169).

(169) Constraint ranking for Baiyina Oroqen rounding harmony



The ranking *COUPLE(nonhigh vowel, self-deactivating lip protrusion) >> SELFDEACTIVATE >> IDENT(deactivation)-IO, PERSIST(LP) has already been shown to account for the role of nonhigh vowels in Baiyina Oroqen rounding harmony in section 3.4.2. The constraint *OVERLAP(high vowel, persistent lip protrusion) can now be added to the ranking to account for the non-triggering and blocking behavior of high vowels as well.

The tableau in (170) illustrates the selection of [onta] ‘leather shoe,’ in which the high vowel /ʊ/ does not trigger rounding harmony, as the optimal candidate, even with a hypothetical input in which /ʊ/ is accompanied by a persistent lip protrusion gesture. Again, for reasons of

space and clarity, I only include vowel gestures, and output candidates are displayed as gestural scores.

(170) Tableau for Baiyina Oroqen [vonta] ‘leather shoe’

Input: / $\text{u}_1 \text{n t a}_2 /$	*COUPLE(nonhigh short V)	SELFDEACTIVATE	*OVERLAP(high V)	IDENT(deactivation)-IO	PERSIST(lip protrusion)	*INHIBIT
		*!	*!			
				*	*	

In candidate (a) [onto], high back round [ʊ] surfaces faithfully with a persistent lip protrusion gesture, triggering harmony and overlapping the following nonhigh vowel. This violates both SELFDEACTIVATE and *OVERLAP(high vowel, persistent lip protrusion); either of these violations is fatal. The winner is candidate (b) [onta], in which the lip protrusion gesture of [ʊ] is self-deactivating and harmony is not triggered. This candidate violates low-ranked IDENT(deactivation)-IO and PERSIST(lip protrusion), but satisfies higher-ranked SELFDEACTIVATE and *OVERLAP(high vowel, persistent lip protrusion).

The same high ranking of *OVERLAP(high vowel, persistent lip protrusion) that renders high back /u/ and /o/ non-triggers of harmony is responsible for their status as blockers. The tableau in (171) illustrates this for the Baiyina Oroqen form [ɔrɔn-dula:] ‘reindeer (destin.).’ For reasons of space, I do not represent the extended length of the vowel [a:] in the candidate gestural scores.

(171) Tableau for Baiyina Oroqen [ɔrɔn-dula:] ‘reindeer (destin.)’

Input: / ɔ ₁ r ɔ ₂ n – d ɔ ₃ l a: ₄ /	*COUPLE(nonhigh short V)	SELFDEACTIVATE	*OVERLAP(high V)	IDENT(deactivation)-IO	PERSIST(lip protrusion)	*INHIBIT
a. [ɔrɔn-dula:]	*!				**	
b. [ɔrɔn-dulɔ:]	*	*!		*	*	
c. [ɔrɔn-dula:]	*		*	*	*	*

In (171), candidate (a) [ɔran-dula:] is ruled out immediately by undominated *COUPLE(nonhigh short vowel, self-deactivating lip protrusion), as it contains a non-triggering short nonhigh [ɔ]. The two remaining candidates both contain harmony-triggering [ɔ], which is accompanied by a persistent lip protrusion gesture. This satisfies *COUPLE(nonhigh short vowel, self-deactivating lip protrusion), at the expense of lower-ranked SELFDEACTIVATE (as well as IDENT(deactivation)-IO, due to the hypothetical input with a self-deactivating lip protrusion gesture). In candidate (b) [ɔrɔn-dolɔ:], the high vowel [ɔ] is overlapped by the harmonizing lip protrusion gesture, resulting in full harmony throughout the word. This satisfies low-ranked *INHIBIT but fatally violates *OVERLAP(high vowel, persistent lip protrusion). The winning candidate is (c) [ɔrɔn-dula:], in which an inhibition relation between the vocalic gesture of [ɔ] and the lip protrusion gesture of [ɔ] results in the blocking of harmony. This violates *INHIBIT but satisfies higher-ranked *OVERLAP(high vowel, persistent lip protrusion).

The pattern of blocking in Baiyina Oroqen is distinguished from that of Halk Mongolian by the fact that high front vowels also block harmony, rather than being transparent to it. *OVERLAP(high vowel, persistent lip protrusion) will also account for this, as illustrated by the tableau for [ɔxixan] ‘flame’ in (172). Having already established that a nonhigh round vowel is a trigger of vowel harmony in Baiyina Oroqen regardless of the input deactivation parameter specification of its lip protrusion gesture, the lip protrusion gestures in the input and both output candidates in (172) are all persistent.

(172) Tableau for Baiyina Oroqen [ɔxixan] ‘flame’

Input: / ɔ ₁ x i ₂ x a ₃ n /	*COUPLE(nomhigh short V)	SELFDEACTIVATE	*OVERLAP(high V)	IDENT(deactivation)-IO	PERSIST(lip protrusion)	*INHIBIT
	*	*				*

In candidate (a) [ɔxyxɔn], the high front round vowel undergoes rounding harmony, incurring a fatal violation of *OVERLAP(high V, persistent lip protrusion). Winning candidate (b) [ɔxixan] eliminates the violation of this *OVERLAP constraint by including an inhibition relation between [i] and the harmonizing lip protrusion gesture. This blocking configuration violates only low-ranked *INHIBIT.³¹

³¹ A conceivable third candidate would look identical to candidate (a) but would include a lip spreading gesture in the representation of [i], rendering it transparent to rounding harmony. It would also be ruled out due to its violation of *OVERLAP(high vowel, persistent lip protrusion), which requires all high vowels to block rounding harmony, whether they include a lip spreading gesture or not. Because of this, it is impossible to tell without phonetic evidence whether the production of high front vowels in Baiyina Oroqen involves active lip spreading that should be reflected in their gestural makeup.

The Gestural Harmony Model has proven itself successful in analyzing the complex patterns of triggering, propagating, blocking, and undergoing of rounding harmony in Baiyina Oroqen. This analysis accounts for the two distinct types of non-triggers in this system: the long nonhigh round vowels that propagate harmony and the high round vowels that block it. More generally, the Gestural Harmony Model provides a unified account of patterns of blocking involving non-triggers of harmony, as exemplified by the cases of rounding harmony in Halk Mongolian and Baiyina Oroqen. The non-triggering and blocking behaviors of high vowels are both accounted for by constraints from the *OVERLAP family. The somewhat rarer case in which a non-trigger of harmony propagates that harmony, rather than blocking it, also receives explanation in this analysis as the result of a constraint from the *COUPLE family. The following subsections focus on patterns of blocking in rounding harmony that are motivated by the avoidance of gestural incompatibility, based on the markedness conditions discussed in section 4.5.1.

4.5.4 *Tuvan: Blocking by Nonhigh Vowels*

Tuvan rounding harmony represents a case in which blocking of harmony is necessary to prevent the concurrent activation of incompatible gestures. As in many Turkic languages, including Kyrgyz (sections 2.2.1 and 3.2.1), Tuvan (Northern Turkic; Republic of Tuva, Russia) words harmonize for both backness and rounding. This section focuses on a gestural analysis of Tuvan rounding harmony, which shows the effect of a restriction on nonhigh round vowels. The language has a symmetrical inventory that contrasts vowels according to height, backness, rounding, and length. The inventory in (173) is reported by Harrison (2000).

(173) Tuvan vowel inventory

	Front		Back	
	Unround	Round	Unround	Round
High	i i:	y y:	w w:	u u:
Nonhigh	e e:	ø ø:	a a:	o o:

As in Kyrgyz, in Tuvan vowels harmonize with a vowel in the initial syllable of a word for backness and rounding. Backness harmony proceeds; both within and across morpheme boundaries, with all of the vowels in a word either front (174a-c) or back (174d-f). Data and description are from Harrison (2000).

- (174) a. [is-ter-im-den] 'footprint (pl. 1p abl.)' d. [at-tar-wum-dan] 'name (pl. 1p abl.)'
 b. [esker-be-di-m] 'notice (neg. past 1p)' e. [udu-va-duw-m] 'sleep (neg. past 1p)'
 c. [xøl-y] 'lake (3p poss.)' f. [to:l-u] 'story (3p poss.)'

Rounding harmony, on the other hand, does not apply throughout entire words without exception. As in many other Turkic languages, rounding harmony in Tuvan is triggered by a round vowel in an initial syllable. While both high and nonhigh round vowels trigger harmony, only high vowels are undergoers, surfacing as [y] and [u]. This is illustrated in (175).

- (175) a. [ulu-zu] ‘dragon (3p poss.)’
 b. [xol-u] ‘hand (3p poss.)’
 c. [byry-zy] ‘wolf (3p poss.)’
 d. [xø:r-y] ‘cemetery (3p poss.)’

cf. [ur-w] ‘song (3p poss.)’
 [is-i] ‘footprint (3p poss.)’

The nonhigh vowels do not undergo rounding harmony, and surface as unround [e] and [a] after a triggering round vowel. These nonhigh vowels block rounding from spreading any further, as in (176).

- (176) a. [udu-va-duu-m] ‘sleep (neg. past 1p)’
b. [nom-nar-um] ‘book (pl. 1p)’ (cf. [nom-um] ‘book (1p)’)
c. [byry-ler-ninj] ‘leaf (pl. gen.)’ (cf. [byry-nynj] ‘book (gen.)’)
d. [xøl-der] ‘lake (pl.)’

From this data it is apparent that Tuvan does not exhibit any sort of trigger asymmetry; both high and nonhigh round vowels are triggers of rounding harmony. However, high vowels are allowed to undergo harmony while nonhigh vowels are not. This can be explained as the result of the prohibition on nonhigh round vowels proposed by Kirchner (1993), Hong (1994) and Kaun (1995, 2004). As discussed in section 4.5.1, Kirchner's and Kaun's constraints against nonhigh round vowels (referred to by Kaun as *RoLO) are redefined within the Gestural Harmony Model as a constraint from the *OVERLAP family. It penalizes the concurrent activation of a lip protrusion gesture and a nonhigh vowel gesture and is defined in (177), repeated from (147) in section 4.5.1.

- (177) *OVERLAP(nonhigh vowel, lip protrusion): Assign a violation mark to a nonhigh vowel gesture and a lip protrusion gesture that are concurrently active.

In order for this *OVERLAP constraint to enforce blocking of rounding harmony in Tuvan, it must outrank *INHIBIT, which penalizes the deactivation of a harmony-triggering gesture. However, *OVERLAP must itself be outranked by MAX(lip protrusion)-IO, which will prevent the deletion of an input lip protrusion gesture. This ranking will preserve any underlying /o/ or /ø/ vowels while preventing a persistent lip protrusion gesture from deriving additional nonhigh round vowels. Finally, MAX(lip protrusion)-IO must be outranked by LICENSE(lip protrusion, first σ) (first proposed in section 3.2.1 for Kyrgyz rounding harmony) in order to account for the restriction of round vowels to the initial syllable of the word in Tuvan (as reported by Harrison (2000)). The full ranking is provided in (178):

- (178) Constraint ranking for Tuvan rounding harmony:

LICENSE(lip protrusion, first σ) >> MAX(lip protrusion)-IO >>
 *OVERLAP(nonhigh vowel, lip protrusion) >> *INHIBIT

The licensing constraint will not be included in the following analysis as it is undominated in Tuvan, and any candidates that violate it will not be considered. The workings of the rest of this constraint ranking are demonstrated in the following tableaux. The first, for the Tuvan form [xol-u] ‘hand (3p poss.)’, is provided in (179). In this form, rounding harmony is triggered by a nonhigh round vowel and targets a high vowel.

(179) Tableau for Tuvan [xol-u] ‘hand (3p poss.)’

Input: / x o ₁ l – u ₂ /	MAX(LP)-IO	*OVERLAP (nonhigh V, LP)	*INHIBIT
	*		
	*	*!	
	*!		

In the winning candidate (a) [xol-u], the persistent lip protrusion gesture of the [o] in the initial syllable overlaps the following vowel gesture. Because it is a high vowel gesture, this overlap does not incur a violation of *OVERLAP(nonhigh vowel, lip protrusion). In candidate (b)

[xol-w] the overlap of the second vowel gesture by the lip protrusion gesture is prevented by an inhibition relation that causes the lip protrusion gesture to deactivate when the following high back vowel activates. This incurs a fatal violation of *INHIBIT. In candidate (c) [xal-w], the lip protrusion gesture of underlying /o/ has been deleted, incurring a fatal violation of MAX(lip protrusion)-IO.

While full harmony is favored when a high vowel follows a triggering round vowel, the situation is different when a potential undergoer of harmony is a nonhigh vowel. In this case, harmony is blocked in order to prevent violation of *OVERLAP(nonhigh vowel, lip protrusion). This is demonstrated in the tableau for [nom-nar-wum] ‘book (pl. 1p)’ in (180). In this form, harmony is blocked by [a] in the plural suffix.

(180) Tableau for Tuvan [nom-nar-um] ‘book (pl. 1p)’

Input: / n o ₁ m – n a ₂ r – u ₃ m /	MAX(LP)-IO	*OVERLAP (nonhigh V, LP)	*INHIBIT
<p>a. [nom-nor-um]</p> <p>[o₁ o₂ u₃]</p>		**!	
<p>b. [nom-nar-um]</p> <p>[o₁ a₂ u₃]</p>		*	*
<p>c. [nam-nar-um]</p> <p>[a₁ a₂ u₃]</p>	*!		

Again, candidates (a) [nom-nor-um] and (b) [nom-nar-um] both incur violations of *OVERLAP(nonhigh vowel, lip protrusion) due to the preservation of underlying nonhigh round /o/ in their respective initial syllables. Candidate (c) [nam-nar-um], in which all vowels surface as unround, eliminates this violation of *OVERLAP(nonhigh V, lip protrusion) by deleting the harmonizing lip protrusion gesture entirely, fatally violating MAX(lip protrusion)-IO. Candidate (a) [nom-nor-um] incurs an additional *OVERLAP(nonhigh V, lip protrusion) violation due to the overlap of the nonhigh vowel in the second syllable by the persistent lip protrusion gesture in the first syllable. This additional violation of the *OVERLAP constraint is fatal to candidate (a). As a

result, candidate (b), [nom-nar-um] in which this overlap is prevented by an inhibition relation between the second vowel gesture and the lip protrusion gesture, emerges as the winner.

This brief sketch of Tuvan rounding harmony has demonstrated that *OVERLAP(nonhigh vowel, lip protrusion) is able to account for the same general pattern as Kaun's *ROLO. Many rounding harmony systems, particularly among the Turkic languages, do not target nonhigh vowels, despite the fact that nonhigh round vowels may exist underlyingly in the language and may even trigger rounding harmony. The constraint ranking in (178) correctly generates the rounding harmony pattern for Tuvan and other languages in which underlying nonhigh round vowels are preserved, but are not created by rounding harmony.

4.5.5 *Yakut: Blocking of Cross-Height Harmony*

Rounding harmony in Yakut (also known as Sakha/Saxa; Turkic; Sakha Republic, Russia; Krueger (1962), Kaun (1995), G. Anderson (1998), Sasa (2001), Walker (2017b)) has received attention as a harmony system that appears to exhibit local, iterative patterns of harmony triggering and propagation based on vowel height. Walker (2017b) points out that this places Yakut rounding harmony in contrast with Baiyina Oroqen rounding harmony (sections 3.4.2 and 4.5.3), which provides evidence for one-to-many, potentially non-local trigger-target relations. This section demonstrates that the Gestural Harmony Model is able to account both for harmony systems that exhibit non-local trigger-target relations, such as Baiyina Oroqen, and those that exhibit apparent local iterativity, such as Yakut.

Yakut has a vowel inventory that is almost perfectly symmetrical for height, backness, and rounding, and length, save for the absence of a long version of the nonhigh front round vowel /ø/. The inventory reported by Krueger (1962) and G. Anderson (1998) is provided in (181).

(181) Yakut vowel inventory

	Front		Back	
	Unround	Round	Unround	Round
High	i i:	y y:	u u:	u u:
Nonhigh	e e:	ø	a a:	o o:
Diphthongs	ie	yø	ua	uo

Yakut has full backness harmony that holds throughout roots and suffixes. Words are either composed of all front vowels (182a-c) or all back vowels (182d-f). All data are from Krueger (1962) and G. Anderson (1998).

- (182) a. [kinige-ler] ‘book (pl.)’ d. [aya-lar] ‘father (pl.)’
 b. [et-ter] ‘meat (pl.)’ e. [baluk-lar] ‘fish (pl.)’
 c. [øj-y] ‘reason (acc.)’ f. [oyo-nu] ‘child (acc.)’

The focus of this section is on rounding harmony in Yakut, which shows interesting asymmetries based on the heights of both triggers and targets. As in other Turkic languages, round vowels must either be in an initial syllable, or be the products of rounding harmony. A high vowel undergoes rounding harmony when it follows either a high or nonhigh round vowel, as in (183).

- (183) a. [oχ-u] ‘arrow (acc.)’
 b. [børø-ny] ‘wolf (acc.)’
 c. [murum-u] ‘nose (acc.)’
 d. [tynnyk-y] ‘window (acc.)’

Harmony also proceeds from a nonhigh vowel to another nonhigh vowel, as in (184).

- (184) a. [son-ton] ‘jacket (abl.)’
 b. [oyo-lor] ‘child (pl.)’
 c. [øj-tøn] ‘reason (abl.)’
 d. [børø-lør] ‘wolf (pl.)’

However, when a nonhigh vowel follows a high round vowel, harmony is blocked, as in (185). This blocking occurs even if the original trigger of harmony (the round vowel in the initial syllable) is nonhigh, as in (185c-d).

Unlike in Tuvan rounding harmony (section 4.5.4), rounding harmony in Yakut can derive nonhigh round vowels; however, this is only possible when that nonhigh round vowel is not preceded by a high round vowel. There have been various analyses proposed in order to account for this pattern of blocking and non-propagation in Yakut rounding harmony. Kaun (1995) analyses the blocking of rounding harmony in a high-nonhigh sequence as the result of a restriction on cross-height rounding harmony, enforced by the constraint UNIFORM[round]. It is defined as in (186).

- (186) UNIFORM[round]: The autosegment [+round] may not be multiply linked to slots bearing distinct feature specifications. (Kaun 1995, p. 142)

In Yakut, UNIFORM[round] is proposed to prevent rounding from spreading from a high vowel to a nonhigh vowel, but to be violated in order to spread rounding from a nonhigh vowel to a high vowel. Kaun analyses this as the effect of the special harmony driving constraint EXTEND(round)IF[-high] being ranked above UNIFORM[round], motivating its violation only when a trigger is a nonhigh vowel. Meanwhile, the general harmony driving constraint EXTEND(round) is ranked below UNIFORM[round], resulting in the blocking of rounding harmony triggered by a high vowel.

However, such an analysis cannot be directly translated into a gestural analysis of the pattern of rounding harmony in Yakut. The issue lies in the differences in how harmony is driven by a maximal harmony-driving constraint such as EXTEND(F) (Kaun 1995) or SPREAD(F) (Padgett 1995; Walker 1998/2000) in featural phonology versus PERSIST(Gest_X) and ANTICIPATE(Gest_X) in the Gestural Harmony Model. EXTEND(F) and SPREAD(F) are only satisfied when additional segments in a word are associated to a harmonizing feature. Because of

this, high-ranked EXTEND(F) and SPREAD(F) can be used to drive harmony in violation of UNIFORM[round]. In contrast, as discussed in section 3.2, the Gestural Harmony Model's PERSIST(Gest_X) and ANTICIPATE(Gest_X) are satisfied if a gesture is specified for a parameter setting that renders it a trigger of harmony, whether or not it actually extends to overlap any other gestures. As a result, constraints calling for gestures to surface as persistent or anticipatory cannot be used to drive violation of UNIFORM[round]. Instead, such violation is motivated by *INHIBIT. Because of this, a rounding harmony system may either permit cross-height harmony (if *INHIBIT outranks UNIFORM[round]) or ban cross-height harmony (if UNIFORM[round] outranks *INHIBIT), regardless of the height of the harmony trigger.

This inability to account for asymmetric cross-height harmony restrictions using UNIFORM[round] in the Gestural Harmony Model is demonstrated below. The constraint PERSIST(lip protrusion) is ranked above SELFDEACTIVATE and IDENT(deactivation)-IO in order to capture the fact that all round vowels in Yakut are attested as triggers of rounding harmony. To account for the restriction on cross-height harmony, a gestural version of UNIFORM[round] is included and is ranked above *INHIBIT. It is implemented as a *OVERLAP constraint and defined as in (187):

- (187) *OVERLAP(lip protrusion; high V, nonhigh V): Assign a violation mark to a lip protrusion gesture that is active concurrently with both a high vowel gesture and a nonhigh vowel gesture. (abbreviated GESTUNI(lip protrusion))

In the Gestural Harmony Model, it is not necessary to rank a markedness constraint responsible for blocking over PERSIST. The ranking of GESTUNI(lip protrusion) over *INHIBIT ensures that cross-height harmony will be banned, even if PERSIST(lip protrusion) is ranked high. This is because PERSIST(lip protrusion) is not a maximal harmony driver; it does not explicitly require spreading. Instead, it is satisfied when a gesture of a certain type surfaces as persistent,

whether or not that triggering gesture actually extends its period of activation. This is demonstrated in the tableau in (188) for the Yakut form [kus-tar] ‘duck (pl.).’

(188) Tableau for [kus-tar] ‘duck (pl.)’

Input: /k u ₁ s – t a ₂ r /	Tongue Body uvular narrow ₁	Tongue Body pharyngeal wide ₂	Lip protrusion ₁	PERSIST(lip protrusion)	*GESTUNI(lip protrusion)	*INHIBIT
a. [kus-tar] [u ₁ a ₂]					*	
b. [kus-tar] [u ₁ a ₂]					*	
c. [kus-tor] [u ₁ o ₂]					*	

The diagram illustrates the temporal sequence of gestures for three candidates (a), (b), and (c). Each row shows a timeline with a grey bar representing the duration of each gesture. In row (a), the Lip protrusion₁ gesture ends at the onset of a₂, indicated by a small circle. In row (b), a dotted arrow from the end of the Lip protrusion₁ bar points to the start of the Tongue Body pharyngeal wide₂ bar, indicating inhibition. In row (c), the Lip protrusion₁ gesture continues until the onset of o₂.

Candidate (a) [kus-tar] is disharmonic due to the presence of a self-deactivating lip protrusion gesture, violating PERSIST(lip protrusion). The winning candidate (b), which also surfaces as [kus-tar], is disharmonic due to the blocking of the persistent lip protrusion gesture of [u] by the nonhigh vowel gesture of the following [a]. This blocking via gestural inhibition

prevents a violation of *GESTUNI(lip protrusion) at the expense of a violation of low-ranked *INHIBIT. However, even though the lip protrusion gesture has not extended beyond the span of time it would be active if it were self-deactivating, it does not violate PERSIST(lip protrusion). This constraint is satisfied even when a persistent gesture is immediately blocked and does not extend its period of activation. The fully harmonic candidate (c) [kus-tor] contains a persistent lip protrusion gesture that overlaps both a high and nonhigh vowel gesture, resulting in a fatal violation of *GESTUNI(lip protrusion).

In (188), cross-height harmony is prevented even though the constraint that enforces this prevention, GESTUNI(lip protrusion), is outranked by the constraint that is responsible for harmony, PERSIST(lip protrusion). This demonstrates that a constraint that requires a gesture to trigger harmony cannot motivate the violation of a cross-height harmony restriction in the same way that a constraint like SPREAD(F) or EXTEND(F) can. Because of this, it is not possible to replicate Kaun's analysis of Yakut's asymmetric cross-height harmony ban using a special harmony driving constraint. The addition of a high-ranked constraint that specifically requires nonhigh vowels to trigger rounding harmony (such as *COUPLE(nonhigh vowel, self-deactivating lip protrusion), introduced in the analysis of Baiyina Oroqen in section 3.4.2) does not generate [o-u] or [ø-y] vowel sequences. This is demonstrated in the tableau for the Yakut word [oχ-u] 'arrow (acc.)' in (189).

(189) Tableau for [oχ-u] ‘arrow (acc.),’ with incorrect candidate selected

Input: / o ₁ χ – u ₂ /	Tongue Body pharyngeal wide ₁	Tongue Body uvular narrow ₂	Lip protrusion ₁	*COUPLE (nonhigh V, self-deact. LP)	PERSIST(lip protrusion)	GESTUNI(lip prorusion)	*INHIBIT
a. [oχ-w]	[o ₁]	u ₂]	Lip protrusion ₁	*!	*		
b. [oχ-w]	[o ₁]	u ₂]	Lip protrusion ₁				*
c. [oχ-u]	[o ₁]	u ₂]	Lip protrusion ₁			*!	

The violation profile for the tableau in (189) is nearly identical to that of (188); the only difference is seen in candidate (a) [oχ-w], in which a nonhigh round vowel is accompanied by a self-deactivating lip protrusion gesture, violating both *COUPLE and PERSIST(lip protrusion). The winner is again candidate (b), [oχ-w], in which harmony is blocked in order to avoid a violation of GESTUNI(lip protrusion). The bomb icon next to this candidate indicates the erroneous selection of this candidate as the winner.

The tableau in (189) demonstrates that the addition of a special constraint that requires nonhigh vowels to trigger harmony cannot motivate the violation of the ban on cross-height harmony in Yakut. Because *COUPLE and PERSIST(lip protrusion) are not satisfied when segments are overlapped by a harmonizing gesture but rather when a gesture is specified as persistent (non-self-deactivating), these constraints cannot be used to overrule the effects of markedness constraints that prevent harmony, such as UNIFORM[round] or its gestural counterpart, *GESTUNI(lip protrusion).

A solution to this problem comes from a proposal by Sasa (2001, 2009), who argues that UNIFORM[round] should be split into two constraints: *H-L[round], which penalizes a high-nonhigh vowel sequence associated to the same [round] feature, and *L-H[round], which penalizes a nonhigh-high vowel sequence associated to the same [round] feature. By splitting this constraint, he is able to analyze the Yakut pattern as the result of the high ranking of *H-L[round] and the low ranking of its counterpart, *L-H[round]. This approach eliminates the need to use the constraint EXTEND(round)IF[-high] to counteract the effect of UNIFORM[round] only in cases in which a nonhigh vowel precedes a high vowel. This is precisely what is needed in order for the analysis within the Gestural Harmony Model to be successful, as there is no way to replicate the effect of EXTEND(round)IF[-high] on patterns of blocking.

In the gestural analysis of Yakut rounding harmony, the ranking of the constraint *H-L[round] above *INHIBIT will generate the correct pattern of asymmetric cross-height harmony restriction seen in Yakut. A sequence like [u-o] is still penalized, but [o-u] sequences are not. A gestural version of *H-L[round] is generated by modifying the *OVERLAP constraint in (187) slightly to specify the sequencing of the two vowel gestures that are prohibited from being overlapped by a lip protrusion gesture. This new constraint is defined in (190).

- (190) *OVERLAP(lip protrusion; high V, nonhigh V): Assign a violation mark to a lip protrusion gesture that is active concurrently with a high vowel gesture followed by a nonhigh vowel gesture. (abbreviated *H-L[round])

With the gestural version of *H-L[round] ranked above *INHIBIT, [u-o] sequences will still be penalized as they were by GESTUNI(lip protrusion) (see the tableau in (188)), but [o-u] sequences will not incur violations of this constraint. A form such as [oχ-u] ‘arrow (acc.)’ can now be correctly selected as the winning candidate. This is demonstrated in the tableau in (191), in which both output candidates contain persistent lip protrusion gestures.

- (191) Tableau for Yakut [oχ-u] ‘arrow (acc.),’ with correct candidate selected

Input: / o ₁ χ – u ₂ /	*H-L[round]	*INHIBIT
<div style="display: flex; justify-content: space-around;"> <div style="border: 1px solid black; padding: 5px; border-radius: 10px;">Tongue Body pharyngeal wide₁</div> <div style="border: 1px solid black; padding: 5px; border-radius: 10px;">Tongue Body uvular narrow₂</div> </div> <div style="text-align: center; margin-top: 10px;"> Lip protrusion₁ </div>	 	*
<p>a. [oχ-u]</p> <p>[o₁ u₂]</p> <div style="display: flex; align-items: center; justify-content: space-between;"> <div style="border: 1px solid black; padding: 5px; border-radius: 10px; background-color: #e0e0e0;">Lip protrusion₁</div> <div style="margin: 0 10px;"></div> <div style="border: 1px solid black; padding: 5px; border-radius: 10px; background-color: #e0e0e0;">Tongue Body pharyngeal wide₁</div> <div style="margin: 0 10px;"></div> <div style="border: 1px solid black; padding: 5px; border-radius: 10px; background-color: #e0e0e0;">Tongue Body uvular narrow₂</div> </div>	*	*
<p>b. [oχ-u]</p> <p>[o₁ u₂]</p> <div style="display: flex; align-items: center; justify-content: space-between;"> <div style="border: 1px solid black; padding: 5px; border-radius: 10px; background-color: #e0e0e0;">Lip protrusion₁</div> <div style="margin: 0 10px;"></div> <div style="border: 1px solid black; padding: 5px; border-radius: 10px; background-color: #e0e0e0;">Tongue Body pharyngeal wide₁</div> <div style="margin: 0 10px;"></div> <div style="border: 1px solid black; padding: 5px; border-radius: 10px; background-color: #e0e0e0;">Tongue Body uvular narrow₂</div> </div>	 	

Candidate (a) [oχ-u] includes an inhibition relation between the high back vowel and the lip protrusion gesture of the [o]. This incurs a violation of *INHIBIT; however, blocking of harmony in this candidate does nothing to improve its performance with respect to *H-L[round],

as neither candidate violates this constraint. The winner in this tableau is candidate (b) [oχ-u], which incurs no violations. *H-L[round] is satisfied because the lip protrusion gesture in this candidate overlaps a nonhigh-high sequence and not a high-nonhigh sequence.

Sasa (2001, 2009) also argues that splitting UNIFORM[round] into two constraints is necessary in order to accurately account for the pattern of rounding harmony in Yakut words with three or more syllables. As illustrated by the data in (185) above, high vowels undergo vowel harmony, but do not allow it to spread further. For instance, the Yakut word for ‘knee (dat.)’ is [tobuk-ka], not *[tobuk-ko]. It is not the quality of the originator of harmony (i.e., the vowel in the initial syllable) that determines whether a given segment undergoes harmony, but the quality of the vowel immediately adjacent to that potential undergoer. This can be contrasted with Baiyina Oroqen rounding harmony (sections 3.4.2 and 4.5.3), in which long nonhigh round vowels do not trigger rounding harmony but do undergo and propagate it.

Sasa points out that Kaun’s analysis, which uses the maximal harmony-driving constraint EXTEND(round)IF[-high] ranked above UNIFORM[round], actually predicts that all vowels should undergo rounding harmony that is triggered by a nonhigh vowel in an initial syllable, even if a high vowel intervenes. The fact that [u] does not trigger rounding harmony in Yakut does not affect its ability to propagate rounding onto a following nonhigh vowel, because in a vowel sequence such as [o₁-u₂-o₃] the initial [o₁] is the trigger, not [u₂]. Walker (2014) shows that this casting of initial [o] as a global trigger of harmony is a property of maximal harmony drivers that require all segments in a harmony domain to associate to a harmonizing feature, even if they are not adjacent to the trigger. Kaun’s constraint EXTEND(round)IF[-high] is such a global harmony driver, and therefore it predicts harmony patterns that are characteristic of nonlocal trigger-target relations as defined by Walker.

However, adoption of the constraint *H-L[round] in place of UNIFORM[round] and the elimination of EXTEND(round)IF[-high] from the analysis of Yakut solves this issue. The gestural analysis of Yakut rounding harmony is able to generate forms in which harmony is triggered by a nonhigh vowel but arrested by an undergoing high vowel. The tableau in (192) for the form Yakut [tobuk-ka] ‘knee (dat.)’ demonstrates.

(192) Tableau for Yakut [tobuk-ka] ‘knee (dat.)’

<p>Input: /t o₁ b u₂ k – k a₃ /</p>	<p>*H-L[round]</p> <p>*INHIBIT</p>
<p>☞ a. [tobuk-ka]</p>	<p>*</p>
<p>b. [tobuk-ko]</p>	<p>*!</p>

In winning candidate (a) [tobuk-ka], the lip protrusion gesture that accompanies the [o] of the initial syllable is inhibited by nonhigh [a] in order to avoid violation of higher-ranked *H-L[round]. In candidate (b) [tobuk-ko], the lip protrusion gesture is allowed to extend throughout the entire word, resulting in an illicit [u-o] sequence in violation of *H-L[round]. Note that both candidates contain the cross-height round vowel sequence [o-u], which is not

penalized. The Gestural Harmony Model has thus proven itself able to account both for patterns of apparent local triggering, as in Yakut, and for patterns of nonlocal trigger-target relations, as in Baiyina Oroqen, provided the proper constraints on cross-height harmony are adopted.

Walker (2017b) argues against the split of UNIFORM[round] into the two constraints *H-L[round] and *L-H[round] on the grounds that the freely rankable *L-H[round] proposed by Sasa (2001, 2009) predicts patterns of rounding harmony that are unattested according to Kaun's (1995, 2004) typological surveys. Within these typologies, many rounding harmony systems allow nonhigh vowels to spread rounding onto high vowels. However, few languages allow high vowels to spread rounding onto nonhigh vowels, and they only do so if nonhigh-to-high spreading of rounding is also permitted. This implicational relationship between types of cross-height harmony is lost if *L-H[round] is admitted into the constraint set. Walker instead proposes an analysis of Yakut rounding harmony that is situated within the framework of Harmonic Grammar (Legendre, Miyata, & Smolensky 1990; Smolensky & Legendre 2006) and relies on cumulative constraint interaction between UNIFORM[round] and *RoLo, which penalizes nonhigh round vowels.

However, within the Gestural Harmony Model it is impossible to generate the asymmetry in cross-height harmony seen in Yakut using a single UNIFORM[round] constraint for the reasons stated earlier in this section. It is necessary to use Sasa's *H-L[round] constraint in order to capture the Yakut pattern within the Gestural Harmony Model. His other constraint, *L-H[round], on the other hand, appears to be unnecessary, in addition to being the potential source of a number of pathological predictions about rounding harmony. One option for eliminating pathological *L-H[round] is to claim that there are two constraints on cross-height harmony that are in a specific-general relationship with one another. While specific *H-L[round]

penalizes only cross-height rounding harmony that involves a high vowel followed by a non-high vowel, general UNIFORM[round] and its gestural counterpart GESTUNI(lip protrusion) penalize all cross-height rounding harmony, as attested in Yowlumne Yokuts. The special-general relationship between these constraints will capture Kaun's typological observation that if a language prohibits nonhigh-to-high cross-height rounding harmony, it also prohibits high-to-nonhigh harmony.

A possible additional reason for splitting UNIFORM[round] into two constraints comes from vowel harmony in Arapaho (Algonquian; Midwestern United States).³² Cowell & Moss (2008) report that Arapaho has two vowel harmony processes that affect backness and rounding, one progressive and one regressive. Progressive harmony is triggered by /o/ and causes a following /i/ to surface as [u], as in [ho:w-u-se:] 'to walk downward' (cf. [ceb-i-se:] 'to walk (along)'). Crucially, this harmony process results in the vowel sequence [o-u]. Regressive harmony is also triggered by /o/; however, it only targets nonhigh /e/ rather than high /i/. This process produces the vowel sequence [o-o], as in [bo:-o:wu] 'the water flows red' (cf. [be:-e:] 'it is red'), but apparently avoids producing the sequence [u-o]. In Yakut, the avoidance of the sequence [u-o] is analyzed by Walker (2017b) to be the result of an avoidance of cross-height harmony when it would also derive a marked nonhigh round vowel. However, vowel harmony in Arapaho exhibits the same avoidance of the sequence [u-o] despite it being the [u] that is derived by vowel harmony, and not the [o]. Cumulative interaction of UNIFORM[round] and *RoLo does not account for this pattern of vowel co-occurrence in Arapaho, while *H-L[round] does.

This study of Yakut rounding harmony has demonstrated that the Gestural Harmony Model is able to account for a case of apparent local iterative harmony, provided the constraint on cross-height harmony is properly defined. This is an important point in favor of the Gestural

³² Thanks to Ksenia Bogomolets for bringing this phenomenon to my attention.

Harmony Model, as it demonstrates that it is capable of accounting for patterns that appear to be cases of locally triggered, iterative harmony in the case of Yakut, as well as global, one-to-many triggering in the case of Baiyina Oroqen (sections 3.4.2 and 4.5.3). Many other analyses of harmony are capable of generating one or the other, but not both. A notable exception is Walker's (2017b) model of harmony in Harmonic Grammar, though it remains to be seen whether that approach is robust across different sets of markedness constraints that are active in harmony systems.

4.5.6 *Summary*

This section has illustrated the Gestural Harmony Model's ability to account for patterns of transparency and blocking in rounding harmony, particularly with respect to the typological asymmetry observed between the sets of attested transparent and blocking segments. While all vowels are attested as blockers of rounding harmony in some system, the ability to surface as transparent is limited only to high front vowels. The Gestural Harmony Model predicts this asymmetry, and analyzes it as the result of the representation of transparent segments as a special type of undergoers of harmony. The special status of high front vowels comes from their inclusion of a gesture for active lip spreading, which is antagonistic to the lip protrusion gesture responsible for rounding harmony.

In addition to accurately predicting the asymmetry between attested transparent and blocking segments, the Gestural Harmony Model is also able to account for harmony systems that exhibit both transparency and blocking. This is exemplified by Halk Mongolian in section 4.5.2. By splitting the sources of transparency and blocking among two distinct theoretical mechanisms, the Gestural Harmony Model correctly predicts that the effects of both of these

mechanisms, transparency via competition between antagonistic gestures and blocking via inhibition between incompatible gestures, should arise in some languages.

Across rounding harmony systems, there are many sources of gestural incompatibility that drive patterns of blocking that can be quite complex. The Gestural Harmony Model has proven itself capable of accounting for them, given the right constraint set. A particular asset to the theory is its ability to account for patterns of blocking that have been described as involving a local, iterative interpretation of harmony triggering (e.g. Yakut, section 4.5.5) as well as those with a global interpretation of triggering (e.g. Baiyina Oroqen, sections 3.4.2 and 4.5.3).

4.6 Transparency and Blocking in Tongue Root Harmony

This section focuses on ATR and RTR harmonies and their attested patterns of transparency and blocking. While nasal harmony and rounding harmony show asymmetries in the sets of attested transparent and blocking segments, no such asymmetry exists across ATR and RTR systems. The Gestural Harmony Model predicts this based on differences in the sources of gestural antagonism and incompatibility across these three types of harmony. How this prediction is borne out with respect to tongue root harmony is the subject of this section, which examines cases of RTR harmony from three dialects of Yoruba.

4.6.1 Sources of Antagonism and Incompatibility

As discussed in section 4.2.3, there is no asymmetry in the crosslinguistically attested sets of transparent and blocking segments in tongue root harmony. In ATR harmony, the low vowel /a/ is the only segment that appears not to participate in some harmony processes; it is transparent in some languages, and a blocker in others. In RTR harmony, the high vowels /i/ and /u/ are attested as both transparent and blocking segments. Despite the distinct mechanisms of neutrality responsible for transparency and blocking in the Gestural Harmony Model, the lack of

an asymmetry within the sets of attested transparent and blocking segments is predicted for tongue root harmony. If the set of segments that are antagonistic to a harmonizing gesture is identical to the set of segments that are incompatible with that harmonizing gesture, no asymmetry between attested transparent and blocking segments is predicted. This is the case in ATR and RTR harmonies.

Archangeli & Pulleyblank (1994) provide a detailed account of restrictions on the co-occurrence of tongue root advancement and retraction with vowels of different heights. They propose a number of phonetically grounded conditions on the co-occurrence of vowel height and tongue root position, which, when active in a language, affect both phonological inventories and processes of ATR and RTR harmony. These conditions are stated in (193).

- (193) Conditions on vowel height and tongue root position (Archangeli & Pulleyblank 1994, pp. 174, 176)³³

- a. ATR/HI Condition: If [ATR] then [+high] / If [ATR] then not [-high]
- b. ATR/LO Condition: If [ATR] then [-low] / If [ATR] then not [+low]
- c. RTR/HI Condition: If [RTR] then [-high] / If [RTR] then not [+high]
- d. RTR/LO Condition: If [RTR] then [+low] / If [RTR] then not [-low]
- e. HI/ATR Condition: If [+high] then [ATR] / If [+high] then not [RTR]
- f. LO/RTR Condition: If [+low] then [RTR] / If [+low] then not [ATR]

All of these conditions that render different combinations of tongue root gestures and vocalic tongue body gestures marked are based upon articulatory incompatibility. In many languages, high vowels require tongue root advancement in order to successfully shift the mass of the tongue body upward; a non-advanced tongue root, whether due to the tongue root being in a neutral position or being actively retracted, interferes with raising of the tongue body. Similarly, low vowels, which are often back vowels, require tongue root retraction in order to successfully achieve the necessary degree of retraction of the tongue body. A non-retracted

³³ Archangeli & Pulleyblank refer to RTR vowels as [-ATR], and to ATR vowels as [+ATR].

tongue root interferes with tongue body retraction for /a/. As a result, high ATR vowels in RTR harmony languages often have no RTR counterparts, while low RTR vowels in ATR harmony languages often have no ATR counterparts. The involvement of tongue root position in the production of vowels of different heights is illustrated in the figure in (194).

(194) High vowel with advanced tongue root, low vowel with retracted tongue root



Because the incompatibility of vowel height and tongue root position is based in articulation, the sets of possible transparent and blocking vowels in ATR harmony systems overlap entirely. This is different from the cases of nasal harmony and rounding harmony, in which gestural incompatibility is rooted in both articulatory and perceptual difficulty. As a result, the Gestural Harmony Model makes different predictions for nasal and rounding harmonies versus tongue root harmonies with respect to which segments can be transparent to harmony and which can block it. Because gestural incompatibility for nasality and rounding is not solely based on articulatory factors, asymmetries in possible transparent and blocking segments are predicted for these types of harmony. However, no such asymmetry is predicted for tongue root harmony.

The effects of Archangeli & Pulleyblank's conditions on vowel height and tongue root position can be replicated in the Gestural Harmony Model with constraints from the *OVERLAP family. The *OVERLAP constraints will penalize a high vowel that is concurrently active with a tongue root retraction gesture (195) and a low vowel that is concurrently active with a tongue

root advancement gesture (196). These constraints will prevent such vowels from arising in a language's surface phonological inventory, and will prevent them from being created via tongue root harmony. For the purposes of defining these constraints, low vowels refer to vocalic segments including a tongue body gesture with constriction in the pharyngeal region.

- (195) *OVERLAP(high vowel, tongue root retraction): Assign a violation mark to a high vowel gesture and a tongue root retraction gesture that are concurrently active.
- (196) *OVERLAP(low vowel, tongue root advancement): Assign a violation mark to a low vowel gesture and a tongue root advancement gesture that are concurrently active.

The relative ranking of these constraints along with *INHIBIT and constraints on faithfulness determine languages' surface phonological inventories, as well as the patterns of transparency and blocking in tongue root harmony systems. As in the analyses of nasal harmony and rounding harmony presented in sections 4.4 and 4.5, blocking of harmony results when a *OVERLAP constraint outranks *INHIBIT. Blocking of ATR harmony by low vowels is the result of *OVERLAP(low vowel, ATR) ranked above *INHIBIT. Likewise, blocking of RTR harmony by high vowels is the result of *OVERLAP(high vowel, RTR) ranked above *INHIBIT. Mid vowels, which are subject to neither *OVERLAP constraint, are correctly predicted not to block tongue root harmony.

When *INHIBIT is ranked above *OVERLAP, blocking of harmony is prohibited, and a harmonizing gesture will be allowed to extend to overlap vowels with which it is incompatible. There are two possible outcomes of this overlap. When a harmonizing tongue root gesture is active concurrently with a vowel that includes a gesture that is antagonistic to it, that vowel will surface as transparent to harmony. For instance, a low vowel gesture may be accompanied by a tongue root retraction gesture. Due to the ranking of *INHIBIT over *OVERLAP(low vowel, ATR), a tongue root advancement gesture will be allowed to overlap the low RTR vowel, resulting in

the concurrent activation of a tongue root advancement gesture and a tongue root retraction gesture. The result of this configuration is transparency via intergestural competition and blending, with the tongue root retraction gesture responsible for transparency overpowering the harmonizing tongue root advancement gesture when it is specified for greater blending strength. Similarly, the presence of a tongue root advancement gesture accompanying a high vowel will induce high vowel transparency to RTR harmony. A high vowel whose representation does not include a tongue root advancement gesture will surface as RTR when overlapped by a harmonizing tongue root retraction gesture.

This typological sketch of tongue root harmony, along with the in-depth examinations of various nasal and rounding harmonies already reported in sections 4.4 and 4.5, demonstrates that it is possible for the Gestural Harmony Model to capture crosslinguistic generalizations about transparency and blocking in various types of harmony, whether they show asymmetries in the sets of transparent and blocking segments or not. Typological asymmetries in attested transparent and blocking segments are accurately reflected in the Gestural Harmony Model's distinct mechanisms of transparency, based on concurrent activation of antagonistic gestures, and blocking, based on intergestural inhibition motivated by gestural incompatibility. However, the prediction of an asymmetry disappears when the class of segments that include antagonistic gestures is not a proper subset of the class of segments that are incompatible with a harmonizing gesture, as is the case in tongue root harmony. These strong typological predictions about the types of segments that can be transparent to harmony versus those that can block it are among the greatest strengths of the Gestural Harmony Model.

The typological patterns predicted by the interaction of the constraint *OVERLAP(high vowel, RTR), *OVERLAP(low vowel, ATR), and *INHIBIT, as well as the gestural makeup of the

vowels in a language's phonological inventory, are summarized in the following tables. The table in (197) contains the constraint rankings and resulting patterns of transparency and blocking for harmony based on tongue root advancement.

- (197) Predicted typology of transparency and blocking in ATR harmony

Ranking	Result	Attested in
*OVERLAP(low V, ATR) >> *INHIBIT	Low vowels block ATR harmony.	Akan (Clements 1981)
*INHIBIT >> *OVERLAP(low V, ATR)	All vowels undergo ATR harmony.	
	Low vowels surface as ATR.	Nandi (Creider & Creider 1989)
	Low vowels surface as transparent.	Budu (Kutsch Lojenga 1994)

A parallel typology emerges from the interaction of constraints on RTR harmony. This typology is provided in (198).

- (198) Predicted typology of transparency and blocking in RTR harmony

Ranking	Result	Attested in
*OVERLAP(high V, RTR) >> *INHIBIT	High vowels block RTR harmony.	Standard Yoruba (Pulleyblank 1988, 1996; Archangeli & Pulleyblank 1989; Ola Orie 2003)
*INHIBIT >> *OVERLAP(high V, RTR)	All vowels undergo RTR harmony.	
	High vowels surface as RTR.	Ekiti Yoruba (Ola Orie 2003)
	High vowels surface as transparent.	Ife Yoruba (Ola Orie 2001, 2003)

As in nasal harmony and rounding harmony, the constraints shape the typology by determining which types of segments will be overlapped by a harmonizing gesture, and which will block harmony by inhibiting a harmonizing gesture. From there, the representation of an overlapped segment (i.e., whether it includes a high-strength gesture that is antagonistic to the harmonizing gesture) will determine whether it surfaces with the harmonizing property, or whether it is transparent to harmony. To illustrate this, the remainder of this section analyses several cases of RTR harmony in different varieties of Yoruba. All varieties of Yoruba display some kind of RTR harmony; however, there is variation between them with respect to whether high vowels block harmony, surface as transparent to it, or surface as RTR. Interestingly, these varieties of Yoruba cover all of the possible patterns of transparency, blocking, and undergoing of RTR harmony listed in the table in (198).

4.6.2 Yoruba: Transparency and Blocking by High Vowels

The patterns of transparency and blocking in tongue root harmony are demonstrated here with examples from three varieties of Yoruba. In Standard Yoruba, high vowels block regressive RTR harmony. In Ife Yoruba, the high vowels are transparent to it. In Ekiti Yoruba, high vowels surface as RTR in the domain of RTR harmony. The data and its interpretation come from multiple sources, including Pulleyblank (1988, 1996), Archangeli & Pulleyblank (1989, 1994), and Ola Orie (2001, 2003).

Looking first at Standard and Ife Yoruba, the oral vowel inventory of both varieties is provided in (199).

(199) Standard Yoruba and Ife Yoruba oral vowel inventory³⁴

	non-RTR		RTR	
	Front	Back	Front	Back
High	i	u		
Mid	e	o	ɛ	ɔ
Low			ɑ	

While the mid vowels in these dialects have both RTR and non-RTR counterparts, the high vowels /i/ and /u/ surface only as non-RTR and the low back vowel /ɑ/ surfaces only as RTR.

The RTR vowels /ɛ/, /ɔ/, and /ɑ/ all trigger regressive RTR harmony in both Standard Yoruba and Ife Yoruba. The data in (200) illustrate.

(200) RTR harmony in Standard Yoruba and Ife Yoruba

- a. [ɛkeɛ] ‘forked stick’ *[ekɛɛ]
- b. [ɔbeɛ] ‘soup’ *[obeɛ]
- c. [ɔkɔ] ‘vehicle’ *[okɔ]
- d. [ɛkɔ] ‘pap’ *[ekɔ]
- e. [ɛpa] ‘groundnut’ *[epa]
- f. [ɔja] ‘market’ *[oja]

In Standard Yoruba, the regressive spread of RTR is blocked when the high vowels /i/ and /u/ precede the triggering word-final RTR vowel, as in the data in (201).

(201) Blocking by high vowels in Standard Yoruba

- a. [ewureɛ] ‘goat’
- b. [elubo] ‘yam flour’
- c. [otito] ‘truth’
- d. [odideɛ] ‘parrot’
- e. [okureɛ] ‘palm kernel’
- f. [orifa] ‘primordial diety’
- g. [ɔsupa] ‘moon’

³⁴ Yoruba also has several nasal vowels; however, this is not crucial to the analysis in this section and is therefore set aside.

However, in Ife Yoruba these high vowels are transparent to RTR harmony, as in the data in (202).

(202) Transparency of high vowels in Ife Yoruba

- a. [ɛwure] ‘goat’
- b. [ɛlubɔ] ‘yam flour’
- c. [ɔtitɔ] ‘truth’
- d. [ɔdide] ‘parrot’
- e. [ɔrisa] ‘primordial diety’
- f. [ɔsupa] ‘moon’

I analyze regressive RTR harmony in Yoruba as the result of the high ranking of the constraint ANTICIPATE(tongue root retraction), which requires a tongue root retraction gesture in an output form to be anticipatory (early-activating). However, in the analysis of blocking that follows I will set this and other constraints on harmony triggering aside and will only compare candidates in which an anticipatory tongue root retraction gesture surfaces in the final syllable of a word. The blocking of RTR harmony by high vowels in Standard Yoruba can be analyzed as the result of the constraint *OVERLAP(high V, RTR) ranked above *INHIBIT. The effect of this ranking is demonstrated in the tableau in (203) for the Standard Yoruba form [odide] ‘parrot.’ Again, I only include the vowel gestures of candidate output forms, which are displayed in gestural score form.

(203) Tableau for Standard Yoruba [odide] ‘parrot’

<p>Input: / o₁ d i₂ d ε₃ /</p>	<p>*OVERLAP(high V, RTR)</p> <p>*INHIBIT</p>
<p>a. [ɔdide]</p>	<p>*!</p>
<p>☞ b. [odide]</p>	<p>*</p>

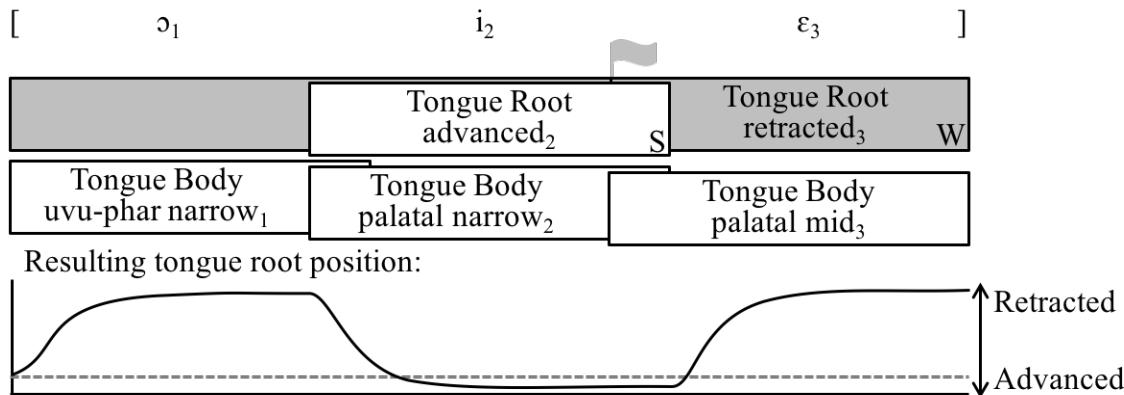
In (203), the anticipatory tongue root retraction gesture of [ε] in candidate (a) [ɔdide] has extended to overlap all preceding vowels in the word, causing them to surface as RTR. The overlap of the high vowel gesture by this tongue root retraction gesture fatally violates high-ranked *OVERLAP(high V, RTR). The winning candidate (b) [odide] avoids this overlap by including an inhibition relation between the palatal gesture of [i] and the harmonizing tongue root retraction gesture. While this results in a violation on low-ranked *INHIBIT, it prevents the tongue root retraction gesture from extending to overlap the high vowel, thus satisfying *OVERLAP(high V, RTR).

It should be noted that the representation of the high vowel in the input and outputs of the tableau in (203) does not include a tongue root advancement gesture. However, there is nothing in the definition of *OVERLAP(high V, RTR) that requires a blocker to include such a gesture in its representation; a high vowel gesture will block regardless of whether it possesses a tongue root advancement gesture. Of course, it may be the case that high vowels in Standard Yoruba are accompanied by tongue root advancement gestures; there is no evidence here either for or against this representation.

In contrast, the high vowels of Ife Yoruba do appear to include tongue root advancement gestures in their representations. According to Qla Orie (2001), in Ife Yoruba high vowels do not block RTR harmony. This can be analyzed as the result of a distinct ranking of constraints in this dialect of the language such that *INHIBIT outranks *OVERLAP(high vowel, RTR). Because of this ranking, high vowels will not block RTR harmony by inhibiting a harmonizing tongue root retraction gesture, but will instead be overlapped by it. Because of the presence of tongue root advancement gestures accompanying these high vowels, however, the result of this overlap will be transparency to harmony rather than retraction of the tongue root.

This is illustrated by the gestural score in (204) for the Ife Yoruba form [ɔdide] ‘parrot,’ in which word-final [ɛ] triggers RTR harmony by including an anticipatory tongue root retraction gesture in its representation. This anticipatory gesture overlaps all preceding gestures in the word. As a result of this overlap, the word-initial mid vowel surfaces as retracted, while the word-medial [i] includes a relatively high-strength antagonistic tongue root advancement gesture that results in the transparency of that vowel to RTR harmony. The dashed line indicates the neutral position of the tongue root.

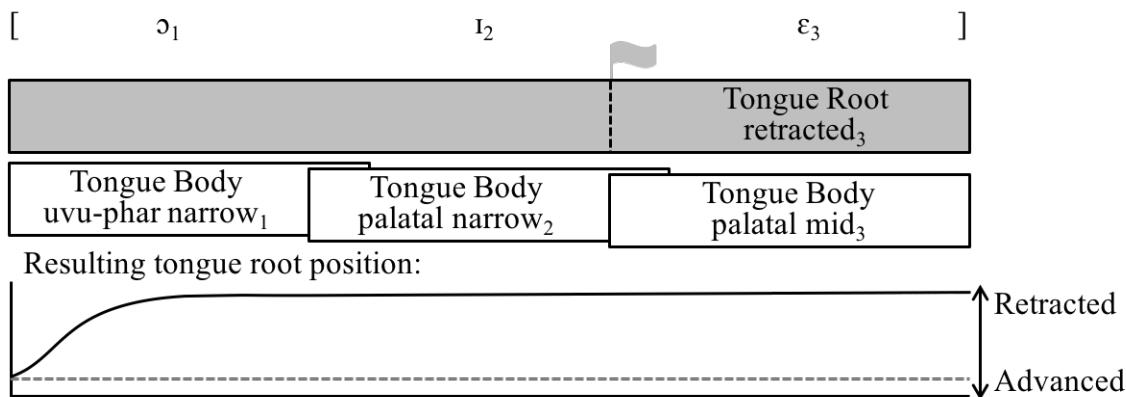
(204) Gestural score for vocalic portion of Ife Yoruba [ɔdide] ‘parrot’³⁵



Standard and Ife Yoruba can be contrasted with Ekiti Yoruba, in which the high vowels undergo RTR harmony and surface as [i] and [ʊ], respectively (Ola Orie 2003). As in Ife Yoruba, the high vowels do not act as blockers of harmony; *INHIBIT must be ranked high in these varieties as well. However, unlike in Ife Yoruba, these high vowels do not appear to include tongue root advancement gestures that are antagonistic to the harmonizing tongue root retraction gesture. As a result, when a high vowel is overlapped by an anticipatory tongue root retraction gesture in Ekiti Yoruba, the result is retraction of the tongue root during the production of these vowels, rather than transparency. This is illustrated by the gestural score in (205) for the Ekiti Yoruba form [ɔdide] ‘parrot,’ a cognate of the Ife Yoruba form in (204) above.

³⁵ Because of the lack of blocking in Ife Yoruba RTR harmony, it is unclear whether this is a case of regressive harmony from a word-final anticipatory gesture or of progressive harmony from a word-initial persistent gesture. Because the standard variety of Yoruba does indicate from its patterns of blocking that it is a regressive harmony process, the tongue root harmony of Ife Yoruba is assumed to also be a regressive harmony process, though this is not a crucial assumption.

(205) Gestural score for vocalic portion of Ekiti Yoruba [ɔdideɛ] ‘parrot’



The Standard, Ife, and Ekiti varieties of Yoruba, then, encompass all of the possible ways in which the high vowels /i/ and /u/ can surface when subject to RTR harmony. Due to their gestural incompatibility with a retracted position of the tongue root, high vowels may be compelled by a high-ranked *OVERLAP constraint to inhibit a harmonizing tongue root retraction gesture, resulting in blocking of RTR harmony. This is exemplified by Standard Yoruba. Alternatively, this incompatibility may be tolerated by the phonological grammar, in which case high vowels will undergo harmony. When this occurs, there are two possible outcomes. In Ife Yoruba, high vowels surface as transparent due to their inclusion of a high-strength tongue root advancement gesture that is antagonistic to the harmonizing gesture. This will result in intergestural competition that favors the target articulatory state of the high vowel, resulting in transparency. In Ekiti Yoruba, on the other hand, high vowels are not accompanied by tongue root advancement gestures and will surface as RTR when overlapped by a harmonizing tongue root retraction gesture.

These three outcomes represent all of the possible outcomes predicted by the RTR typology listed in (198). The same logic that holds here for the possible outcomes of high vowels in RTR harmony also hold for the converse pattern of the possible outcomes of low vowels in

ATR harmony. There are also three ways in which a low vowel is predicted to surface in the environment of ATR harmony; all are attested, as listed in the table in (197).

4.6.3 *Summary*

This section has focused on patterns of transparency and blocking in tongue root harmony, which are considerably simpler than those observed in either nasal harmony (section 4.4) or rounding harmony (section 4.5). Whereas both nasal harmony and rounding harmony show crosslinguistic asymmetries such that the classes of attested transparent segments are a subset of the classes of attested blocking segments, in ATR and RTR harmony no such asymmetry exists. In ATR harmony, low vowels are attested as transparent and blocking segments. Likewise, in RTR harmony, high vowels are attested as transparent and blocking segments.

The fact that the Gestural Harmony Model makes no predictions regarding asymmetries in attested transparent and blocking segments in tongue root harmony is in itself an important prediction of the model. This model will predict an asymmetry between transparent and blocking segments precisely where there is an asymmetry in the sets of antagonistic and incompatible segments. In nasal harmony and rounding harmony, antagonism to a harmonizing gesture arises from a small set of segment types (obstruents with a velum closure gesture in the case of nasal harmony, and high front vowels with a lip spreading gesture in the case of rounding harmony). However, in both of these types of harmony incompatibility with a harmonizing gesture arises from a larger set of segment types based on both articulatory and perceptual markedness factors. In contrast, within ATR and RTR harmony the sets of segments that are antagonistic to a harmonizing tongue root gesture are not proper subsets of the sets of incompatible segments.

Therefore, the Gestural Harmony Model is able to accurately predict the existence of typological asymmetries in attested transparent and blocking segments in the types of harmony that exhibit such asymmetries (nasal and rounding harmony) while also accurately predicting the lack of such a typological asymmetry in the types of harmony that do not exhibit these asymmetries (ATR and RTR harmony). It is in this respect that the Gestural Harmony Model's dual mechanisms of transparency via intergestural competition and blending and blocking via intergestural inhibition show their major strength. Many accounts within featural phonology that employ a single theoretical mechanism to account for both transparency and blocking do not match this success in accounting for typological asymmetries between the two. This is discussed in the following section.

4.7 Comparing Analyses of Transparency and Blocking

The analysis of transparency in harmony as the result of the competition between two gestures with antagonistic target articulatory states represents a substantial departure from previous accounts of this phenomenon. This section examines properties of the Gestural Harmony Model's representation of transparency and blocking, as well as the typological predictions made by the model; it also compares these predictions to those made by several alternative accounts. Earlier work has relied upon derivational opacity or gapped representations to capture transparency in harmony. More recently, featural co-occurrence constraints have played a key role in analyses of both transparency and blocking in harmony. Other analyses rely on a continuum or scale of likelihood of certain segment types to be transparent or to block a harmony process. This section demonstrates that the Gestural Harmony Model's representation of transparency and blocking improves upon many previous analyses in several areas.

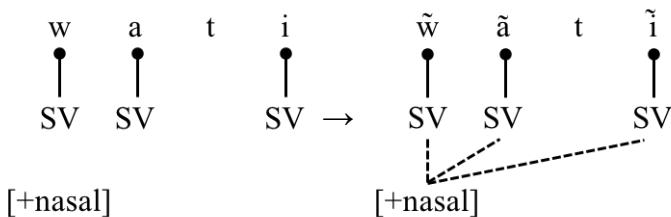
4.7.1 Locality of Spreading

A long-standing debate within the study of harmony revolves around how (and whether) to maintain a local representation of a harmonizing element in harmony systems that exhibit transparency. Some previous proposals rely on derivational opacity in order to capture instances of transparency while preserving locality of the harmony process. Piggott (1988), for instance, provides an analysis of Guaraní, which exhibits regressive (leftward) nasal harmony with transparent voiceless obstruents, in which the feature [+nasal] first spreads onto voiceless obstruents but is then denasalized by the later default rule [-voice] → [-nasal]. While this analysis preserves the locality of the harmony process, it does so by relying on a derivationally opaque rule ordering. As discussed in section 3.6.3, such analyses are incompatible with output-oriented frameworks such as OT without adopting additional theoretical mechanisms. One such mechanism is Harmonic Sympathy, a variant of Sympathy Theory (McCarthy 1999) proposed by Walker (1998/2000, 2003). Walker analyzes transparency in nasal harmony using Harmonic Sympathy to mimic the effect of derivational opacity within OT. In this analysis, the selected output form is faithful to another candidate in which nasality has spread fully throughout a word (including onto any obstruents), but differs from that candidate by not nasalizing those obstruents in order to satisfy a high-ranked feature co-occurrence constraint.

The Gestural Harmony Model's account of transparency similarly represents transparent segments as having undergone harmony; they are overlapped by a persistent and/or anticipatory gesture. However, such segments' surfacing as transparent does not rely upon a subsequent step of repair as Piggott's (1988) featural account does. Instead, a segment surfaces as transparent to harmony due to its gestural makeup, i.e. due to its including a gesture that is antagonistic to the harmonizing gesture that overlaps it. The Gestural Harmony Model also does not require any elaboration of the constraint evaluation mechanism in OT, as required by Harmonic Sympathy.

An alternative method for capturing transparency in harmony involves allowing a feature to spread beyond a transparent segment without associating with it, resulting in a gapped autosegmental configuration. In some cases, this skipping is motivated by assuming subsegmental feature geometric nodes (Clements 1985; Sagey 1986), and identifying the set of possible targets of a harmony process by which segments possess the proper node to which to associate a harmonizing feature. This is the case in Piggott's (1992) analysis of nasal harmony in Southern Barasano (also known as Barasana-Eduria; Tucanoan; Colombia). Piggott motivates the skipping of obstruents in nasal harmony by proposing that in languages with transparency to nasal harmony, the feature [nasal] is a dependent of the Spontaneous Voicing node. When the feature [nasal] spreads, it will only target segments that bear this node, namely the class of sonorants, which potentially includes voiced stops. The figure in (206) demonstrates this for the Southern Barasano form [w̄āt̄í] 'demon' provided by Piggott (1992; p. 53). In this figure, the harmonizing [nasal] feature does not associate with the obstruent [t] as it is lacking a Spontaneous Voicing node, thereby eliminating it as a possible target of nasal harmony.

(206) Derivation of Southern Barasano [w̄āt̄í] 'demon' proposed by Piggott (1992)



However, as discussed in section 2.3, work by Gafos (1996/1999), Ní Chiosáin & Padgett (2001), Walker (1998/2000), and others claims that such gapped autosegmental configurations are universally ill-formed. According to this view, all spreading must respect strict segmental

locality. Skipping of segments in feature spreading is not permitted; therefore, a form such as that in (206) would be universally ruled out.

The Gestural Harmony Model's coactivation account of transparency encounters no such issues concerning gapped representations and locality of spreading. In this model, harmony is the result of either a persistent (non-self-deactivating) or anticipatory (early-activating) gesture extending to overlap undergoing segments. Even segments that appear to be skipped over by a harmony process are overlapped by a harmonizing gesture. However, this continuous activation of the harmonizing gesture is not perceived during the production of a transparent segment due to the effects of intergestural antagonism and blending. Because of this, locality of spreading can be maintained while also maintaining the idea that transparent segments surface without having taken on a harmonizing property.

4.7.2 Asymmetries in Attested Transparent and Blocking Segments

Many analyses of neutrality in harmony, both rule- and constraint-based, rely on the use of restrictions on featural co-occurrence to render certain segment types neutral to a harmony process. The Gestural Harmony Model rejects neutrality as a concept unifying both transparency and blocking, instead utilizing two distinct mechanisms to account for them. As a result, the model correctly predicts that the sets of attested transparent and blocking segments in a given type of harmony may be distinct. However, there are numerous feature-based analyses of harmony that utilize feature co-occurrence constraints to account for the ‘neutral’ status of both blockers and transparent segments. Though all of these approaches differ in the details of their implementation, without invoking additional theoretical assumptions they make the undesirable prediction that all segments that are attested as blockers for a certain type of harmony should also be able to be transparent to harmony as well. This runs contrary to the crosslinguistic patterns

observed among transparent and blocking segments in nasal harmony and rounding harmony, reported in section 4.2.

Phonetically grounded featural co-occurrence restrictions have long played a central role in analyses of transparency and blocking in harmony. In the rule-based framework developed by Archangeli & Pulleyblank (1994), certain segments may not undergo harmony processes because the set of targets of a spreading rule may be limited to those that obey a feature co-occurrence restriction. The only difference between blockers and transparent segments is in the format of the rule itself: blocking arises when a rule that inserts an association line between a feature and a segment is prevented from applying to a restricted target. In contrast, transparency arises when a rule inserts an additional token of a spreading feature on the other side of the transparent segment, allowing that feature to avoid associating with a potential target that would violate the rule's co-occurrence restriction.

Many OT analyses of neutrality in harmony are similar to Archangeli and Pulleyblank's approach in their use of feature co-occurrence constraints to motivate both transparency and blocking, though not necessarily in terms of featural insertion or copying. In several of these constraint-based models, segments are parsed into the domain of a harmonizing feature that is optimally aligned with a word edge. In Optimal Domains Theory (Cole & Kissoberth 1994, 1995), Headed Span Theory (McCarthy 2004, O'Keefe 2005), and Smolensky's (1993) theory of embedded feature domains, segments are parsed into feature domains that optimally span an entire word. Transparency arises when a segment in the domain of harmony does not bear the harmonizing feature due to the incompatibility of that harmonizing feature with one of the segment's other features. This incompatibility is captured by a feature co-occurrence constraint. In all of these theories, in order to motivate transparency the co-occurrence constraint must

outrank some constraint that requires all segments in a harmony domain to bear that domain's feature. In Optimal Domains Theory, this constraint is called EXPRESSION; in Headed Span Theory, it is ASSOCIATEHEAD; and in the theory of embedded feature domains, it is *EMBED.

A drawback of these accounts, which use feature co-occurrence constraints to capture both transparency and blocking effects, is that they incorrectly predict that the sets of attested blocking and transparent segments will be identical for a given harmony phenomenon. As discussed in sections 4.2 to 4.4 and by C. Smith (2016a), this is not the case for nasal harmony, in which all consonants are attested blockers but only obstruents are attested as transparent, and for rounding harmony, in which all vowels are attested blockers but only high front vowels are attested as transparent. I illustrate the issue with an example from Optimal Domains Theory, but it should be noted that this problem extends to all analyses that use feature co-occurrence to capture both blocking and transparency in harmony, whether rule- or constraint-based.

Cole & Kissoberth (1995) present a case of obstruent blocking of nasal harmony as the result of the ranking of the co-occurrence constraint *[Nasal, Obstruent] (no nasalized obstruents) and EXPRESSION (no transparency) over the harmony driving constraint WSA (Wide-Scope Alignment, aligning a feature domain with a relevant word edge). This is demonstrated in the tableau in (207) for the hypothetical input form /nata/. Following Cole & Kissoberth, parsing into a nasal feature domain is indicated by parentheses.

(207) Obstruent blocking due to a featural co-occurrence restriction

Input: /nata/	*[Nasal, Obstruent]	EXPRESSION	WSA(Right)
a. [(nā̃tā)]	*!		
b. [(nā̃tā)]		*!	
c. [(nā̃)ta]			**

Candidate (a) [nātā] parses all segments in the word into the nasal feature domain, where they surface as nasalized, satisfying WSA and EXPRESSION but violating *[Nasal, Obstruent], which prohibits the nasal feature from being realized on the obstruent [t]. Candidate (b) [nātā], the transparency candidate, parses all segments into the nasal domain, including the [t], but violates EXPRESSION by not nasalizing the [t] in order to satisfy *[Nasal, Obstruent]. Candidate (c) [nāta], the blocking candidate, neither parses the [t] into the nasal feature domain nor nasalizes it, violating WSA as the feature domain has not reached the right edge of the word. However, higher-ranked *[Nasal, Obstruent] and EXPRESSION are satisfied, and candidate (c) [nāta] is chosen as the winner.

Though they do not provide an example of transparency in nasal harmony, Cole & Kisseeberth state that transparency can be achieved by ranking *[Nasal, Obstruent] and WSA over EXPRESSION. This is illustrated by the tableau in (208), which subjects the candidates in the tableau in (207) to this new ranking. Now, the winner is the transparent candidate (b), [nātā], which violates only low-ranked EXPRESSION.

(208) Obstruent transparency due to a featural co-occurrence restriction

Input: /nata/	*[Nasal, Obstruent]	WSA(Right)	EXPRESSION
a. [(nātā)]	*!		
☞ b. [(nātā)]			*
c. [(nā)ta]		*!**	

However, obstruents are not the only attested blockers of nasal harmony, and *[Nasal, Obstruent] is not the only featural co-occurrence constraint necessary to capture the full range of nasal harmony blocking patterns (see Walker (1998/2000) for an overview). Liquids also frequently block nasal harmony, which would presumably be captured by the constraint *[Nasal, Liquid]. Liquid blocking of nasal harmony would thus be captured by the ranking *[Nasal,

Liquid], EXPRESSION >> WSA. However, this constraint set is also able to generate a nasal harmony system in which liquids are transparent to nasal harmony. This occurs under the ranking *[Nasal, Liquid], WSA >> EXPRESSION. The tableau in (209) demonstrates.

- (209) Liquid blocking and unattested liquid transparency due to a featural co-occurrence restriction

Input: /nala/	*[Nasal, Liquid]	EXPRESSION	WSA(Right)
a. [(nālā)]	*!		
b. [(nālā)]		*!	
☞ c. [(nā)la]			**
Input: /nala/	*[Nasal, Liquid]	WSA(Right)	EXPRESSION
a. [(nālā)]	*!		
☞ b. [(nālā)]			*
c. [(nā)la]		*!*	

In (209), the violation profile for the first input mirrors that of the tableau in (207), while the violation profile for the second input mirrors that of the tableau in (208). Crucially, the ranking *[Nasal, Liquid], WSA >> EXPRESSION selects a candidate with liquid transparency to nasal harmony. This is an undesirable outcome, as liquid (and other non-obstruent) transparency in nasal harmony is unattested according to Piggott (1992) and Walker (1998/2000). A simple reordering of constraints is able to classify any natural class of segments as either blockers or transparent segments based on that class's incompatibility with a harmonizing feature. This leads to the incorrect prediction that any segmental class that is attested as a blocker of some type of harmony may also be transparent to that type of harmony.

This overgeneration of predicted transparent segments is not unique to Optimal Domain Theory, however. Analyses of neutrality such as those proposed by Bakovic & Wilson (2000) and Walker (1998/2000) rely on frameworks that compare candidates exhibiting transparency to candidates with full harmony. They differ only in the mechanisms by which this comparison takes place. In Bakovic & Wilson's theory, inter-candidate comparison takes place because the

co-occurrence constraints that motivate segments' neutrality to harmony are targeted constraints (Wilson 2000, 2001, 2003). In Walker's theory, this comparison is situated within Harmonic Sympathy, as discussed in section 4.7.1. In both cases these mechanisms are triggered by high-ranking constraints on co-occurrence between a harmonizing feature and the features of a potential target. Because of this, both theories suffer from the same issue of overgeneration of possible transparent segment types discussed above for featural domain theories. Walker addresses this issue with her framework, suggesting a metric, based in perception and ease of acquisition, by which harmony systems with transparent segments can be evaluated, with systems with too many predicted transparent segments ruled out. However, this metric represents a bias against unattested patterns of transparency in harmony rather than an outright ban.

In contrast, the Gestural Harmony Model makes no such predictions as transparency and blocking are treated as the products of fundamentally different mechanisms with distinct functional groundings. Transparency in harmony is the result of the concurrent activation and subsequent blending of two antagonistic gestures, not an operation of the grammar. It is the underlying representation of obstruents as including a velum closure gesture that leads to their special status as the only attested transparent consonants in nasal harmony. Likewise, the representation of high front vowels as including a lip spreading gesture is responsible for their status as the only attested transparent vowels in rounding harmony. Co-occurrence constraints crucially play no role in rendering certain segment types transparent to harmony in the Gestural Harmony Model. Such restrictions do, however, come into play in the analysis of blocking of nasal harmony. By applying the use of co-occurrence restrictions only to the analysis of blocking segments, the Gestural Harmony Model is able to make different predictions about the types of segments that can be transparent versus those that can serve as blockers.

Other analyses of neutrality in feature-based frameworks, including those proposed by Kaun (1995) and Kimper (2011), have attempted to build segments' tendencies to be transparent or to block into the phonological grammar. This is achieved by positioning different segment types along a neutrality scale or continuum, with those segments most likely to block on one end and those most likely to be transparent on the other. While many of these approaches still utilize co-occurrence restrictions to determine that some segment is neutral to a given harmony process, its status as either a transparent or blocking segment is determined by its place on a neutrality continuum. However, the neutrality continuum approach also makes incorrect predictions about which segments may surface as transparent to harmony, again overgenerating predicted types of transparent segments in both rounding and nasal harmony. Furthermore, any attempt to construct a continuum of transparency and blocking for nasal harmony fails due to the special status of obstruents as both the most likely blockers and the most likely (in fact, only) transparent segments. The continuum approach generates several pathological patterns of neutrality in nasal harmony.

One of the first proposals that neutral segment behavior should be captured by a neutrality continuum is made by Kaun (1995). According to Kaun, certain segment types are better suited to being transparent to a harmony process than other segment types. In addressing this, she states the following:

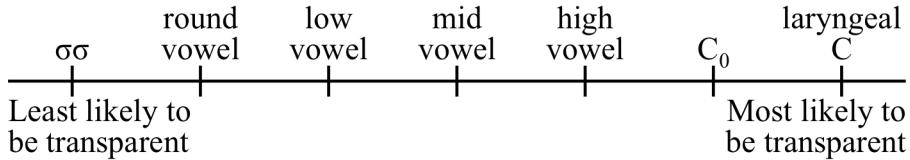
'Transparent elements are those elements which may occur during the span of some feature while still allowing for the interpretation of that span as a cohesive phonetic event...Elements or strings of segments may exhibit transparency if their occurrence does not constitute a substantial interruption of the signal associated with the extended feature' (p. 211).

Precisely what constitutes a substantial interruption remains undefined, however. One possibility is that it is the inherent length of a certain type of element that determines how

substantial an interruption it poses to an extended feature. Another possibility is that the notion of a substantial interruption of a featural span is perceptually defined; a related proposal regarding how speakers perceive harmony spans across transparent segments is made by Boersma (1998, 2003). In this case, a segment type that is a perceptually strong bearer of some featural contrast would present a greater interruption of a featural span than a weak bearer of that featural contrast. This is certainly the case in terms of the different patterning of consonants and vowels in vowel harmony. Consonants, as weak bearers of vocalic features such as rounding or tongue root position, are considered to be transparent to vowel harmony in the vast majority of cases, while vowels are transparent to harmony much less often. However, this does not extend to the distinction between vowel heights as posited in Kaun's continuum. In rounding harmony, for instance, high vowels are strong bearers of a rounding contrast, while nonhigh vowels are weak bearers of this contrast. This means that rounding is more perceptually salient when it occurs on high vowels. If this is the case, the perception of a high unround vowel such as /i/ as unround should be quite salient, while the unround quality of /e/ or /a/ should be less salient. If perceptual salience is tied to what constitutes a substantial interruption of a featural span, then unround /i/ would constitute a substantial interruption of a [+round] span relative to nonhigh unround vowels and would therefore be less likely to behave transparently in rounding harmony. This is in direct conflict with the typological facts of rounding harmony and the transparency continuum that Kaun constructs from those facts. This indicates that the likelihood of surfacing as transparent to vowel harmony is based on some factor other than a lack of perceptual salience, or that it is based on multiple factors, such as perceptual salience and length.

Whatever the basis of segments' positions along the neutrality continuum, Kaun infers these positions based on typological patterns of neutrality. Based on these patterns, she provides the neutrality continuum in (210):

- (210) Transparency continuum, modified from Kaun (1995, p. 214)



On one end of this continuum are laryngeal consonants, which are considered the most likely to be transparent to vowel harmony. Oral consonants are the next most likely segment type to be transparent to harmony, followed by vowels of various heights. The least likely elements to be transparent to harmony, and therefore most likely to serve as blockers, are series of two syllables containing neutral vowels. Kaun proposes that every language with harmony determines a cutoff point between transparent and blocking segments at some point along this continuum. This is implemented in the grammar via a family of CONTINUITY constraints, as defined in (211):

- (211) CONTINUITY_X : No element to the left of X on the transparency continuum may interrupt an extended feature domain. (Kaun 1995, p. 215)

CONTINUITY is an anti-transparency constraint; it penalizes skipping of a segment in a harmony process unless that segment is positioned sufficiently close to the right edge of the continuum in (210). Kaun proposes that there is a CONTINUITY constraint for each position along the transparency continuum.

When some markedness constraint is ranked above $\text{EXTEND}(F)$ (Kaun's harmony driving constraint, which like $\text{SPREAD}(F)$ (Padgett 1995; Walker 1998/2000) is evaluated by assigning

violation marks for non-undergoers), it prevents a segment from taking on a harmonizing feature. Whether this neutral segment acts as a blocker or is transparent to harmony is determined by the most stringent CONTINUITY constraint (i.e., the constraint that admits the fewest transparent segments) that is ranked above EXTEND.

Kaun uses this constraint set to account for the distinct patterning of neutrality in Mongolic and Tungusic rounding harmonies, both of which hold only among nonhigh vowels. According to Kaun, these language families differ in what type of neutrality high vowels exhibit in rounding harmony: in Mongolic languages, high front vowels are transparent, while in Tungusic languages, high front vowels are blockers. Kaun accounts for high vowel neutrality in both language families by ranking UNIFORM[round] over harmony-driving EXTEND(round)IF[-high]; these families differ in which CONTINUITY_X constraint is ranked above EXTEND, as in (212).

(212) Constraint rankings for high vowel transparency versus blocking

- a. Tungusic (consonants transparent, high vowels block):

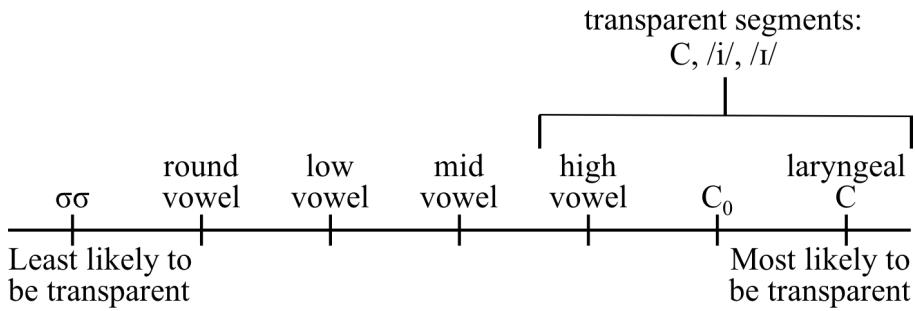
CONTINUITY_{C0}, GESTUNI >> EXTEND(+R)IF[-high]

- b. Mongolic (consonants and high vowels transparent):

CONTINUITY_{HighV}, GESTUNI >> EXTEND(+R)IF[-high] >> CONTINUITY_{C0}

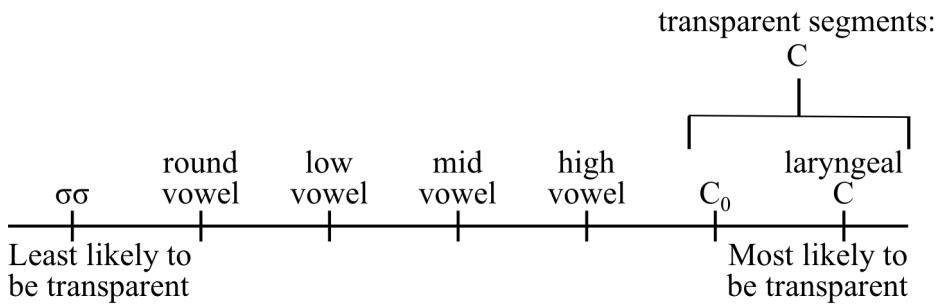
In Mongolic, the most stringent CONTINUITY constraint to outrank EXTEND is CONTINUITY_{HighV}, which sets the cutoff point along the transparency continuum between high and mid vowels, as in (213).

(213) Transparency continuum cutoff for Mongolic languages



In contrast, in Tungusic languages the most stringent CONTINUITY_X constraint to outrank EXTEND is CONTINUITY_{C_0} , resulting in a transparency continuum cutoff in which only consonants are transparent to rounding harmony, while any neutral vowels will block, as illustrated in (214).

(214) Transparency continuum cutoff for Tungusic languages



While this approach makes more constrained predictions than typical co-occurrence restriction-based analyses in accounting for certain segment types' tendencies to be transparent to or to block harmony, these predictions are still not constrained enough to capture the typological asymmetries observed in nasal and rounding harmonies (section 4.2). I illustrate the issue by applying Kaun's neutrality continuum theory to neutrality in Turkic rounding harmonies. As illustrated by the case of Tuvan rounding harmony in section 4.5.4, in Turkic languages neutrality is usually driven by a restriction on nonhigh round vowels and enforced by the constraint *RoLo (Kirchner 1993, Kaun 1995). With *RoLo above $\text{EXTEND}(+R)$, nonhigh vowels will be rendered neutral segments. In Tuvan and other Turkic languages, these nonhigh

vowels block rounding harmony, suggesting that CONTINUITY_{C0} is ranked above $\text{EXTEND}(+R)$. The result is a cutoff along the transparency continuum identical to that of the Tungusic languages; the only difference is in which vowels are determined to be neutral to rounding harmony.

However, with these constraints it is also possible to generate a rounding harmony system in which $\text{EXTEND}(+R)$ is outranked by the less stringent $\text{CONTINUITY}_{\text{LowV}}$, while CONTINUITY_{C0} is low-ranked. According to this ranking, nonhigh vowels are neutral to vowel harmony, and all unround neutral vowels (and consonants) are transparent. This pattern generated by the constraint ranking in (215b), in which nonhigh vowels such as /e/ and /a/ are transparent to rounding harmony, is unattested.

(215) Constraint rankings for nonhigh vowel transparency versus blocking

- a. Turkic (consonants transparent, nonhigh vowels block):

$\text{CONTINUITY}_{C0}, *_{\text{RoLo}} >> \text{EXTEND}(+R)$

- b. Unattested (consonants and nonhigh vowels transparent):

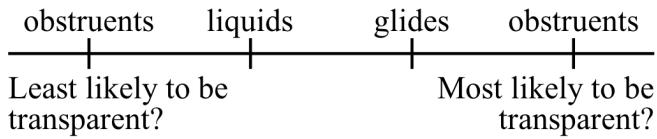
$\text{CONTINUITY}_{\text{LowV}}, *_{\text{RoLo}} >> \text{EXTEND}(+R) >> \text{CONTINUITY}_{C0}$

The neutrality continuum approach, then, does not avoid the overgeneration of harmony patterns with unattested types of transparent segments. While it is certainly true that high vowels are more likely to be transparent to rounding harmony than mid or low vowels, it is only because mid and low vowels are entirely unattested as transparent segments in rounding harmony. However, any analysis relying on a continuum of neutrality is unable to capture this, as it is designed to make use of the entire continuum and not just one edge of it.

In addition, the neutrality continuum approach is unable to accurately account for patterns of neutrality in nasal harmony, for which it is unclear how to even establish the

neutrality continuum. On one end, obstruents are the most likely segments to be transparent to harmony, due solely to the fact that they are the only type of segment that can be transparent to nasal harmony. They are also the most likely type of segments to block harmony, indicating that they should be simultaneously at either end of the neutrality spectrum. In addition, glides are the least likely to block nasal harmony but are unattested as transparent segments, and liquids are moderately likely to block nasal harmony but are also unattested as transparent segments, rendering their positions on the continuum unclear. Following the line of reasoning that lesser likelihood to block harmony translates to greater likelihood to be transparent to it, the continuum in (216) is the closest possible approximation of a neutrality continuum for nasal harmony.

(216) Pathological transparency continuum for nasal harmony

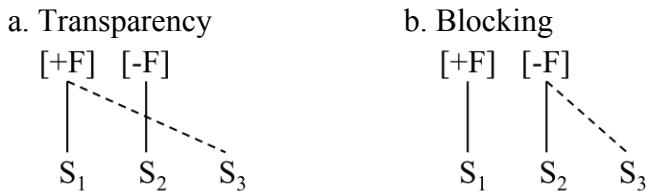


The use of this continuum leads to a number of pathological predictions about possible patterns of neutrality in nasal harmony. It predicts that not just obstruents, but all consonants should be able to surface as transparent to nasal harmony in some language. The unique patterning of obstruent transparency in nasal harmony is precisely what has led Walker (1998/2000) to build an implicational hierarchy of blocking behavior around the idea that transparent obstruents are best thought of as ‘permeable’ to nasal harmony, surfacing as transparent to harmony as a specially conditioned consequence of undergoing harmony. This is similar to the view of transparent segments in the Gestural Harmony Model, and is responsible for accurately accounting for the status of obstruents as the only segment type that is able to be

transparent to nasal harmony. The use of a neutrality continuum, by contrast, generates a number of pathological patterns of neutrality in nasal harmony.

Kimper's (2011) competing triggers analysis of neutrality to harmony bears some similarity to Kaun's neutrality continuum approach. In Kimper's framework, blocking of the spread of a feature [+F] is modeled as triggering of the spread of the opposite feature value [-F]. When a harmony process encounters a neutral segment, the choice between transparency and blocking comes down to competition between the segment bearing feature value [+F] and the neutral segment bearing feature value [-F] to determine which will trigger further feature spreading. This is illustrated in (217).

(217) Transparency and blocking as the result of competing triggers



In (217), S_3 is the target of harmony and S_2 is a segment that is neutral to a harmony process that spreads the feature value [+F]. According to the competing triggers analysis, S_1 and S_2 compete to determine which will associate its feature specification to segment S_3 . In (217a), S_1 wins the competition to spread its feature value onto S_3 , and S_2 surfaces as transparent to the spread of [+F]. In (217b), on the other hand, S_2 wins this competition, and spreads [-F] onto segment S_3 . This renders it a blocker of the spread of [+F].

Kimper's competing triggers analysis of harmony is situated within the framework of Serial Harmonic Grammar (Kimper 2011; Mullin 2011; Pater 2012), a variant of Harmonic Serialism (McCarthy 2000, 2008a, 2008b; McCarthy & Pater 2016) in which constraints are weighted rather than ranked. In this framework, harmony is driven by a positively-defined

constraint SPREAD(F), which assigns rewards for undergoers of harmony rather than violations for non-undergoers. When a segment is prevented from undergoing harmony due to the ranking of a relevant markedness or faithfulness constraint above SPREAD(F), that segment will surface as neutral to harmony. In such cases, in order to choose between candidates displaying transparency versus blocking, as in (217), Kimper adopts scaling conditions that alter the amount of reward incurred by SPREAD(F). One of these scaling conditions increases the reward incurred by SPREAD(F) according to the degree of perceptual impoverishment of the trigger. When a reward incurred by spreading feature [-F] from a neutral segment, as in (217b), is greater than the reward incurred by spreading a feature [+F] across a neutral segment, blocking occurs. Therefore, a segment's likelihood to either act as a blocker of harmony or to permit transparency is determined by its placement on a scale of perceptual impoverishment.

In this way, Kimper's approach mirrors Kaun's (1995) appeal to a continuum of likelihood to be transparent or to block harmony. One set of constraints determines whether a segment is neutral, and another determines where along a scale or continuum to draw the line between transparent and blocking segments. As a result, the issues that arise with the neutrality continuum are mirrored by the competing triggers framework. There is nothing constraining the values of the scaling factors of SPREAD(F) such that they wholly prevent certain types of segments from ever surfacing as transparent to harmony. Instead, the competing triggers framework is only able to represent relative likelihood of a segment to be transparent or to block harmony. In addition, there remains the ambiguity of obstruent placement on any scale necessary to analyze transparency and blocking in nasal harmony. The Gestural Harmony Model avoids these issues by recasting transparent segments as undergoers of harmony, rather than as a type of neutral segment.

4.7.3 Harmony Systems with Transparency and Blocking

Another area in which analyses of harmony can be distinguished is in their ability to account for harmony systems in which some segments are transparent and some are blockers. This is the case in many harmony systems, including Halk Mongolian rounding harmony (Svantesson 1985; Svantesson et al. 2005), discussed in section 4.5.2, Coatzospan Mixtec nasal harmony (Gerfen 1999, 2001), and Menominee ATR harmony (Archangeli & Pulleyblank 1994; Archangeli & Suzuki 1995). Because the Gestural Harmony Model splits transparency and blocking among two distinct theoretical mechanisms, in this model the two mechanisms may operate concurrently within a single harmony system. As a result, the Gestural Harmony Model is able to account for such patterns. Feature-based analyses of harmony, however, meet with mixed success in accounting for such patterns.

An issue with many featural accounts of neutrality in harmony lies in their reliance on the relative ranking of constraints to determine whether neutral segments in a given harmony system will be transparent or blocking segments. In Optimal Domains Theory (Cole & Kissoberth 1994, 1995), for instance, the ranking of anti-transparency EXPRESSION over harmony-driving WSA determines that any neutral segments in a harmony system will be blockers, while the reverse ranking determines that any neutral segments will be transparent to harmony. This property is shared by Bakovic & Wilson's (2000) analysis of transparency and blocking in harmony using targeted versions of AGREE (Baković 2000). In their theory, segments are neutral to harmony if a co-occurrence constraint prevents them from taking on a harmonizing feature value; whether that segment is transparent to or blocks harmony is determined by the relative rankings of different types of AGREE constraints. If an AGREE constraint requiring a neutral segment to agree with both adjacent segments for feature F is ranked higher, blocking is generated; if an AGREE

constraint requiring a neutral segment to agree with only one adjacent segment is ranked higher, transparency is generated.

However, this sort of broad determination of what type of neutrality a harmony system will exhibit is unable to account for harmony systems exhibiting both transparency and blocking. By splitting transparency and blocking among two distinct theoretical mechanisms, the Gestural Harmony Model allows these mechanisms to operate independently, and in some cases concurrently. This is the case in Halk Mongolian rounding harmony (section 4.5.2), in which high front vowels are transparent to harmony due to their inclusion of a lip spreading gesture that is antagonistic to harmonizing lip protrusion gestures, and high back vowels blocking harmony due to a constraint against their concurrent activation with lip protrusion gestures.

This success is shared by approaches that rely on a continuum or scale of segment neutrality, such as those proposed by Kaun (1995) and Kimper (2011), discussed in greater detail in section 4.7.2. Both of these frameworks are able to account for concurrent transparency and blocking. Regarding Halk Mongolian, Kaun claims that while both front and back high vowels are rendered neutral to rounding harmony by high-ranked UNIFORM[round], preventing cross-height harmony, they occupy different positions on her proposed transparency continuum and are on opposite sides of the transparency cutoff point put in place by the constraint CONTINUITY_{HighV}, depicted in the figure in (213) in section 4.7.2. In other frameworks there is one constraint that determines whether a segment type is neutral to harmony and another constraint that determines whether the harmony system as a whole exhibits transparency or blocking. In contrast, in Kaun's transparency continuum framework, markedness constraints such as UNIFORM[round] and *RoLo determine which segments are neutral to harmony, and CONTINUITY_X constraints determine which segments are transparent and which block.

Analyses of transparency and blocking utilizing Agreement by Correspondence are also successful in accounting for harmony systems exhibiting both transparency and blocking. Such analyses are proposed by Rhodes (2012) for Halk Mongolian rounding harmony and by Walker (2009, 2018) for Menominee ATR harmony. In Agreement by Correspondence, harmony is driven as agreement between segments that are in surface correspondence relations. Transparency results from a lack of surface correspondence between dissimilar segments, while blocking results when similar segments are in correspondence but do not agree with one another. Crucially, both of these configurations may arise in the same language. Like the Gestural Harmony Model, the Agreement by Correspondence framework is successful in this regard because it relies on two distinct theoretical mechanism to account for transparency and blocking.

4.7.4 *Partial Harmony and Sour Grapes*

Different analyses of harmony also make distinct predictions in the generation of ‘sour grapes’ patterns of harmony. Originally coined by Padgett (1995), the term sour grapes refers to patterns in which a harmonizing feature either spread throughout a domain, or not at all. That is, harmony will not be triggered when a blocker is present in a word and harmony is unable to reach the edge of a domain. As pointed out by Wilson (2003) and McCarthy (2003a, 2004), such patterns are predicted by analyses that rely on the use of harmony drivers requiring adjacent segments to agree for some feature value, such as AGREE (Baković 2000; Mahanta 2007, 2009; Finley 2008, 2010).

This is demonstrated by the tableau in (218). The constraint AGREE(round) is ranked above IDENT(round)-IO, resulting in rounding harmony. However, ranking of the constraint *y over AGREE(round) prevents the vowel high front vowel /i/ from undergoing this process. As a result of the presence of this blocking segment, harmony is prevented altogether.

(218) Tableau with sour grapes due to presence of a blocker

Input: /o-a-i/	*y	AGREE(round)	IDENT(round)-IO
a. [o-o-y]	*!		**
b. [o-o-i]		*	*
c. [o-a-i]		*	

In candidate (a), all vowels surface as rounded, satisfying the harmony driving constraint AGREE(round), but fatally violating higher-ranked *y. In candidate (b), rounding spreads onto the second vowel, which surfaces as [o], but not the third vowel, which surfaces faithfully as [i]. This satisfies *y, but violates AGREE(round) because it includes a round-nonround vowel sequence. In candidate (c), harmony is not triggered, and all vowels surface faithfully. Of note is that this candidate also contains a round-nonround vowel sequence, and therefore also violates AGREE(round). Because candidates (b) and (c) perform equally well with respect to the constraint AGREE(round), the decision between these candidates falls to the constraint IDENT(round)-IO. This constraint favors the candidate with no harmony, as it is the most faithful to the input.

The tableau in (218) demonstrates that local agreement constraints such as AGREE(F) encounter issues with both over- and undergeneration of blocking patterns in harmony. The set of constraints utilized here generates unattested sour grapes, while at the same time is unable to generate robustly attested patterns of partial harmony with blocking. The candidate exhibiting partial harmony is harmonically bounded, indicating that this set of constraints does not generate partial harmony under any constraint ranking. Various strategies to avoid this undesirable prediction have been employed. Bakovic & Wilson (2000) propose that blocking can be generated in an analysis in which the markedness constraints that prevent segments from undergoing harmony are targeted (on targeted constraints, see Wilson (2000, 2001, 2003)). However, McCarthy (2002) argues against the effectiveness of targeted constraints in constraining typological predictions when large sets of candidates are considered. Finley (2008,

2010), on the other hand, proposes that partial harmony can be generated, and sour grapes patterns avoided, by assuming that local agreement constraints are evaluated directionally, i.e., by scanning an output candidate either left-to-right or right-to-left. Such directional constraint evaluation is proposed by Eisner (2000). Under this proposal, a constraint like $\text{AGREE}(F)$ could be defined such that a candidate's violations of the constraint are less costly the further they occur from the trigger of harmony. While this approach does successfully generate patterns of partial harmony, the broader typological consequences of admitting this sort of directional constraint evaluation into OT remain largely unexplored.

In contrast, maximal harmony drivers that require a harmonizing feature to be associated with as many segments in a domain as possible, such as $\text{ALIGN}(F)$, $\text{EXTEND}(F)$, and $\text{SPREAD}(F)$, generate partial harmony without issue and do not predict sour grapes patterns. In contrast with local agreement constraints, maximal harmony drivers assign fewer violations to candidates in which fewer segments fail to undergo a harmony process. As a result, such constraints are able to account for harmony patterns in which a harmonizing feature spreads as far as it can within a domain, and stops when it reaches either a blocker or a domain edge.

The Gestural Harmony Model is only partially successful in accounting for partial harmony without sour grapes. This chapter has provided analyses of several harmony systems in which a harmonizing gesture extends in activation until it is inhibited by a blocker. See, for example, the analyses of nasal harmony in Orejón (section 4.4.3) and Capanahua (section 4.4.4), rounding harmony in Baiyina Oroqen (section 4.5.3) and Tuvan (section 4.5.4), and tongue root harmony in Standard Yoruba (section 4.6.2). These analyses indicate that the Gestural Harmony Model is capable of generating patterns of partial harmony with blocking, avoiding the undergeneration issue encountered by many analyses that rely on local agreement constraints to

drive harmony. However, the model does not avoid those constraints' issue with overgeneration; it also predicts that sour grapes patterns of harmony are generated under certain constraint rankings.

As discussed throughout chapter 4, in the Gestural Harmony Model blocking results when a grammar ranks a constraint from the *OVERLAP family over *INHIBIT. A sour grapes pattern arises when both of these constraints outrank a constraint requiring a gesture to surface as persistent or anticipatory. Under such a ranking, the grammar favors candidates in which the overlap of incompatible gestures is prevented not by intergestural inhibition, but by not triggering harmony at all. This is illustrated by the tableau in (219).

(219) Tableau with sour grapes due to high-ranked *OVERLAP and *INHIBIT

Input: / o ₁ a ₂ i ₃ /	Tongue Body pharyngeal wide ₁	Tongue Body pharyngeal wide ₂	Tongue Body palatal narrow ₃	*OVERLAP(high V, persistent LP)-IO	*INHIBIT	PERSIST(LP)
	Tongue Body pharyngeal wide ₁	Tongue Body pharyngeal wide ₂	Tongue Body palatal narrow ₃			
	Lip protrusion ₁					
a.	[o ₁ o ₂ y ₃]	Lip protrusion ₁		*!		
b.	[o ₁ o ₂ i ₃]	Lip protrusion ₁		*		
c.	[o ₁ a ₂ i ₃]	Lip protrusion ₁				*

In (219), candidate (a) [o-o-y] contains a persistent lip protrusion gesture that is not inhibited by the high front vowel, resulting in full harmony and a fatal violation of high-ranked *OVERLAP(high V, persistent LP). In candidate (b), the high front vowel blocks rounding harmony via inhibition of the lip protrusion gesture, incurring a violation of *INHIBIT. In the winning candidate (c), the lip protrusion gesture surfaces as self-deactivating and does not trigger rounding harmony. This violates low-ranked PERSIST(lip protrusion), but satisfies both higher-ranked oconstraints *OVERLAP(high V, persistent LP) and *INHIBIT.

While the Gestural Harmony Model is able to generate patterns of partial harmony with blocking, this tableau demonstrates that the model also predicts the possibility of sour grapes spreading when constraints like *OVERLAP and *INHIBIT are ranked sufficiently high. One possible solution to this issue is a reconceptualization of intergestural inhibition as the result of one type of gesture being specified as a deactivator of another type of gesture, rather than as a means of satisfying constraints from the *OVERLAP family. This possibility is discussed further in section 6.2.2.

4.7.5 *Non-Undergoers of Harmony*

The final comparison of model predictions concerns the status of non-undergoers of harmony in different frameworks, and how different treatments of non-undergoers make distinct typological predictions. Wilson (2003) and McCarthy (2004) show that maximal harmony drivers generate several pathological patterns by which the phonological grammar minimizes the number of segments that do not undergo harmony due to the presence of a blocker in an output form. This arises due to these constraints' assigning violations to all non-undergoer segments within some domain, regardless of their distance from a harmony trigger. Walker argues that this non-locality between triggers and targets is an asset in generating some patterns of triggering, as discussed in section 3.4.2. However, this same non-locality also leads to pathologies in blocking.

This is illustrated by the tableau in (220), adapted from an illustration by Wilson (2003, p. 3). In this hypothetical nasal harmony system, nasal harmony proceeds through sonorants and is blocked by obstruents. When the constraint that drives this harmony, SPREAD(nasal), is ranked above another constraint motivating epenthesis, *CC, epenthesis occurs when the resulting segment undergoes harmony, and does not occur when the resulting segment is inaccessible to a

spreading nasal feature due to the presence of a blocker. A high-ranked feature co-occurrence constraint is assumed to motivate the blocking of nasal harmony by obstruents.

(220) Tableau with deletion of non-undergoers after a blocker

Input: /nawal-t/	SPREAD(nasal)	*CC
a. [nãwãl̩-t]	*	*
☞ b. [nãwãl̩-ət]	*	
Input: /nawak-t/		
☞ a. [nãwãk-t]	**	*
b. [nãwãk-ət]	**!**	

For the first input in (220), the winning candidate is candidate (b) [nãwãl̩-ət], in which epenthesis breaks up a consonant cluster and nasality spreads onto the epenthetic vowel. However, the stem of the second input ends in an obstruent. Now the winner is candidate (a), in which epenthesis does not apply. While candidate (b) satisfies *CC, epenthesis results in an additional fatal violation of SPREAD(nasal) because the epenthetic vowel is blocked from undergoing nasal harmony by the stem-final obstruent [k]. Wilson (2003) and McCarthy (2004) argue that this issue extends beyond blocked epenthesis to include additional pathologies involving the minimization of the number of non-undergoer segments in a word.

The Gestural Harmony Model, on the other hand, does not generate pathologies related to the minimization of non-undergoer segments. As discussed in section 3.2, the constraints PERSIST(Gest_X) and ANTICIPATE(Gest_X) are satisfied when a gesture of type X surfaces as persistent and anticipatory, respectively. Whether a persistent or anticipatory gesture actually overlaps any other segments in a word is irrelevant. As a result, there is no motivation to minimize the number of non-undergoers of harmony when harmony is blocked, as is the case for constraints that drive maximal spreading of a feature. This is an asset to the Gestural Harmony

Model, as it allows the model to avoid the generation of the harmony pathologies identified by Wilson (2003) and McCarthy (2004).

4.8 Summary

One of the primary strengths of the Gestural Harmony Model lies in its distinct representations of transparent and blocking segments, as evidenced by the discussion of various types of harmony throughout this chapter. Key to the success of this model lies in its division of the representations of transparency and blocking between two distinct theoretical mechanisms. Relying on the Task Dynamic Model's concepts of gestural competition and blending, transparency is represented in the Gestural Harmony Model as the result of the concurrent activation of antagonistic gestures. In this sense, transparent segments are undergoers of harmony, albeit undergoers that are able to temporarily counteract the effect of a harmonizing gesture upon the state of the vocal tract. Blocking, on the other hand, is the result of a ban on the overlap of incompatible gestures, whose concurrent activation is either articulatorily or perceptually marked in some way. This ban on the overlap of incompatible gestures is implemented by a newly proposed intergestural relation by which gestures inhibit one another's levels of activation. The presence of such inhibition relations is motivated by constraints in the phonological grammar.

Because transparency and blocking are split among two different theoretical mechanisms and have different motivations underlying them, the Gestural Harmony Model makes distinct predictions with respect to what types of segments are able to surface as transparent or blocking segments. In nasal harmony and rounding harmony, gestural antagonism between a transparent and a harmonizing gesture arises from a small set of segment type, while gestural incompatibility with a harmonizing gesture arises from a larger set of segment types. Obstruents are the only

segments attested as being transparent to nasal harmony, and the only types of segments that include a velum closure gesture that renders them antagonistic to a nasal harmony triggering velum opening gesture. High front vowels are the only segments attested as being transparent to rounding harmony, and the only types of segments that include a lip spreading gesture that renders them antagonistic to a rounding harmony triggering lip protrusion gesture. In contrast, there is no restriction on which types of segments may inhibit one another; any type of gesture may inhibit any other type of gesture provided that inhibition is motivated by *OVERLAP constraints in the phonological grammar. Because of this, the types of segments that are predicted by the Gestural Harmony Model to serve as blockers of harmony is less constrained relative to the types of segments that are predicted to surface as transparent to harmony. In capturing the crosslinguistic asymmetries in nasal and rounding harmony discussed in section 4.2, this is a desirable prediction of the Gestural Harmony Model. Featural analyses that assume the unitary concept of neutrality to harmony and treat transparent and blocking segments simply as two possible types of neutral segments, on the other hand, do not match these predictions.

The splitting of the mechanisms responsible for transparency and blocking also ensures that the Gestural Harmony Model is able to generate harmony systems that display both transparency and blocking. This was exemplified by the examination of Halk Mongolian rounding harmony in section 4.5.2. While transparency arises directly from segments' gestural representations, blocking is a product of the phonological grammar. By occupying distinct theoretical spaces, the mechanism responsible for transparency and blocking are able to operate concurrently with one another. Featural analyses that assume no such split between transparency and blocking, meanwhile, meet with mixed success in accounting for these systems.

A major source of the success of the Gestural Harmony Model in accounting for typological asymmetries between transparent and blocking segments lies in its reliance on the concepts of intergestural competition and blending in its representation of transparency. Chapter 5 presents a more in-depth examination of these concepts, both in terms of how they are implemented by the Task Dynamic Model of Speech Production and the role they play in the phonological grammar.

Appendix B: Constraint Definitions

This appendix contains definitions for all of the constraints used in the analyses presented in chapter 4.

*INHIBIT: Assign a violation mark to an inhibition relation between gestures in a coupling graph.

*INHIBIT(glide, velum opening): Assign a violation mark for an inhibition relation between a glide and a velum opening gesture.

*INHIBIT(sonorant C, velum opening): Assign a violation mark for an inhibition relation between a sonorant consonant and a velum opening gesture.

*INHIBIT(oral C, velum opening): Assign a violation mark for an inhibition relation between an oral consonant and a velum opening gesture.

*OVERLAP(oral C, velum opening): Assign a violation mark to the gesture(s) of an oral consonant that is/are active concurrently with a velum opening gesture.

*OVERLAP(nonhigh vowel, lip protrusion): Assign a violation mark to a nonhigh vowel gesture and a lip protrusion gesture that are concurrently active.

*OVERLAP(front vowel, lip protrusion): Assign a violation mark to a front vowel gesture and a lip protrusion gesture that are concurrently active.

*OVERLAP(high back vowel, persistent lip protrusion): Assign a violation mark to a high back vowel gesture that is active concurrently with a persistent lip protrusion gesture.

*OVERLAP(nonhigh vowel, lip protrusion): Assign a violation mark to a nonhigh vowel gesture and a lip protrusion gesture that are concurrently active.

*OVERLAP(lip protrusion; high V, nonhigh V): Assign a violation mark to a lip protrusion gesture that is active concurrently with both a high vowel gesture and a nonhigh vowel gesture.

*OVERLAP(lip protrusion; high V, nonhigh V): Assign a violation mark to a lip protrusion gesture that is active concurrently with a high vowel gesture followed by a nonhigh vowel gesture.

*OVERLAP(high vowel, persistent lip protrusion): Assign a violation mark to a high vowel gesture and a persistent lip protrusion gesture that are concurrently active.

*OVERLAP(high vowel, tongue root retraction): Assign a violation mark to a high vowel gesture and a tongue root retraction gesture that are concurrently active.

*OVERLAP(low vowel, tongue root advancement): Assign a violation mark to a low vowel gesture and a tongue root advancement gesture that are concurrently active.

*COUPLE(nonhigh short V, self-deactivating lip protrusion)

LICENSE(velum closure, glottis open): Assign a violation mark to a velum closure gesture that is not active concurrently with glottal opening gesture.

LICENSE(lip protrusion, first σ): Assign a violation mark to a lip protrusion gesture that is not in an initial syllable.

MAX(velum closure)-IO: Assign a violation mark to a segment (set of gestures) that includes a velum closure gesture in the input if its output correspondent does not include that gesture.

MAX(lip protrusion)-IO: Assign a violation mark to a segment (set of gestures) that includes a lip protrusion gesture in the input if its output correspondent does not include that gesture.

IDENT(deactivation)-IO: Assign a violation mark to a gesture whose input and output correspondents do not have identical deactivation specifications.

PERSIST(lip protrusion): Assign a violation mark to a lip protrusion gesture that is self-deactivating.

SELFDEACTIVATE: Assign a violation mark to a gesture that is not self-deactivating.

Chapter 5

A Closer Look at Gestural Strength

5.1 Introduction

The concepts of intergestural competition and blending adopted into the Gestural Harmony Model from the Task Dynamic Model of speech production (Saltzman & Munhall 1989) are crucial to the representation of transparency to harmony in chapter 4. A segment is predicted to be able to surface as transparent to a harmony process only if its gestural makeup includes a gesture that is antagonistic to a harmonizing gesture. The result of this antagonism is intergestural competition for control over the state of a vocal tract articulator. In this analysis of transparency, the gesture of the transparent segment is always assumed to be stronger than the harmonizing gesture that overlaps it, resulting in its ability to temporarily counteract the effect of the harmonizing gesture on the vocal tract.

In this chapter, I provide a fuller explanation of how the results of intergestural competition are calculated from gestures' specified individual strengths and target articulatory states. By defining intergestural competition, blending, and strength more explicitly, the validity of the Gestural Harmony Model's analysis of transparency is further strengthened. Another aspect of this chapter's strengthening of the claim that intergestural competition can result in transparency involves the computational modeling of the articulatory trajectories and acoustic outputs of concurrently active antagonistic gestures. This modeling is conducted in TADA (Nam, Goldstein, Saltzman, & Byrd 2004), a MATLAB-based implementation of the Task Dynamic Model of speech production.

I also challenge the assumption that transparency to harmony solely involves configurations in which a transparent gesture is sufficiently strong to fully counteract the effect of a harmonizing gesture upon the vocal tract. Gestural strength, as it is defined within the Task Dynamic Model of speech production, is a gradient property. As such, it is predicted that cases of *partial transparency* should also arise from this model. Such a case of partial transparency to harmony is plausibly attested in the faecal harmony of Coeur d'Alene Salish.

In addition, in this chapter I examine the role that gestural strength may play in the phonological grammar. Gestural strength is not merely a device that is employed in the calculations of the Task Dynamic Model; it is a parameter that makes up part of the specification of the phonological unit of the gesture. As such, there is no reason to assume that this parameter is invisible to phonology. In particular, I focus on cases in which gestural strength appears to serve a contrastive function and examine what sorts of phonological patterns this contrastive gestural strength generates. Analyses based on contrastive gestural strength are proposed for patterns of vowel retraction in Coeur d'Alene Salish faecal harmony, as well as two vowel-consonant assimilation processes in Barrow Inupiaq.

The chapter is organized as follows. Section 5.2 provides more formal definitions of gestural blending and gestural strength within the Task Dynamic Model. It also introduces the TADA model and demonstrates how it can be used to computationally model the blending of gestures with antagonistic target articulatory states that results in transparency to harmony. The following two sections provide phonological analyses that demonstrate the utility of gestural strength as a phonologically active parameter. Section 5.3 is an examination of faecal harmony in Coeur d'Alene Salish, which serves as an interesting example of partial transparency to harmony. It also introduces the possibility of contrastive gestural strength. This ability of

gestural strength to be contrastive is further explored in section 5.4 with a case study of two phonological processes in Barrow Inupiaq. This case study examines the advantages of adopting contrastive gestural strength as a possible explanation for cases of apparently exceptional application of phonological processes. Section 5.5 concludes.

5.2 Gestural Strength in the Task Dynamic Model of Speech Production

5.2.1 *Formal Definition of Gestural Strength*

Discussions of gestural strength thus far have been largely informal in nature, referring to gestures as ‘strong’ or ‘weak,’ and describing their influence on one another in terms of ‘competition.’ While these terms are descriptively useful, it is difficult to assess their theoretical status or to examine the predictions they make without more explicit definitions. In this section, I present these formal definitions.

Articulatory Phonology (Browman & Goldstein 1986, 1989, et seq.) assumes that during the period of time in which a gesture is active, it gradually and asymptotically achieves its target articulatory state. The time course of the achievement of this target articulatory state is determined by a dynamically defined equation of motion, provided in (221).

(221) Dynamically defined equation of motion

$$\ddot{x} = -k(x - x_0) - b\dot{x}$$

In this equation, x represents the current tract variable value, while x_0 represents the value of this tract variable that is the gesture’s target articulatory state. The \dot{x} represents the first derivative (velocity) of the gesture’s attainment of its target state, while \ddot{x} represents its second derivative (acceleration). The b in this equation is a damping constant, which ensures that the tract variable value x will asymptotically approach its target articulatory state x_0 , rather than oscillating around it. As discussed in section 1.2.1, k represents the gesture’s stiffness parameter,

which determines how quickly a gesture approaches its target articulatory state. While a gesture is active, this equation of motion determines the state of the vocal tract with respect to the specific tract variable referred to by the parameter x .

As discussed throughout chapter 4, concurrently active antagonistic gestures, i.e., those with conflicting target articulatory states, enter into a state of competition with one another. This competition is formalized as the blending of these two antagonistic gestures. The blending of two gestures is calculated as the weighted averaging of the values of the parameters referenced in the two gestures' individual dynamically defined equations of motion. The parameters referenced by that equation are the gestures' respective target articulatory states x_0 and their respective stiffness values k . The weighted averaging of these values is determined by each gesture's strength, denoted α . After two gestures' α values are normalized such that they add up to 1, the blending of those gestures' individual target articulatory states is calculated as in (222).

(222) Blending of target articulatory states of gestures i and j

$$x_{0ij} = (x_{0i} * \alpha_i) + (x_{0j} * \alpha_j)$$

Likewise, the blending of two gestures' individual stiffness parameter values is calculated as in (223). Again, this equation uses normalized α values that add up to 1.

(223) Blending of stiffness parameter values of gestures i and j

$$k_{ij} = (k_i * \alpha_i) + (k_j * \alpha_j)$$

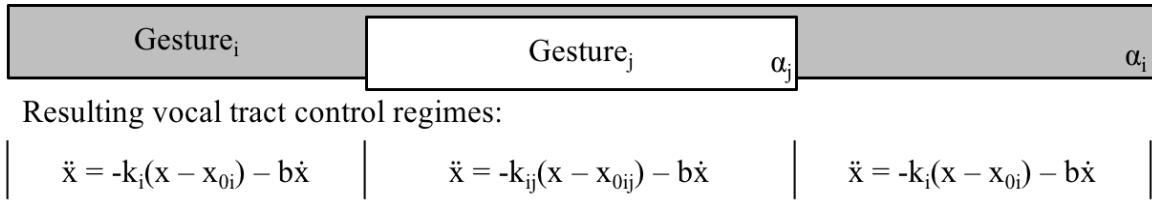
From these blended values for x_0 (target articulatory state) and k (stiffness), a new equation of motion describing the achievement of the blended target articulatory state of two gestures can be stated as in (224).

(224) Blended equation of motion

$$\ddot{x} = -k_{ij}(x - x_{0ij}) - b\dot{x}$$

If each active gesture is viewed as a control regime that holds over the vocal tract and is defined by a dynamic equation of motion, then the blending of two gestures can be viewed as the creation of a new blended control regime for the vocal tract that holds throughout the period of time during which the two blended gestures are concurrently active. This is depicted in (225).

(225) Gestural score with resulting blended vocal tract control regimes



The proposals made regarding transparency as intergestural competition in chapter 4 can now be restated more formally. In section 4.4.2, for instance, I propose that an obstruent is transparent to nasal harmony in Tuyuca because it includes a strong velum closure gesture that competes with and counteracts the effect of the harmonizing, relatively weak velum opening gesture that overlaps it. More formally, a strong velum closure gesture is one with a high α value, while a weak velum opening gesture has a relatively lower α value. The ‘competition’ between the two gestures is formalized as gestural blending according to the equations in (221)-(224), and ‘winning’ an intergestural competition occurs when one gesture’s target articulatory state is favored by the weighted averaging of the blending function in (222). Implemented as a weighted averaging function, gestural blending does not represent a case in which a strong gesture wholly overpowers a weak gesture. Rather, the equation of motion that results from the blending of the two gestures more closely resembles that of the gesture with the higher value of α .

Demonstrating this result via computational modeling of the Task Dynamic Model of speech production is the subject of the following section.

5.2.2 Computational Modeling of Transparency to Nasal Harmony

In this section I report the results of computational modeling of transparency via the concurrent activation of antagonistic gestures. To put the Gestural Harmony Model's analysis of transparency to the test, simultaneous activation of velum opening and velum closure gestures of various strengths were modeled in TADA (Nam et al. 2004), a MATLAB-based implementation of the Coupled Oscillator Model and the Task Dynamic Model of speech production.

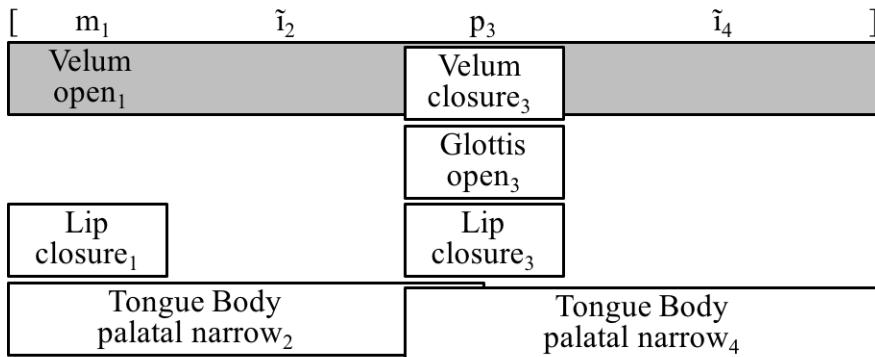
From the activation durations and gestural specifications in a gestural score, including each gesture's target articulatory state and strength parameter, TADA calculates the articulatory trajectories necessary to achieve the target articulatory states specified for each gesture in a gestural score according to the workings of the Task Dynamic Model of speech production. In addition, it generates the acoustic output of the vocal tract shapes produced by the movements of the articulators.

Recall from section 4.4.2 that in Tuyuca voiceless obstruents are transparent to nasal harmony. This is illustrated by the data in (226), repeated from (130a-d) in section 4.4.2.

- (226) a. [m̩p̩i] 'badger'
b. [w̩t̩i] 'demon'
c. [j̩uk̩ã] 'yucca soup'
d. [j̩os̩õ] 'bird'

TADA was used in order to test whether Tuyuca forms such as [m̩p̩i] 'badger' can indeed be produced with a closed velum for the transparent [p] despite being produced during the extended activation of a harmonizing velum opening gesture, as proposed in section 4.4.2. To do this, a gestural score with the gestural specifications and durations in (227) was input to TADA.

(227) Gestural score input to TADA

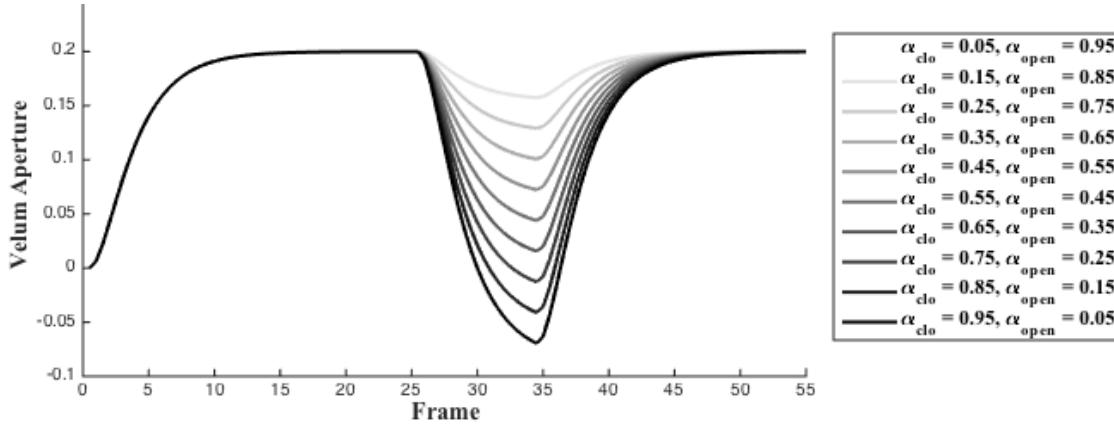


The simulated [m̩p̩] output by TADA is 55 frames (550 ms) long, with the velum opening gesture active throughout that entire length of time. During frames 25 to 34, the velum closure gesture is active as well. The target articulatory states of both gestures are specified relative to velum aperture; however, they have different target values for the state of the velum. Therefore, the resulting velum aperture tract variable that governs the state of the velum during this time period is a weighted average of the velum aperture specifications of the two gestures according to their α values. According to the gestural parameters built into TADA, the velum opening gesture is specified for a target aperture of 0.2, while the velum closure gesture is specified for a target aperture of -0.1.³⁶ These values are abstract, and their precise values are not crucial here; what matters is that the target values for each gesture are distinct, with one specified for an open velum, and the other a closed velum.

Velum closure gestures of various strengths were input to the model in order to examine how gestural strength affects the resolution of the antagonism between the velum opening and velum closure gestures. By varying the relative α values for the velum opening and velum closure gestures of [m̩p̩], the velum aperture trajectories displayed in (228) were obtained.

³⁶ A target constriction degree with a negative value indicates a tight closure.

- (228) TADA modeling of velum aperture for antagonistic gestures of different relative strengths



While the velum opening gesture alone is active, the velum approaches its goal aperture of 0.2. However, during frames 25 to 34, the velum closure gesture is active and its goal velum aperture is blended with that of the velum opening gesture. During this period, velum aperture is reduced to varying degrees according to the gestures' relative α values. For the first simulation (in lightest gray), the α value of the velum closure gesture is quite small relative to the α value of the velum opening gesture, and very little change in velum aperture takes place. This can be contrasted with the final simulation (in black) in which the α value of the velum closure gesture is much greater than the α value of the velum opening gesture, resulting in a drastic change in velum aperture and complete closure of the velopharyngeal port (i.e., velum aperture at or below 0). Intermediate manipulation of relative α values results in intermediate levels of velum aperture change throughout the concurrent activation interval of the two velum gestures.

It should be noted that these simulations were carried out using TADA's default gestural specifications, which specify abstract goal velum apertures for velum closure and velum opening gestures of -0.1 and 0.2, respectively. The values of α that result in a blended velum aperture of zero or less for concurrently active gestures are based on these specifications. However, the specific values used in these simulations are not as crucial as the overall result: it is possible for a

closed velum to result during a period of which a velum opening gesture is active. These simulations therefore lend validity to the Gestural Harmony Model's analysis of transparency as the activation of an antagonistic gesture during the extended activation of a harmonizing gesture.

The results of this modeling of transparency to nasal harmony also bring to light interesting predictions of the Gestural Harmony Model regarding the role of gradience of gestural strength. Gestures are not simple 'strong' or 'weak,' but rather may take on any strength value between one and zero. As a result, many of the velum aperture trajectories output by TADA and depicted in (228) involve the blending of gestures of roughly equal strengths, resulting in intermediate target states of the velum, neither fully open nor fully closed. Rather than being a liability to the Gestural Harmony Model, I claim that the ability of the model to generate these intermediate blending outcomes due to the gradient nature of the gestural strength parameter is an asset to the theory.

Recall that in Tuyuca (section 4.4.2), voiced and voiceless obstruents are analyzed as patterning differently with respect to nasal harmony. Voiced obstruents are overlapped by a harmonizing velum opening gesture and surface as nasalized, while voiceless obstruents are overlapped and surface as transparent to nasal harmony. I attribute the distinct patterning of voiced and voiceless obstruents to the voiced obstruents' lack of a velum closure gesture in the surface forms of Tuyuca. However, the results of TADA modeling suggest another possibility: that voiceless and voiced obstruents are not distinguished from one another based on the presence versus absence of a velum closure gesture, but instead on the strengths of their velum closure gestures. It could be the case that while voiceless obstruents possess a high-strength velum closure gesture whose activation results in full closure of the velum, voiced obstruents possess a velum closure gesture whose strength is not sufficient to result in full closure of the

velum when overlapped by a velum opening gesture. Such an analysis could have implications for the analysis of across-morpheme nasal harmony in Tuyuca, in which voiced obstruents pattern with voiceless obstruents in blocking nasal harmony from a root to a suffix (Barnes & Takagi de Silzer 1976; Barnes 1996; Walker 1998). The matter is certainly worthy of further study.

Beyond velum gestures, the results of TADA modeling also introduce a more general prediction of the Gestural Harmony Model that gestures with strengths roughly equal to that of a harmonizing gesture will surface as only partially transparent to harmony. I propose that such a case of partial transparency does exist in the faecal harmony system of Coeur d'Alene Salish. This case is discussed in section 5.3.

5.3 Partial Transparency via Gradient Gestural Strength

5.3.1 *Partial Transparency in Coeur d'Alene Salish Faecal Harmony*

In Coeur d'Alene Salish (also known as Snchitsu'umshtsn; Salishan; Washington, Idaho), a process of regressive vowel-consonant harmony causes vowels to surface as retracted and lowered. The language is described by researchers including Doak (1992) and Bessell (1998) as having the five surface vowels indicated in (229). (There is also a non-phonemic schwa that surfaces as the result of vowel reduction.)

- (229) Coeur d'Alene Salish surface vowel inventory³⁷

	Front	Back
High	i	u
Nonhigh	ɛ	ɑ ɔ

³⁷ Cole (1987) transcribes the front vowel [ɛ] as [ä]. Bessell and Doak both transcribe this vowel as [ɛ], though Doak claims its quality ranges anywhere from [e] to [æ]. While Cole transcribes the vowel [ɔ] as [o] and classifies it as a mid vowel, I assume that vowels in Coeur d'Alene Salish are only distinguished between high and nonhigh, and treat [ɔ] as the round version of nonhigh back [ɑ].

The surface distributions of these vowels are dependent upon a process referred to as faecal harmony. In faecal harmony, vowels surface as retracted preceding a ‘faecal’ consonant. This faecal class includes the primary uvular/pharyngeal consonants /q/, /χ/, and /f/, as well as the coronal rhotic transcribed as /r/, whose production includes some kind of secondary pharyngeal constriction.³⁸

Retraction of vowels preceding these consonants is demonstrated by the data in (230), in which the alternating vowels are underlined. All data are from Doak (1992) and Bessell (1998).³⁹

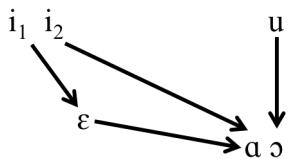
- (230) a. [t^siʃ-t] ‘it is long’
 b. [dlim] ‘he galloped hither’
 c. [q^wit^s-t] ‘warm’
 d. [sɛt̪t̪-nt̪s] ‘he twisted it’
 e. [χɛt̪-p] ‘he become curious’
 f. [ʔɛ-niʔ-kus-əlſtʃn] ‘hair curls back
 from forehead’
 g. [s-t-pum-əlx^w] ‘hide with fur’
 h. [t^sɛʃ-alq^w] ‘he is tall’
 i. [t^f-dləm-alq^w] ‘train’
 j. [q^wat̪-qən] ‘hat’
 k. [nɛʔ-sat̪-ɛʔqs-n] ‘crank (on a car)’
 l. [t-χat̪-χət̪-us] ‘he has curious eyes’
 m. [ʔat̪-kɔs-qn] ‘his hair is curled’
 n. [s-pɔm-alqs] ‘fur coat’

Note that the non-retracted vowels in (230c,e) demonstrate that this consonant-triggered harmony is only regressive; vowels following a triggering faecal consonant are not retracted. In most cases, uvular and pharyngeal consonants cause preceding vowels to surface as a non-high back vowel. In the environment of faecal harmony, underlying /i/, /ɛ/, and /ɑ/ surface as [ɑ], while underlying /u/ surfaces as [ɔ], analyzed here as the round counterpart of [ɑ]. There are, however, some lexical items (such as (230a,h) above) that indicate that underlying /i/ sometimes surfaces as [ɛ] rather than [ɑ] in faecal contexts. This vowel shift in faecal harmony contexts is illustrated in (231).

³⁸ All of these faecal consonants contrast with their labialized and/or glottalized counterparts, which also trigger faecal harmony.

³⁹ Doak and Bessell use slightly different consonant transcriptions. In particular, the consonant transcribed as [c] by Doak is transcribed as [t^s] by Bessell. I follow Bessell's transcriptions here.

(231) Vowel shift in faecal harmony contexts in Coeur d'Alene Salish



This surface distribution of vowel qualities preceding faecal consonants holds not only for the alternating forms in (230h-n) but also for static, within-morpheme vowel-faecal sequences. Within a morpheme containing a faecal consonant, that consonant may only be preceded by the vowels [ε], [a], and [ɔ]. This is shown in the data in (232) from Doak (1992), as well as the forms in (230h,i,k,n) above.

- (232) a. [s-leq'-m] 'baking camas in the ground' *[s-liq'-m]
 b. [n-pax^w-ət] 'he went outside' *[n-pix^w-ət]
 c. [s-tɔpq-s] 'thread' *[s-tupq-s]

At first glance, Coeur d'Alene Salish faecal harmony appears to contradict the claim made in section 2.3 that primary consonantal gestures involving oral closure or critical constriction degree may not surface as persistent (non-self-deactivating) or anticipatory (early-activating) and therefore may not trigger harmony. With the exception of /r/, the primary gestures of the consonants that trigger faecal harmony involve either full or critical closure of the vocal tract, and are predicted not to be able to extend in duration via persistence or anticipation.

The triggering of harmony by faecal consonants can be resolved by assuming that it is not their primary consonantal gestures that serve as the triggers of faecal harmony. Instead, the ability of a faecal consonant to trigger harmony in Coeur d'Alene Salish can be attributed to its hypothesized gestural makeup including a secondary vocalic gesture for retraction of the posterior tongue body in the pharyngeal region. I propose that it is this vocalic gesture, rather than a faecal consonant's primary oral closure gesture, that triggers faecal harmony. The inclusion of a vocalic retraction gesture in the representation of rhotic consonants is well

supported. Many phonetic studies show that rhotic production often involves pharyngeal constriction; see, for example, work by Delattre & Freeman (1968), Lindau (1985), Gick, Iskarous, Whalen, & Goldstein (2003), and Proctor (2009). The inclusion of a retraction gesture in the representations of the consonants /q/, /χ/, and /Ω/, on the other hand, is somewhat more controversial. I propose that the presence of this gesture is motivated as a way of enhancing or aiding in the production of the uvular/pharyngeal closure gesture of a faecal consonant.

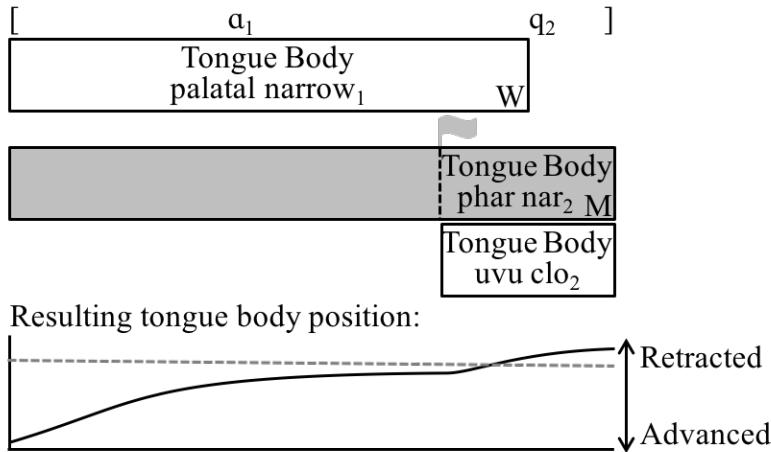
Generating regressive (leftward) faecal harmony in Coeur d'Alene Salish involves the relative ranking of constraints ANTICIPATE(Gest_X), SELFACTIVATE, and IDENT(activation)-IO that should be familiar from the discussion throughout chapter 3. Therefore, I will not provide an analysis of the constraint interactions necessary to derive the faecal harmony system of Coeur d'Alene Salish. Instead, I will focus on the results of the gestural blending that arises from overlap by the faecal harmony triggering tongue body retraction gesture.

Having determined the representations of faecal consonants in Coeur d'Alene Salish, faecal harmony can be analyzed as being triggered by a tongue body gesture specified for pharyngeal narrowing. Because it is anticipatory, this pharyngeal gesture extends regressively (leftward) to overlap other segments. When preceding vowel gestures are overlapped, their target articulatory states for tongue body position are in conflict with the target state of the anticipatory tongue body retraction gesture. In order for this overlap to result in retraction of the tongue body, the pharyngeal constriction gesture of the faecal consonant must be specified for a higher strength than the gestures of vowels.

The result of overlap of a vowel gesture by an anticipatory tongue body gesture specified for pharyngeal narrowing is illustrated in (233) for an /iq/ sequence in which the vowel /i/ is specified for a relatively low strength. The result of overlap of the weak /i/ vowel by a

pharyngeal constriction gesture is that the vowel surfaces as [ɑ]. The dashed line indicates a closed constriction degree.

(233) Full retraction of weak /i/



In (233), despite the gesture of /i/ being specified for a narrow constriction in the palatal region, the vowel surfaces as [ɑ] due to overlap by the pharyngeal narrowing gesture. The vowels /ɛ/ and /u/ will similarly surface as retracted when overlapped by this gesture.

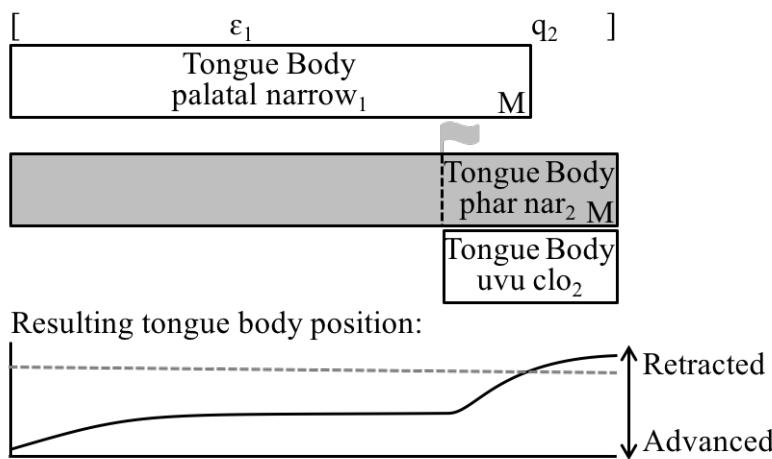
However, there appear to be two different versions of the high front vowel /i/ in the vowel inventory of Coeur d'Alene Salish. While most vowels in the inventory appear to fully undergo harmony, surfacing as either [ɑ] or its rounded variant [ɔ], some high front vowels only partially retract, surfacing as [ɛ] rather than [ɑ]. This is exemplified by forms such as [t^sɛʃ-alq^w] ‘he is tall’ (cf. [t^siʃ-t] ‘it is long’).

This pattern, in which a gesture has undergone harmony to some extent but appears to have at least partially resisted it, can be analyzed within the Gestural Harmony Model as a case of partial transparency to harmony. Rather than being strong enough to surface as fully transparent to harmony, as in the cases of transparency discussed in chapter 4, in Coeur d'Alene the /i/ that is found in some morphemes appears to be of an intermediate strength. As a result, when its target articulatory state is blended with that of the harmonizing pharyngeal constriction

gesture, the result will be neither full retraction of the tongue body, nor full transparency. Rather, the result is a vowel with a target intermediate state between the individual targets of the overlapped tongue body gestures; this vowel is transcribed as [ɛ].

This overlap of a medium-strength /i/, resulting in partial retraction of the tongue body, is illustrated in (234).

- (234) Partial retraction/partial transparency of medium-strength /i/

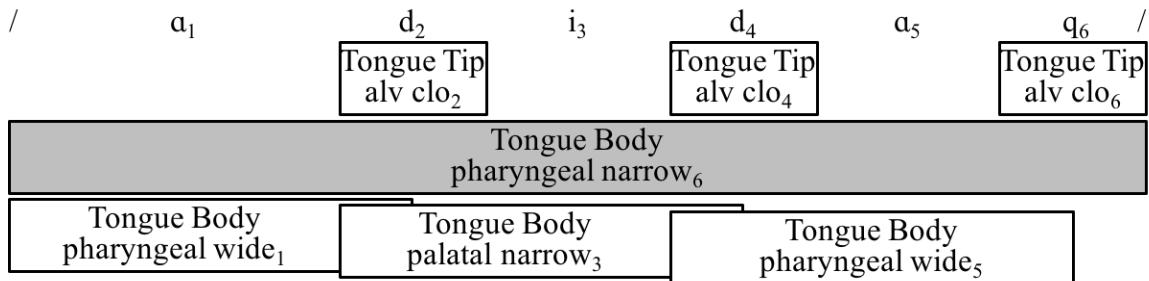


The ability of gestural strength to take on intermediate values, rather than simply being specified as weak or strong, is crucial to the success of this account of Coeur d'Alene Salish faecal harmony. The partial transparency exhibited by the /i/ → [e] mapping in Coeur d'Alene Salish faecal harmony is also important in that it fulfills a prediction of the Gestural Harmony Model's representation of transparency. If transparency is the result of blending between two concurrently active antagonistic gestures, and gestural blending strength is a gradient property, the model predicts that intermediate gestural strength of a transparent gesture will result in partial transparency.

5.3.2 Computational Modeling of Coeur d'Alene Salish Faucal Harmony

The viability of the analysis of vowel retraction in Coeur d'Alene Salish faecal harmony as a case of partial transparency to harmony is demonstrated in this section via computational modeling of the harmony process in TADA. In order to test the hypothesis that both the /i₁/ → [ɛ] and /i₂/ → [a] mappings in Coeur d'Alene can result from overlap of the palatal /i/ gesture by a vocalic gesture specified for pharyngeal constriction, the sequence /adidaq/ was synthesized. The gestural score in (235) served as the input to TADA.

(235) Gestural score for /adidaq/, the input to TADA



Three versions of this gestural score were input to TADA, each with a different strength ratio between the palatal gesture of high front vowel /i/ and the pharyngeal constriction gesture. The table in (236) summarizes.

(236) Blending strength values for inputs to TADA

	α for palatal gesture	α for pharyngeal gesture
Strong /i/	0.83	0.17
Medium-strength /i/	0.5	0.5
Weak /i/	0.17	0.83

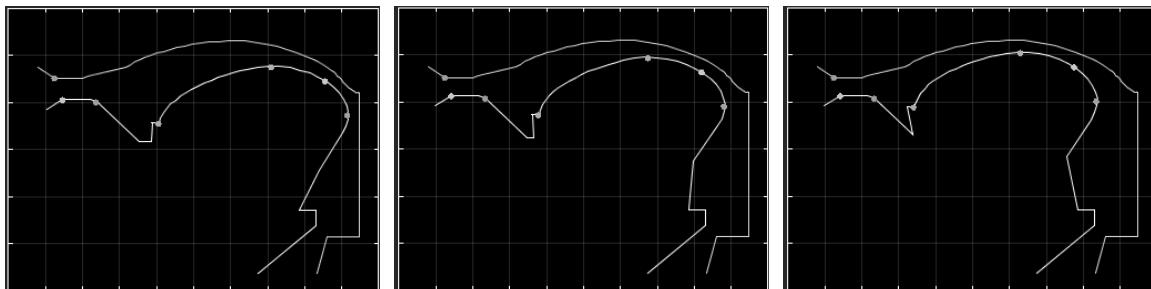
The medium-strength /i/ gesture is intended to correspond to partially transparent /i₁/ in the figure in (234), and is equal to the harmonizing tongue body retraction gesture in strength. The retraction gesture is five times stronger than weak /i/, which is intended to correspond to fully retracting /i₂/ in the figure in (233). The strong /i/ gesture is intended to correspond to the

fully transparent /i/ vowel that is found in other closely related varieties of Salish according to Bessell (1998). This strong /i/ gesture is five times stronger than the harmonizing retraction gesture.

For each gestural score, TADA produced a time series of vocal tract postures, as well as synthesized audio. The results of TADA modeling of the gestural score in (235) with different strengths of the palatal constriction gesture for high front /i/ show distinct degrees of tongue body retraction during the production of /i/, as predicted. The synthesized vocal tract postures during the production of /i/ are provided in (237).

(237) Synthesized tongue positions during production of underlying /i/ of different strengths

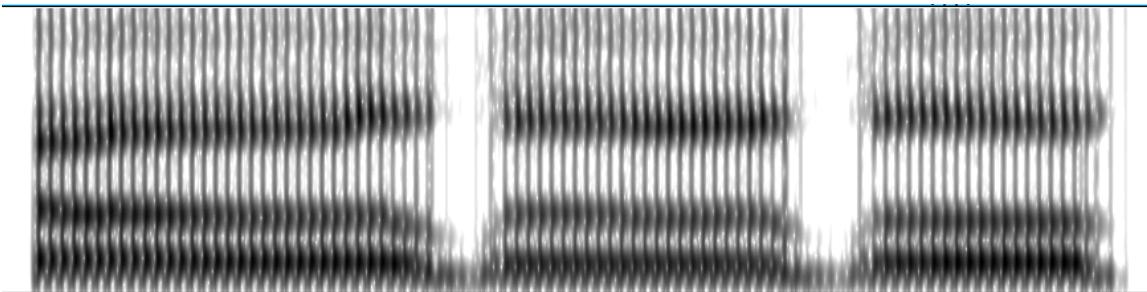
- a. Fully retracted tongue position during production of weak /i/
- b. Partially retracted tongue position during production of medium-strength /i/
- c. Unretracted tongue position during production of strong /i/



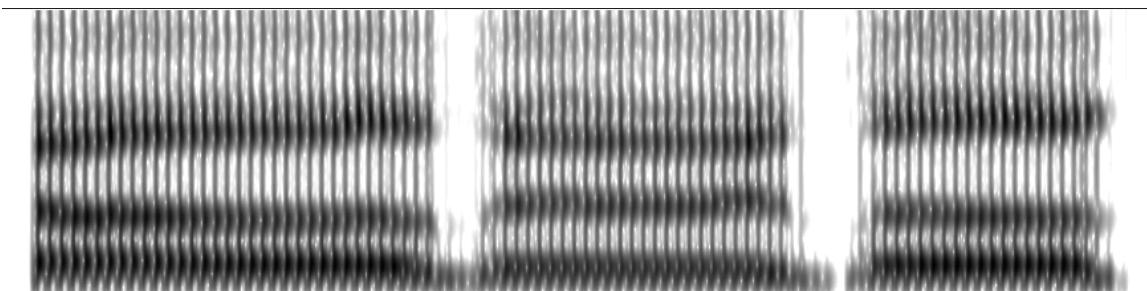
For weak /i/ in (237a) the tongue body position achieved during the production of the medial vowel is strongly retracted, despite this vowel's underlyingly identity as /i/. For strong /i/ in (237c), the tongue body is quite advanced despite the presence of concurrently active pharyngeal constriction gesture. Due to its high gestural strength, this /i/ appears to have surfaced as fully transparent to harmony. Intermediate between these two vocal tract postures is the medium-strength /i/ in (237b), which has surfaced as partially transparent to faecal harmony.

The three degrees to which the overlapped /i/ vowels have retracted as a function of their different gestural strengths is also apparent in their acoustic signals, provided in the figures in (238).

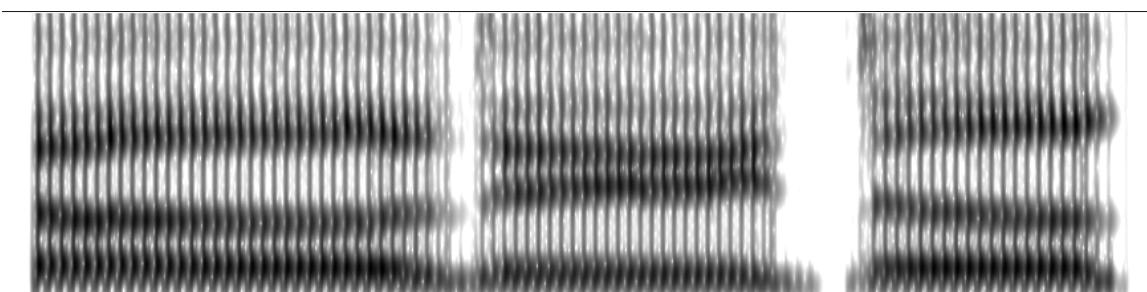
- (238) Synthesized spectrograms for underlying /adidaq/ with /i/ gestures of different strengths
- Produced as [adadaq] with weak /i/ gesture



- Produced as [adədaq] with medium-strength /i/ gesture



- Produced as [adidəaq] with strong /i/ gesture



In the spectrograms in (238), the formant structure of the medial vowel varies depending on the specified strength of the palatal gesture of underlying /i/. In (238a), the formant structure of the medial vowel matches that of the nonhigh back vowels around it. As a result of faecal

harmony, the underlying /i/ vowel has surfaced as fully retracted and is indistinguishable from the nonhigh back vowels around it. This gestural blending strength for /i/ is consistent with the /i/ in Coeur d'Alene Salish forms such as [dlim] 'he galloped hither' ~ [t^f-dlam-alq^w] 'train.' In (238b), the less retracted tongue body results in a raised second formant relative to the spectrogram of (238a). This intermediate strength for /i/ appears to be consistent with the /i/ in Coeur d'Alene Salish forms such as [tsiʃ-t] 'it is long' ~ [tseʃ-alqw] 'he is tall.' In (238c), the spectral profile of the medial vowel closely resembles that of an [i], with a second formant substantially higher than either of the vowels around it; this is despite having been overlapped by a tongue body retraction gesture. While this /i/ that exhibits full transparency to faecal harmony does not appear in Coeur d'Alene Salish, Bessell (1998) notes that there are several closely related Salish varieties, including the dialect continuum of Spokane-Kalispel-Flathead Salish, in which /i/ is fully transparent to faecal harmony.

TADA modeling has confirmed that the Task Dynamic Model of speech production can represent different degrees of /i/ retraction as the result of the blending of tongue body gestures of different strengths. It also confirms a prediction of the gestural representation of harmony that there should be attested some harmony system in which a transparent gesture surfaces as only partially transparent to a harmony process.

5.4 Contrastive Gestural Strength in Barrow Inupiaq

The analysis of Coeur d'Alene Salish presented in section 5.3 introduces the idea that the parameter of gestural blending strength is able to serve a contrastive function within phonology. In Coeur d'Alene Salish, lexical items can either contain a weak /i/, which surfaces as fully retracted as the result of faecal harmony, or a medium-strength /i/, which is partially transparent to faecal harmony and surfaces as only partially retracted. This introduces the interesting

possibility that within gestural phonology it is possible to use the gestural strength parameter to represent contrasts among segments based on their susceptibility to undergo a phonological process. This possibility is further explored in this section.

There has been some recent work that suggests that gestural strength plays an active role in phonological processes. Iskarous, McDonough, & Whalen (2012), for instance, propose that the velar fricative in Navajo is specified for a low gestural strength, which accounts for its patterns of allophony based on surrounding vowel context. In the Gestural Harmony Model, high gestural strength is proposed to be responsible for transparency to harmony processes. These analyses are based upon the idea that gestural strength is a crucial part of a gesture's phonological representation and can determine its participation in certain phonological processes. However, it is still assumed in these analyses that the specified strengths of gestures, while phonologically active, are a fixed, language-specific property.

The case of the two high front vowels of Coeur d'Alene Salish suggests that the phonological role played by gestural strength be expanded to include the possibility that the setting of a gestural strength parameter can serve a contrastive function. However, instead of a contrast based on a directly observable property of the production of a segment, such as its place of articulation, contrastive gestural strength is only observable in terms of whether, or to what degree, a gesture participates in some phonological process. Because of this, contrastive gestural strength manifests as patterns that are often analyzed as cases of exceptionality in the application of phonological processes.

Another case of apparent phonological exceptionality that can be analyzed instead as the result of contrastive gestural strength comes from Barrow Inupiaq (Inuit; Alaska; L. Kaplan (1981), Archangeli & Pulleyblank (1994), C. Smith & Blaylock (2017)). I focus in particular on

two phonological processes in this language. First, a process of coronal palatalization causes underlyingly coronal consonants to become palatalized following a high front vowel. This process can occur across an intervening consonant and targets the coronals /t/, /n/, and /l/, which surface as [s]~[ç], [ɲ], and [ʎ], respectively. What is interesting about this process of coronal palatalization is that it is triggered by some /i/ vowels and not others. This is illustrated by the data in (239). In (239a-b), the high front vowel triggers palatalization of the following lateral, while in (239c-d), palatalization does not take place. All data are from L Kaplan (1981).

- (239) a. [iki-ʎu] ‘and wound’ c. [ini-lu] ‘and place’
 b. [savig-ʎu] ‘and knife’ d. [kamig-lu] ‘and boot’

Another process, dorsal assimilation, causes the high front vowel /i/ to retract and surface as [a] before a velar or a uvular consonant. Again, the process does not apply uniformly across all lexical items. Interestingly, it is precisely those lexical items that trigger coronal palatalization that fail to undergo dorsal assimilation. This is illustrated by the data in (240), which include the same roots as (239). In (240a-b), the vowel of the second syllable surfaces as [i], while in (240c-d) the vowel retracts, surfacing as [a].

- (240) a. [iki-k] ‘wound (dual)’ c. [inna-k] ‘place (dual)’
 b. [savvi-k] ‘knife (dual)’ d. [kamma-k] ‘boot (dual)’

It is apparent from the data in (239) and (240) that these processes do not apply uniformly among all instances of the vowel /i/. Instead there are a set of /i/ vowels that triggers palatalization while failing to undergo dorsal assimilation, and a set of /i/ vowels that fail to triggers coronal palatalization while undergoing dorsal assimilation.

L. Kaplan (1981) and Archangeli & Pulleyblank (1994) analyze the inconsistent application of coronal palatalization and dorsal assimilation in Barrow Inupiaq by proposing that there are two vowels in the language that surface as [i]. L. Kaplan claims that underlyingly

Barrow Inupiaq has the vowels /i/ and /ɪ/, the latter of which he describes as a schwa-like vowel. Under his analysis, while both /i/ and /ɪ/ surface as [i] outside of the environment for dorsal assimilation, their underlying featural specifications cause them to participate in these phonological processes differently. He claims that at the step in the derivation at which coronal palatalization applies, /ɪ/ lacks the featural specification to trigger this process alongside high front /i/. It is this same featural specification that renders it a target of dorsal assimilation, while underlying /i/ is not targeted. Similarly, Archangeli & Pulleyblank analyze the [i] that triggers coronal palatalization and resists dorsal assimilation as underlying /i/, while an underlyingly featureless vowel fails to trigger palatalization and undergoes dorsal assimilation.

I also adopt the line of analysis in which there are two /i/ vowels in the phonological inventory of Barrow Inupiaq. However, the basis of the contrast between these vowels is considerably different. Following C. Smith & Blaylock (2017), I propose that these two /i/ vowels have identical palatal constriction targets, but contrast for gestural blending strength. The processes of coronal palatalization and dorsal assimilation in Barrow Inupiaq are the results of the overlap and subsequent blending of the conflicting goal states of two antagonistic gestures. While strong /i/ triggers coronal palatalization and resists dorsal assimilation, weak /i/ does not trigger coronal palatalization and undergoes dorsal assimilation. Like Coeur d'Alene Salish, then, Barrow Inupiaq appears to have a surface phonological inventory that includes two /i/ vowels that contrast for gestural blending strength.

The gestural analysis of coronal palatalization and dorsal assimilation in Barrow Inupiaq is centered upon the gestural blending that takes place between these /i/ vowels and gestures with which it is concurrently active. Under this analysis, palatalization occurs due to the overlap of an alveolar constriction gesture by a preceding palatal gesture for an /i/. The result of this overlap is

antagonism with respect to the position of the tongue blade and anterior tongue body, as illustrated by the vocal tract diagrams in (241).

(241) Antagonism between high front vowel and apical coronal gestures

a. Tongue position for /i/



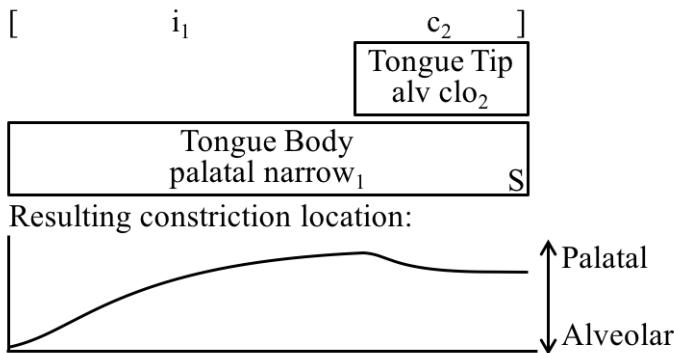
b. Tongue position for coronal consonant



The /i/ gesture requires the anterior tongue body to be high and domed, bringing the tongue tip to a lower position, while the alveolar gesture requires a lower position of the tongue blade and anterior tongue body in order to achieve an apical constriction at the alveolar ridge. Due to conflicting target articulatory states, when these gestures are concurrently active they will undergo gestural blending to determine what position the tongue will take. The result of this gestural blending is determined by the gestures' relative blending strength values.

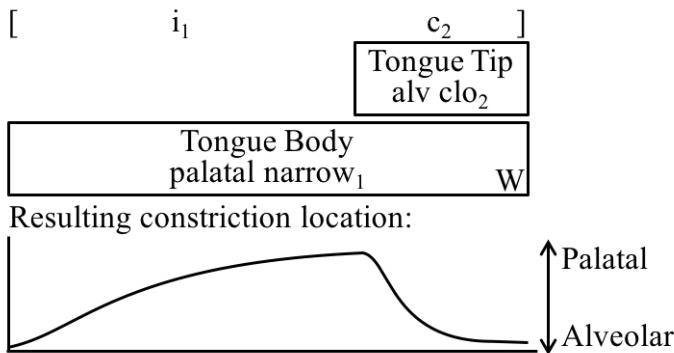
In the case of strong /i/, gestural blending favors the target articulatory state of the strong /i/ gesture at the expense of the alveolar gesture. The result is a palatal constriction during the time in which the two gestures are concurrently active. Palatalization is a direct result of the overlap of the alveolar gesture by the palatal gesture, and is output by the calculations of the Task Dynamic Model of speech production. The process is illustrated by the gestural score and resulting constriction location time course in (242).

(242) Gestural score for sequence of strong /i/ and coronal consonant



In the case of weak /i/, gestural blending favors the target articulatory state of the alveolar gesture over that of the concurrently active palatal gesture. Therefore, palatalization does not result during the overlap of the two gestures, and alveolar consonants surface as alveolar. The failure of this /i/ to trigger palatalization can be attributed to its low gestural blending strength. This is illustrated in (243).

(243) Gestural score for sequence of weak /i/ and coronal consonant

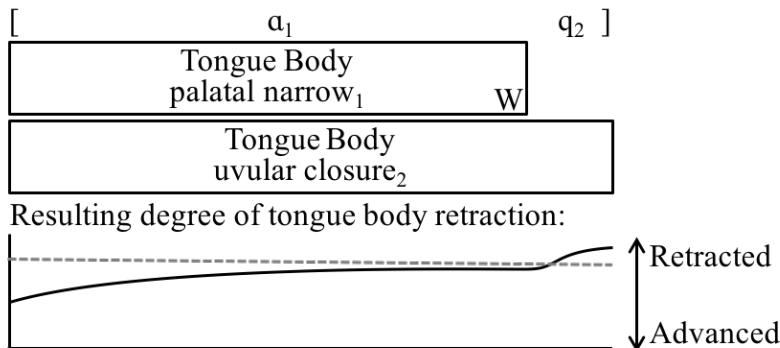


The same distinction between strong and weak /i/ comes into play in the analysis of dorsal assimilation. However, in this case the distinction affects whether or not /i/ is targeted by the process, rather than triggering it. Again, the process is analyzed as the result of the overlap of two antagonistic gestures. I claim that dorsal assimilation in Barrow Inupiaq is the result of a uvular or velar consonantal gesture not strictly following a vowel gesture, but instead overlapping a preceding vowel gesture to some degree, as in the gestural scores in (244) and

(245). I assume that these consonantal gestures are of a sufficiently low stiffness that they will not reach their consonantal target closures until after the deactivation of the vowel gesture. Overlap between the vowel gesture for the /i/ and the gesture of a velar or uvular consonant results in antagonism; /i/ requires a high front position of the tongue body, while a velar or uvular consonantal gesture requires the tongue body to be retracted in the uvular region. Again, the outcome of the overlap of these antagonistic gestures is determined by their relative strengths.

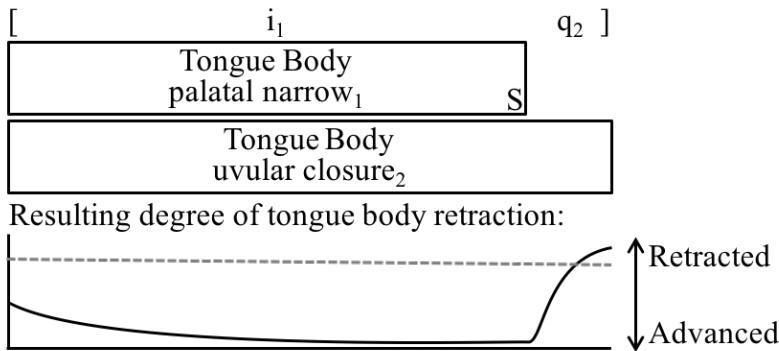
The blending of a uvular closure gesture and a weak palatal gesture for /i/ will favor retraction of the tongue body. The result of this overlap will be the back vowel /ɑ/, as in (244).

(244) Gestural score for weak /i/ overlapped by following uvular consonant



The goal articulatory state of a strong /i/, on the other hand, will be favored over that of a uvular consonantal gesture. As a result, vowel retraction does not result during the overlap of the two gestures, and /i/ is able to surface as palatal. The /i/ gesture has resisted dorsal assimilation due to its high specified strength. This is illustrated in (245).

(245) Gestural score for strong /i/ overlapped by following uvular consonant



There are a number of advantages to the contrastive gestural strength analysis of these processes in Barrow Inupiaq. First, it recruits an independently necessary element of gestural representations, gestural strength, to account for this phonological behavior. In addition, it provides a unified explanation for the apparently exceptional applications of palatalization and dorsal assimilation, rather than treating them as unrelated processes. Finally, the gestural strength analysis also eliminates the need to rely on various theoretical mechanisms that are typically employed to account for cases of apparent exceptionality.

Because they include no direct analog to gestural strength, more traditional feature-based analyses of apparently exceptional or inconsistent application of a phonological process must distinguish between seemingly identical segments or lexical items in other ways. In derivational analyses, that often involves positing a fully abstract underlying phoneme that never appears in surface forms. This is the case for analyses of Barrow Inupiaq by L. Kaplan (1981) and Archangeli & Pulleyblank (1994), who posit an abstract underlying vowel that later merges with /i/. Under these analyses, a coronal palatalization rule will apply before the abstract vowel is merged with /i/, preventing it from triggering coronal palatalization. This is a case of counterfeeding opacity. Likewise, the dorsal assimilation rule will apply before the rule that

derives [i] from the underlying abstract vowel, accounting for its susceptibility to dorsal assimilation.

As discussed in section 3.6.3, this sort of analysis based on absolute neutralization with counterfeeding opacity is incompatible with parallel phonological frameworks such as Optimality Theory or Harmonic Grammar, unless additional theoretical architecture is adopted. The gestural account of Barrow Inupiaq avoids this issue as it does not rely on abstract underlying phonemes, absolute neutralization, or rule ordering. Instead, under this account the contrastive element, gestural strength, is not neutralized; it persists from the underlying to the surface form and results in the different consequences of overlap observed in (242)-(245).

One way of dealing with these sorts of apparently exceptional patterns in a way that is compatible with parallel phonological frameworks is indexation between morphemes and constraints (Pater 2000, 2009a; Flack 2008; Becker 2009). Exceptional triggering of palatalization can be generated by indexing a high ranked markedness constraint to triggering morphemes; for the sake of simplicity this constraint will be referred to as PALATALIZE. Ranking a relevant faithfulness constraint between the indexed and unindexed versions of this constraint, as in (246), ensures that only morphemes bearing the index X will trigger palatalization.

(246) Constraint ranking for exceptional triggering of palatalization by X-indexed morphemes

PALATALIZE_X >> IDENT(high)-IO >> PALATALIZE

Similarly, exceptional failure to undergo dorsal assimilation can be generated via indexing of a high-ranked faithfulness constraint. Ranking the indexed version of this constraint above the markedness constraint that drives dorsal assimilation and the unindexed version of this constraint below that markedness constraint, as in (247), ensures that the grammar will only preserve the underlying backness value of vowels in morphemes bearing the index Y.

- (247) Constraint ranking for exceptional resistance to dorsal assimilation by Y-indexed morphemes

IDENT(back)-IO_Y >> ASSIMILATE >> IDENT(back)-IO

While these rankings will generate the patterns of palatalization and dorsal assimilation exhibited by Barrow Inupiaq, several issues arise by adopting this constraint indexation analysis. The first issue is that if a morpheme contains multiple high front vowels, the indexation of that morpheme to PALATALIZE and IDENT(back)-IO predicts uniform behavior of all /i/ vowels in the morpheme with respect to palatalization and dorsal assimilation. In other words, a morpheme will contain either all palatalizing /i/ vowels or all non-palatalizing /i/ vowels. However, there are a number of morphemes in Barrow Inupiaq that contain both palatalizing and non-palatalizing /i/ vowels. One example is the word [ilvi-*k*i] ‘and you, in your turn,’ in which the first [i] does not trigger palatalization of the immediately following [l], but the second [i] does. Another example is the stem /sipik/ ‘sleep.’ The first [i] triggers palatalization of following [n], as in [sipik-pa] ‘is he sleeping?’, while the second [i] does not, as in [sipik-tuq] ‘sleeps’ (*[sipik-cuq]). This indicates that the exceptional patterning of vowels in this language must be assessed for an element smaller than the morpheme.

A possible solution is to consider that constraints are indexed to individual segments rather than entire morphemes, as proposed by Temkin Martínez (2010). With the indexed constraint rankings necessary for an account of Barrow Inupiaq, an inventory with two /i/ vowels can be posited, with one /i/ indexed to both high-ranked constraints, PALATALIZE and IDENT(back)-IO, and one that is indexed to neither. This vowel inventory is provided in (248).

- (248) Barrow Inupiaq vowel inventory with two indexed /i/ phonemes

/a/, /u/, /i_{XY}/, /i/

However, under the constraint indexation approach, the indexation of the gestural analysis' strong /i/ to both PALATALIZE and IDENT(back)-IO is entirely accidental. It is also possible to generate a system in which PALATALIZE and IDENT(back)-IO are not indexed to the same sets of /i/ vowels. That is, an /i/ vowel may be indexed only to PALATALIZE, or only to IDENT(back)-IO, and a phonological inventory may include any combination of these indexed /i/ vowels, or even all of these vowels. This is illustrated by the possible vowel inventory in (249).

- (249) Predicted possible high vowel inventory with two indexed constraints

/i_{XY}/, /i_X/, /i_Y/, /i/

When it is only necessary to propose the indexation of two constraints, the predicted increase in the size of a possible phonological inventory is not ideal, but also not a serious problem. The indexation of two constraints results in four possible vowel-index combinations. However, there are additional phonological processes in Barrow Inupiaq that rely on the distinction between what the gestural analysis calls strong and weak /i/. According to L. Kaplan (1981), there is also a process in which weak /i/ retracts to surface as [u] in certain environments, as well as a process in which weak /i/ is deleted. The analysis of each of these processes will need to make use of both an indexed and a general version of a constraint in order to differentiate between weak /i/ and strong /i/. With four indexed constraints, there are sixteen possible vowel-index pairs, and therefore a predicted phonological inventory that contains sixteen /i/ vowels, each with a different set of constraint indices. This points out an important point about the constraint indexation approach to dealing with apparent exceptionality: as the number of indexed constraints increases, the size of a language's possible segment inventory will increase at a rate

of 2^n , where n is the number of indexed constraints in the grammar. By allowing the constraints that motivate different processes to index to segments independently from one another, this approach misses a generalization about the relatedness of certain processes.

The account of apparent phonological exceptionality in Barrow Inupiaq based on contrastive gestural strength encounters no such issues with exploding inventory size. In contrast, the gestural strength account of coronal palatalization and dorsal assimilation in Barrow Inupiaq relies on a single gestural parameter, gestural blending strength, to generate the patterning of the high front vowel with respect to multiple processes. In doing so, this analysis captures the generalization that a vowel's ability to trigger palatalization and its failure to undergo dorsal assimilation are related. By capturing this relatedness, the contrastive gestural strength analysis avoids the kinds of inventory size explosions predicted by an account based on segment indexation to constraints.

There is an open question as to how many gestural strength parameter settings may be utilized contrastively by a language. The cases of Coeur d'Alene Salish and Barrow Inupiaq discussed here are each analyzed as involving a contrast between vowels of two different gestural strengths. However, because gestural strength is specified on a gradient scale, potentially much more fine-grained contrasts are also predicted to be possible. For instance, a language could in principle contrast five /i/ vowels: very weak ($\alpha=0.20$), weak ($\alpha=0.40$), medium ($\alpha=0.60$), strong ($\alpha=0.80$), and very strong ($\alpha=1.0$). There is no theoretical upper limit on how fine-grained the contrasts between gestures of different strengths may be, and therefore no theoretical limit on the number of segments that may contrast for gestural strength in some language.

However, I claim that contrastive gestural strength still does not necessarily predict the types of inventory size explosions as constraint indexation, because the contrasts between gestures based on their strength parameter settings must be sufficiently perceptually distinct. While it is true that a language could, in principle, contrast two gestures with specified strengths of 0.82 and 0.83, such a contrast is unlikely to ever arise. The differences in how these gestures would blend with and affect the production of the gestures around them would be so slight as to render those differences imperceptible. As a result, any contrast between them would likely be highly unstable. Contrasts between gestures based on their strengths are only predicted to arise if those distinct gestural strengths result in perceptually distinct results of blending. Therefore, the number of gestural strength parameter settings that can be utilized contrastively by a language is constrained by perceptual factors.

This section has demonstrated that the gestural analysis of multiple apparently exceptional processes in Barrow Inupiaq avoids issues of both undergeneration and overgeneration of phonological patterns. Beyond that, it has also demonstrated the utility of gestural blending strength in accounting for phonological processes other than harmony. This suggests that many of the innovations introduced by the Gestural Harmony Model can be generalized beyond the study of harmony. In the case of granting contrastive status to gestural blending strength, these innovations extend into the realm of phenomena that are often treated as cases of phonological exceptionality.

5.5 Summary

This chapter has provided an in-depth examination of gestural strength and blending, concepts that play a key role within gestural phonology. Originally conceived within the Task Dynamic Model of speech production, gestural strength and blending are recruited by the

Gestural Harmony Model to account for transparency as the result of overlap between antagonistic gestures. A major consequence of this approach is in the ability of the Gestural Harmony Model to account for asymmetries between attested transparent and blocking segments, as discussed in chapter 4. In addition, the gradient nature of gestural strength allows the Gestural Harmony Model to account for cases of partial transparency, exemplified by Coeur d'Alene Salish faecal harmony in section 5.3.

Looking beyond the study of harmony, the case of Barrow Inupiaq fulfills a prediction that gestural strength, as a phonological parameter of a gesture, should play an active role in phonology, even taking on a contrastive function in some languages. In addition to the case of Barrow Inupiaq, there are a number of other possible cases of apparent phonological exceptionality that could benefit from an analysis based on contrastive gestural strength as well. These include processes that distinguish between the standard and ‘superclose’ high vowels in various Bantu languages, including Bemba (Hyman 1994; Zoll 1995); the two /i/ vowels of Kashaya (Buckley 1994); and the two /w/ glides of Fula (S. Anderson 1976a, 1976b). In Kashaya (Pomoan; northern California), Buckley analyzes the idiosyncratic patterning of several processes that target the vowel /i/ as the result of the language’s inventory containing an abstract vowel. This is remarkably similar to the analyses of Barrow Inupiaq by L. Kaplan (1981) and Archangeli & Pulleyblank (1994). In Bemba (also known as Cibemba; Bantu; Zambia), Zoll (1995) analyzes the idiosyncratic ability of high surface vowels to trigger various consonant mutations as the result of the distinction between underlying vowels that are historically derived from the Bantu ‘superclose’ vowels and underlying vowels that are derived from standard high vowels.

Fula represents an especially interesting case of apparent exceptionality. S. Anderson (1976, 1976) suggests that there are two types of /w/ in the language, one in which the labial component is consonantal, and one in which the dorsal component is consonantal.⁴⁰ For each of these versions of /w/, its consonantal portion determines how it patterns with respect to a process of consonant mutation involving alternation between stop and continuant. Such a pattern could be captured straightforwardly within gestural phonology. In an inventory with two versions of /w/, both would have a lip protrusion gesture and a tongue body gesture specified for uvular constriction. However, they would differ as to which of the gestures is the stronger of the two. In addition to providing another potential case of contrastive gestural strength, the two /w/ glides of Fula also speak to the assumption within gestural phonology that consonantal gestures are generally strong and vocalic gestures are generally weak. Fula would provide a valuable case through which to examine how gestures are classified as consonantal and vocalic, and the role that gestural strength plays in that classification.

⁴⁰ Thanks to Nick Danis for bringing this case to my attention.

Chapter 6

Conclusion and Further Issues

6.1 Summary of the Dissertation

This dissertation has introduced the Gestural Harmony Model and argued for the representation of harmony as the result of a gesture's extended duration such that it overlaps other gestures in a word. The ability of a gesture to surface with this extended duration is the result of two newly proposed gestural parameters. One parameter determines whether a gesture self-deactivates once its target articulatory state is achieved, or whether it is a persistent gesture that does not self-deactivate and therefore acts as a trigger of progressive harmony. The other parameter determines whether a gesture activates at the 0° phase of its planning oscillator, or whether it is an anticipatory gesture that activates before this phase and acts as a trigger of regressive harmony.

By casting the triggering of harmony as the result of a gestural parameter setting, the grammar of triggering in the Gestural Harmony Model is one based on shaping surface phonological inventories such that they contain harmony-triggering (persistent and/or anticipatory) gestures, as well as placing distributional restrictions on members of those inventories. In reconceptualizing the driving of harmony in this way, the Gestural Harmony Model provides novel solutions to some of the issues that arise in the analysis of harmony triggering patterns. The model successfully accounts for harmony systems in which harmony triggers are restricted to specific positions (such as Kyrgyz rounding harmony, sections 2.2.1 and 3.2.1), as well as those that place conditions on the identities of triggers of harmony (such as Baiyina Oroqen rounding harmony, section 3.4.2). The Gestural Harmony Model finds particular

success in accounting for patterns of contrastive triggering in harmony, including those in which the contrast between triggers and non-triggers is restricted to privileged positions. This is exemplified by analyses of nasal harmony in Acehnese and Rejang (section 3.3), as well as tongue root harmony in Classical Manchu (section 3.5).

The Gestural Harmony Model also makes major inroads in the study of transparency and blocking, and the observed typological asymmetries between them. In this model, a transparent segment is analyzed as a special type of undergoer, one that includes a gesture that is antagonistic to the harmonizing gesture. This antagonism results in the temporary counteracting of the effect of the harmonizing gesture on the vocal tract due to the blending of the antagonistic gestures' individual target articulatory states. Blocking, on the other hand, is the result of a grammatical restriction on the overlap of incompatible gestures, whose concurrent activation is either articulatorily or perceptually marked in some way. This restriction is enforced by a newly proposed type of intergestural relation: inhibition. When two gestures are in an inhibition relation, an inhibiting gesture will leech the activation from the inhibited gesture, either preventing it from activating (in the case of regressive harmony) or deactivating it (in the case of progressive harmony).

By analyzing transparent segments as undergoers of harmony, the Gestural Harmony Model makes important predictions about the types of segments that should be able to surface as transparent to harmony. Only those segments whose representations include a gesture that is antagonistic to a harmonizing gesture are predicted to be transparent to harmony. Because of this, the Gestural Harmony Model correctly predicts observed typological asymmetries between attested transparent and blocking segments in nasal harmony and rounding harmony. Obstruents are the only segments attested as being transparent to nasal harmony, and the only types of

segments that include a velum closure gesture that is antagonistic to a velum opening gesture that is responsible for nasal harmony. High front vowels are the only segments attested as being transparent to rounding harmony, and the only types of segments that include a lip spreading gesture that is responsible for rounding harmony. In contrast, there is no restriction on which types of segments may inhibit one another. Because of this, the types of segments that are predicted by the Gestural Harmony Model to serve as blockers of harmony are unconstrained relative to the types of segments that are predicted to surface as transparent to harmony.

There are a number of additional advantages to the Gestural Harmony Model's representations of transparency and blocking. By representing transparency as the result of blending between two gestures according to their specified strength parameters, the Gestural Harmony Model is able to account for cases of partial transparency, exemplified by Coeur d'Alene Salish faecal harmony (section 5.3). In addition, the splitting of transparency and blocking among two distinct theoretical mechanisms ensures that the Gestural Harmony Model is able to generate harmony systems that display both transparency and blocking, such as Halk Mongolian rounding harmony (4.5.2).

In addition, the gestural analysis of coronal palatalization and dorsal assimilation in Barrow Inupiaq (section 5.4) suggests that the innovations of the Gestural Harmony Model are not limited to the study of harmony. By expanding the phonological role of gestural blending strength to include cases in which gestural strength serves a contrastive function, gestural representations are able to account for patterns that have previously been treated as cases of phonological exceptionality.

6.2 Further Issues

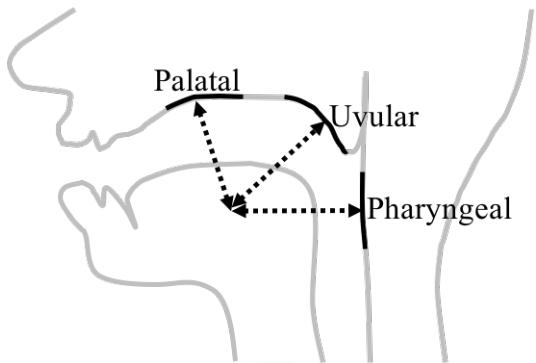
The development of the Gestural Harmony Model advances our understanding of what drives many of the crosslinguistic patterns observed across harmony systems. However, this dissertation also leaves some questions open to further study. In this section I discuss some of these open questions, as well as avenues for further research. I focus on issues involving (1) the representation of vowel place within gestural phonology, (2) an elaboration of the theory of intergestural inhibition, and (3) directionality of harmony.

6.2.1 *Gestural Representation of Vowels*

Throughout this dissertation, the focus has been on harmony systems that are based on the extended duration of a secondary gesture of a segment, e.g. nasal harmony (velum opening), rounding harmony (lip protrusion), and tongue root harmony (tongue root advancement/retraction). It has not addressed two common types of vowel harmony: those based on vowel height and backness. This is because as the gestural phonology framework currently stands, these types of harmony cannot be represented as the result of extended gestural duration due to the absence of gestural analogs to height and backness.

Recall from section 1.2.1 that Articulatory Phonology assumes that lingual gestures (those for either the tongue tip or tongue body) for both consonants and vowels are specified in terms of constriction location and constriction degree. Front vowels are specified for palatal constriction, while high back vowels are specified for uvular constriction and nonhigh back vowels are specified for pharyngeal constriction. This gestural coordinate system, based on constriction location and constriction degree, is illustrated in (250).

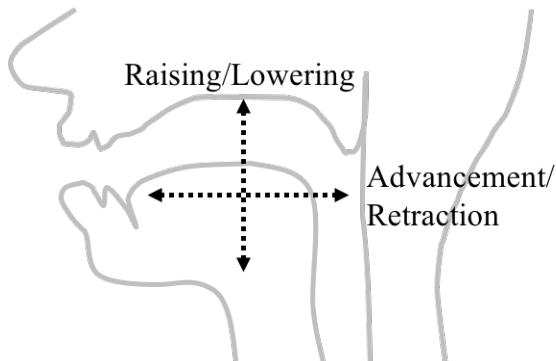
(250) Gestural representation of constriction location for vowels



This polar coordinate system can be contrasted with a typical featural mapping of vowel place along a Cartesian coordinate system with two dimensions: height and backness. Assuming a featural system for vowels based upon these dimensions, the representation of height harmony and backness harmony as feature spreading is straightforward. The same cannot be said for a gestural framework that assumes vowel representations based on palatal, uvular, and pharyngeal constriction location. The question, then, is how to reconcile attested harmony systems based on the spread of vowels' properties of height and backness with a gestural representational system that does not rely on these dimensions in the representation of vowels.

One possible solution is to redesign the representation of vowels within gestural phonology such that they do rely on gestures that specify the height and backness of the tongue body, rather than the location and degree of tongue body constriction. Instead of relying on gestures specified for the dimensions of constriction location and degree, this new gestural system for vowels could be constructed using a set of one-dimensional tongue body raising and/or lowering gestures, as well as a set of one-dimensional tongue body retraction and/or advancement gestures. This new coordinate system for vowel gestures is illustrated in (251).

(251) Proposed new gestural representation of vowel place



A vowel, then, would be specified for height and backness according to its unique combination of raising/lowering and advancement/retraction gestures of the tongue body. These gestures would then only need to be specified for a single dimension, constriction degree (how raised, how retracted, etc.). For instance, the vowel /u/ could be represented by the combination of a tongue body raising gesture and a tongue body retraction gesture (as well as a lip protrusion gesture responsible for rounding). The result of the concurrent activation of these lingual gestures is a high back tongue body position. This is somewhat similar to proposals made within particle theory (Schane 1984, 1990) and element theory (Kaye, Lowenstamm, & Vergnaud 1985), in which vowels are represented by combinations of subsegmental particles or elements.

A major advantage to this approach is in its ability to represent harmonies based on the spreading height and backness. For instance, if a tongue body retraction gesture surfaces as either persistent (non-self-deactivating) or anticipatory (early-activating), it will trigger backness harmony. If a tongue body raising gesture surfaces as either persistent or anticipatory, it will trigger height harmony.

Another advantage to this approach to vowel representation is its unification of gestural types. In the current model, non-lingual gestures are based on the one-dimensional position of an articulator. For instance, the velum is specified only for height/aperture. Even with this one-

dimensional representation of articulator position for a given gesture, it is still possible to represent the possibility of two-dimensional articulator movement. Lip gestures, for instance, may specify either the vertical distance between the lips, as for lip closure gestures, or for horizontal position, as for lip protrusion and spreading. However, these distinct vertical and horizontal lip positions are the results of different gestures; there is no single lip gesture with two tract variables, one for the vertical dimension and one for the horizontal dimension. Similarly, using this newly proposed coordinate system, both the horizontal and vertical position of the tongue body can be specified; however, this position is the result of different gestures. This model of vowel place would bring vowel gestures in line with many other non-lingual gestures based on the one-dimensional position of an articulator.

Under this new model of vowel place, several questions remain and should be addressed in further research. For one, it is not clear how to represent an unmarked vowel, i.e., a vowel whose place corresponds to the neutral position of the tongue body. In a language with active tongue body raising, a high vowel would be represented by a tongue body raising gesture, while a nonhigh vowel would be represented by the absence of such a gesture. However, there must still be some gestural element present that acts as the nucleus of a syllable; otherwise, onset and coda consonants would have nothing to which to couple. Further work should explore what exactly that nuclear gestural element is, whether it is a gesture specifying the neutral position of the tongue body, a gesture that represents a syllable timing node, or something else entirely.

Another question that arises from the adoption of this new coordinate plane for vocalic gestures concerns what, if anything, should be done with respect to the gestural representation of lingual consonants. If vowels are represented by one or more gestures for tongue body height and backness, the question arises as to whether consonants should be represented in the same way.

There has been a great deal of work conducted within featural phonology that suggests that consonants and vowels should be represented by the same sets of features in order to account for phenomena in which consonants and vowels interact with one another (see Clements & Hume (1995) for a summary). It makes intuitive sense that the same logic could transfer to gestural phonology, and that all types of gestures should be specified within a single coordinate system. Otherwise, it is unclear how the result of blending between a consonantal and a vocalic gesture should be calculated if the two gestures are specified along two completely different sets of dimensions.

One possibility is to assume that while vowels are phonologically specified for height and backness, the instructions that are sent to the articulators (following the calculation of articulatory trajectories by the Task Dynamic Model) are formatted in the polar coordinate system that is assumed within Articulatory Phonology. The primary drawback to such an approach is the addition of what is essentially a phonetic implementation component that performs the translation from phonological to phonetic specifications for vocalic gestures. While such a phonetic implementation component is generally assumed within feature-based phonological frameworks, one of the central tenets of Articulatory Phonology is that no such component is necessary. In this framework, the phonological and phonetic units of representation are identical. This insight would be lost if a phonetic implementation component were added to translate the constriction parameters of vowels.

Alternatively, it could be the case that both consonantal and vocalic tongue body gestures specify the target position of the tongue in terms of height and backness. Within this system, consonants would be represented by tongue body raising/lowering and advancement/retraction gestures whose constriction degrees result in either critical (fricative noise producing)

constriction degree or full closure of the vocal tract. Further research is necessary to determine the viability of this proposal, as well as the full set of predictions that is made by such a system of consonantal representation.

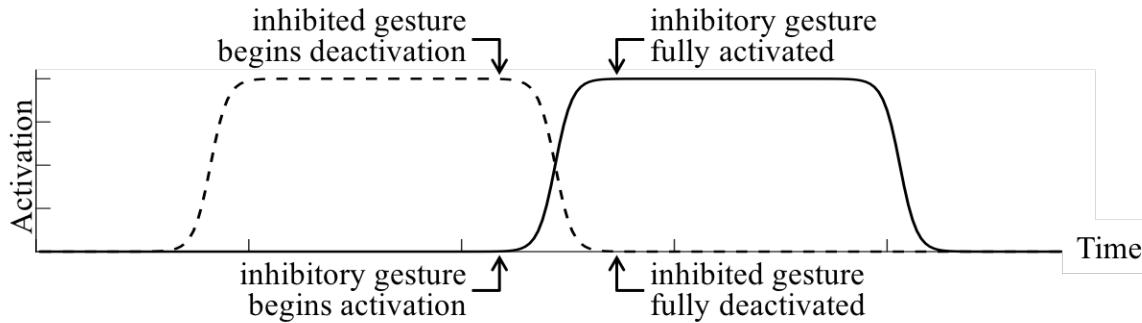
6.2.2 Intergestural Inhibition

Section 4.3 introduced the concept of intergestural inhibition as a mechanism for accounting for the blocking of harmony. Its current implementation within the Gestural Harmony Model is fairly uncomplicated. In the case of progressive harmony, an inhibiting gesture completely and immediately deactivates an inhibited gesture in order to avoid the overlap of incompatible gestures. In the case of regressive harmony, an inhibiting gesture prevents an inhibited gesture from activating until immediately after the deactivation of the inhibiting gesture. This is sufficient to capture basic cases of blocking by segments that are deemed by the phonological grammar to be incompatible with a harmonizing property. However, there are many harmony systems whose patterns of blocking do not fit this basic schema. Further research should examine whether the mechanism of intergestural inhibition can be elaborated in order to account for these more complex patterns of blocking. In particular, this research should focus on questions of whether deactivation due to intergestural inhibition need always be complete and immediate, or whether it can be partial and/or gradual.

As discussed in section 4.3, the Gestural Harmony Model's representation of blocking as intergestural inhibition is consistent both with a representation of gestural activation as involving instantaneous activation and deactivation as well as ramped activation and deactivation. In a traditional model of gestural activation, a gesture's activation level goes from zero to one instantaneously, and during deactivation, that activation level goes from one to zero

instantaneously. In a model of ramped gestural activation, the transition is not instantaneous, but is still rapid. This is illustrated by the figure in (252), repeated from (133) in section 4.3.

- (252) Persistent gesture (dashed) is fully inhibited and immediately deactivated by a following blocking gesture (solid)

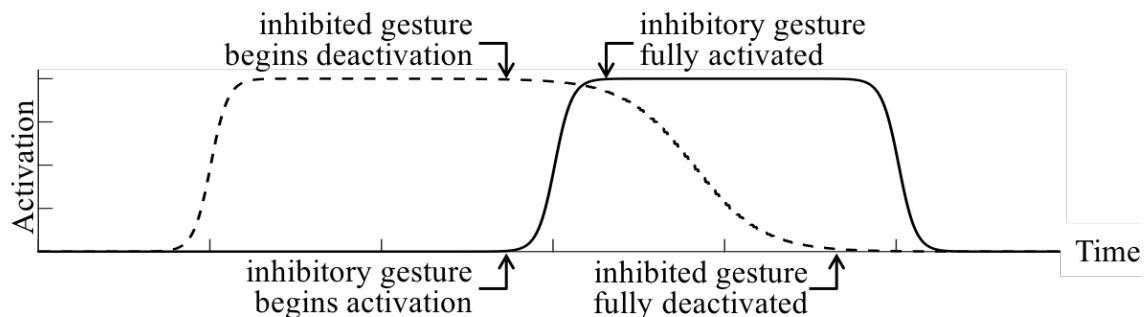


It is assumed that during one of these transition periods, a gesture's activation level may only take on a value between zero and one; a gesture cannot settle into an activation level other than zero or one. However, doing away with this assumption may have interesting consequences for the types of intergestural inhibition it is possible to represent within the Gestural Harmony Model.

One issue worth examining is whether intergestural inhibition should always involve the complete and immediate deactivation of an inhibited gesture, or whether gradience in the strength of an inhibition relation, and in the resulting level of activation of an inhibited gesture, should be admitted to the theory. Such gradient inhibition has several possible advantages. One is the ability to account for harmony systems in which blockers of harmony partially take on the harmonizing property. For instance, in Terena (Arawakan; Brazil), progressive (rightward) nasal harmony targets vowels and glides and is blocked by obstruents (Bendor-Samuel 1960, 1966). Interestingly, while these obstruents block nasal harmony, they also partially undergo it, surfacing as prenasalized. A similar pattern is found in Epena Pedee (Harms 1985, 1994; Walker 1998/2000); its progressive nasal harmony targets vowels, glides, and liquids, while obstruents

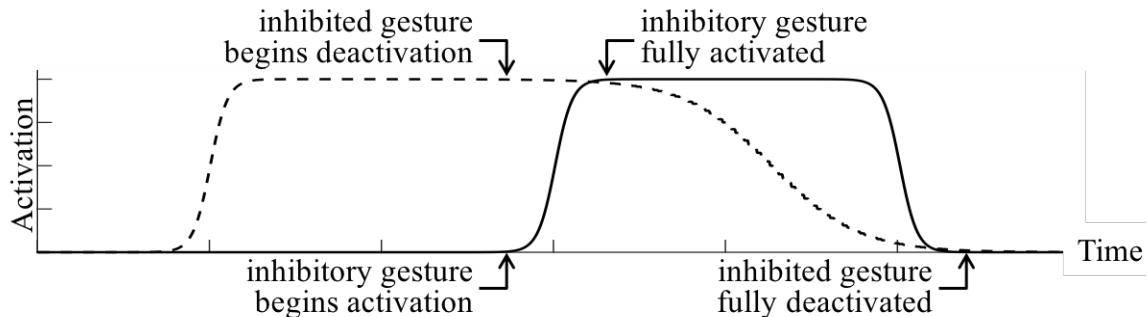
block harmony and surface as prenasalized. Both of these languages present cases of nasal harmony in which a blocker seemingly does not immediately deactivate a harmonizing gesture. Within the Gestural Harmony Model, this could be accounted for if inhibition were not assumed to always involve complete and immediate deactivation of a harmonizing gesture. While deactivation of a persistent velum opening gesture begins when the activation of an obstruent begins, this deactivation of the velum opening gesture would not be completed until well into the period of activation of the obstruent. The figure in (253) demonstrates.

- (253) Persistent gesture (dashed) is gradually inhibited and gradually deactivated by a following blocking/partially undergoing gesture (solid)



If gestural activation levels and the strengths of the inhibition relations between them are more gradual than previously assumed, such cases could potentially be provided with a straightforward analysis. It may also be possible to leverage the idea of gradual deactivation to capture what Jurgec (2011) refers to as ‘icy targets,’ those segments that fully undergo a harmony process but halt the further spread of a harmonizing property. Within the Gestural Harmony Model, icy targets could represent a special case of gradual inhibition in which the deactivation of a harmonizing gesture occurs at such a slow rate that it overlaps a blocking gesture entirely. This is illustrated in the figure in (254).

- (254) Persistent gesture (dashed) is gradually inhibited and gradually deactivated by a following ‘icy target’ gesture (solid)



The ability for gestural activation levels to take on values other than zero or one would also have implications for harmony patterns in which it appears that blocking occurs only if two potential blocking conditions are present. For instance, in Tuyuca (section 4.4.2; Barnes & Takagi de Silzer (1976), Barnes (1996)), obstruents do not block nasal harmony within a morpheme, but do block nasal harmony when in the initial position of a suffix that follows a harmony-triggering root. This suggests that while obstruents cannot block nasal harmony on their own, the combination of an obstruent and a morpheme boundary is enough to block nasal harmony. Similarly, tongue root harmony in Lango (Western Nilotc; Uganda; Noonan (1992), Archangeli & Pulleyblank (1994), Smolensky (2006)) displays complex patterns of blocking based on multiple sources of markedness. As part of this complex pattern, ATR harmony is blocked when it would proceed across a geminate consonant and also target a nonhigh vowel. However, geminate consonants and nonhigh vowels do not block harmony on their own.

If intergestural inhibition relations are allowed to take on intermediate degrees of strength, these more complex patterns of blocking can be accounted for within the Gestural Harmony Model. Taking the case of Tuyuca nasal harmony as an example, the account would be roughly as follows. In Tuyuca, a persistent (non-self-deactivating) velum opening gesture is inhibited by obstruents; however, this inhibition is too weak to actually deactivate the velum

opening gesture. As a result, obstruents do not act as blockers of within-morpheme nasal harmony. A persistent (non-self-deactivating) velum opening gesture is also inhibited by a following suffix. There are a number of ways that this could be implemented. The inhibition could come from the gestures in the segment at the edge of the morpheme. Alternatively, this inhibition could come from a gesture corresponding to a higher organizational node for the morpheme as a whole. For some suffixes, this inhibition is strong enough to deactivate the velum opening gesture, and the suffix surfaces as a fixed oral suffix. For other suffixes, this inhibition is not strong enough, and the suffix undergoes nasal harmony rather than blocking it. However, when a suffix begins with an obstruent, it will always block nasal harmony due to the combined effect of two inhibition relations (one from the morpheme boundary, one from the obstruent) working to deactivate the harmonizing velum opening gesture. Under this analysis, gradient intergestural inhibition would account for the somewhat complex patterning of fixed and varying suffixes in Tuyuca nasal harmony.

While incorporating gradience of gestural activation and intergestural inhibition relations into the Gestural Harmony Model would make it possible to account for more complicated patterns of blocking than those addressed in chapter 4, this gradience also introduces some significant theoretical questions. Chief among these is what it means for a gesture to be partially active, both to the phonological grammar and to the Task Dynamic Model of speech production. It is currently unclear whether a partially active gesture should count as present in a phonological form, and whether it would be fully visible to constraints in the grammar. From the perspective of speech production, it is also unclear whether a partially active gesture would only command the vocal tract to an intermediate degree, thus affecting the achievement of its target articulatory state.

One way of addressing these issues is to incorporate some kind of thresholding mechanism for gestural activation, as in the model of gestural activation proposed by Tilsen (2013, 2016). In Tilsen's Selection-Coordination Model, gestures are gradually active at some abstract level of representation, but are categorically present within a gestural score during the period in time in which their activation levels are greater than some threshold value. This ability to represent gestural activation as both gradient and categorical could be a useful addition to the Gestural Harmony Model's inhibition mechanism if it were elaborated to include gradient activation. It is also possible that Smolensky & Goldrick's (2016) Gradient Symbolic Computation framework, in which input elements may have gradient activation levels but output elements must be categorically present or absent, could provide some useful insights in this area. Their framework could prove especially useful in addressing questions concerning how the phonological grammar references gradually active gestures, and how it manipulates this gradience between underlying and surface forms.

The discussion of blocking of nasal harmony by certain suffixes in Tuyuca brings up another issue regarding patterns of blocking and the representation of intergestural inhibition in the Gestural Harmony Model. In many harmony systems, morphemes can be classified as being either fixed or alternating for a harmonizing property. While alternating morphemes undergo harmony when attached to another morpheme containing a trigger of harmony, fixed or invariant morphemes do not undergo harmony. This is the case in several nasal harmony systems, including Tuyuca nasal harmony (section 4.4.2; Barnes & Takagi de Silzer (1976), Barnes (1996)). Fixed morphemes are also commonly found among tongue root harmony systems, including Nandi ATR harmony (sections 2.2.3 and 3.2.2; Creider & Creider (1989)). In these

tongue root harmony systems, morphemes may have a fixed ATR value, a fixed RTR value, or an alternating value for tongue root position.

If the presence of intergestural inhibition relations in surface forms is motivated solely by markedness constraints such as *OVERLAP, there is no clear way to account for the existence of morphemes that appear to idiosyncratically block harmony. To address this, it may be advantageous to redefine the mechanism of intergestural inhibition even further by recasting a gesture's ability to block harmony as a property of that gesture rather than as the result of an intergestural relation. Under this approach, *deactivators* would be represented as phonological objects that are associated with certain gestures. A deactivator could be conceived of as an object that is somehow affiliated with a gesture; for instance, the velum closure gesture of an obstruent that blocks nasal harmony could include a deactivator for a velum opening gesture. Alternatively, it is possible that the gestures themselves could serve as deactivators of certain other gestural types. In either case, casting a gestural deactivator as a type of phonological entity would allow it to appear not only in surface forms as dictated by the phonological grammar, but also in underlying forms as part of the phonological specification of a lexical item. As a result, these deactivators would be able to serve a contrastive function and provide an account for idiosyncratic blocking of harmony. In addition, casting gestures as being specified to deactivate certain other types of gestures, rather than relying on *OVERLAP constraints to motivate intergestural inhibition, could possibly address the Gestural Harmony Model's issue with generating sour grapes patterns of harmony, discussed in section 4.7.4.

Under the gestural deactivator approach, the question remains as to whether contrastive deactivation should be permitted at the level of the segment/gesture or at the level of the morpheme. If the ability of a gesture to serve as a deactivator of another gesture is encoded

within its representation, then this predicts that this contrastive blocking may occur at the segment level. However, it is unclear whether this is supported by crosslinguistic typology. While morpheme-level idiosyncratic blocking of harmony is attested, examples of idiosyncratic blocking at the level of the segment are elusive. Such analyses have been suggested for some harmony patterns; perhaps the most well-known example is Hungarian backness harmony (see Törkenczy (2011) for an overview). However, it is possible that these harmony systems instead represent cases of contrastive triggering, similar to those discussed in sections 3.3 and 3.5, rather than contrastive blocking. For instance, rather than analyzing Hungarian as exhibiting backness harmony with front vowels that idiosyncratically block harmony, this pattern could instead be analyzed as a case of frontness harmony in which front vowels idiosyncratically trigger harmony. With the development of a new set of vowel representations to include the representations of vowel height and backness, as discussed in the previous section, such cases should be examined thoroughly in order to determine the optimal way in which to analyze them.

In any case, the idea of inhibition as the product of gestural activation rather than intergestural relations is an intriguing one that should be examined further. It provides an appealing parallel to the account of idiosyncratic harmony triggering via gestural parameter presented in sections 3.3 and 3.5, which has already been demonstrated to provide significant advantages in accounting for sometimes complex patterns exhibited by harmony patterns.

6.2.3 *Directionality of Harmony*

The current implementation of gestural duration extension in the Gestural Harmony Model includes no directional asymmetries. Progressive harmony is the result of gestural persistence, by which a gesture does not self-deactivate when it reaches its target articulatory state. Regressive harmony is the result of gestural anticipation, by which a gesture activates

before the starting 0° phase of its clock. Further work within the Gestural Harmony Model should focus on whether and how the model should incorporate any asymmetries relating to the representation of progressive and regressive harmony.

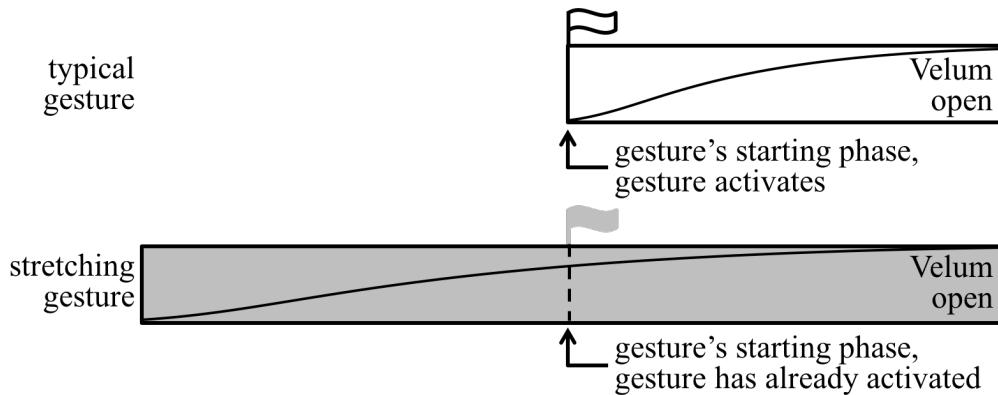
Claims about directional asymmetries in harmony are numerous and sometimes inconsistent. Kaun (1995) claims that the directionality of a harmony system is predictable based on which positions in a word a harmony-triggering segment may surface. Baković (2000) makes a similar claim that directionality is directly predictable from the morphological structure of a language. While these generalizations seem to hold true of the rounding harmonies of Altaic languages that make up Kaun's survey and the Niger-Congo and Nilo-Saharan languages that make up Bakovic's survey, these claims do not seem to hold more generally. Hyman (2002) picks up on this and suggests that where morphology does not determine the direction of harmony, there is a regressive (leftward) bias. Again, however, this claim does not appear to generalize to different types of harmony.

When examining crosslinguistic tendencies in the directionality of harmony, the following observations can be made. The typological patterns of directionality in harmony vary by the harmonizing element, by language family, and by area. While some types of harmony do appear to show a regressive (leftward) bias (e.g., post-velar vowel-consonant harmonies), many others (e.g., nasal harmony, rounding harmony, backness harmony) show a bias toward progressive (rightward) harmony. A successful theory of harmony should be able to account for these biases, and their possibly articulator-specific nature.

If there is a directional bias, whether across all types of harmony or within a given type of harmony, further research should work to determine its source. If harmony is driven by a desire to maximize the period of activation of a gesture such that its perceptibility is maximized, then a

difference in the attestation of progressive versus regressive harmony could be based in an asymmetry in the perceptual payoff of extending in one direction or the other. For instance, if regressive harmony is less prevalent, it could be the case that anticipatory gestures do not involve simple early activation, but should instead be modeled via some kind of gestural stretching in which a gesture activates earlier than its 0° phase, but reaches its target articulatory state at the same time it would have as a typical gesture. This could be achieved by assuming that the early activation of a gesture is automatically accompanied by a lowering of gestural stiffness such that the time point at which it achieves its target articulatory state is stable, regardless of the time point at which the gesture activates. This is shown in the figure in (255), using velum opening gestures as an example.

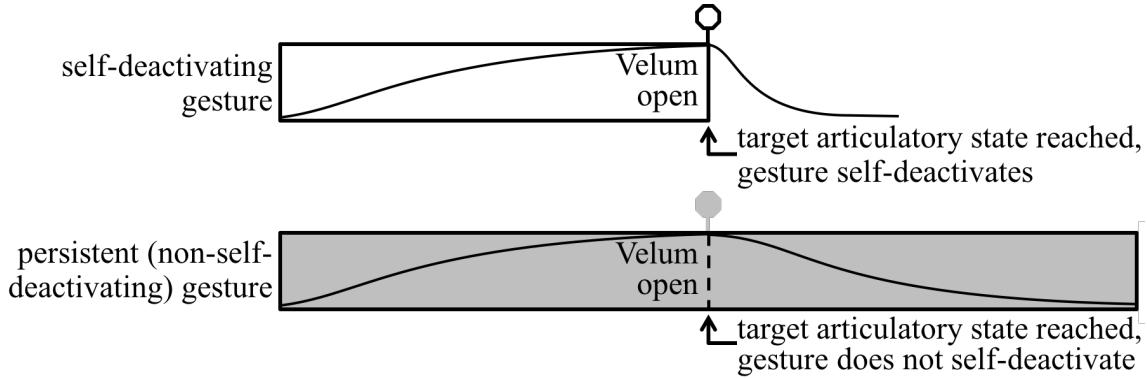
(255) Possible alternative representation of gestural anticipation as stretching



Alternatively, if progressive harmony is less prevalent, it could be the case that persistent gestures do not involve simply staying active as long as they are able, but instead represent a gradual deactivation. This could be modeled by some kind of decay parameter that determines the rate at which a gesture's activation reaches zero. While a typical gesture would have a relatively high decay rate, and would deactivate simultaneously with the achievement of its

target articulatory state, a persistent gesture could be modeled as a gesture with a low decay rate that causes it to remain active for a longer period of time. This is illustrated in the figure in (256).

(256) Possible alternative representation of gestural persistence as gradual decay



It could also be the case that the gestural representations of harmony in the progressive and regressive directions vary across different types of harmony. This is a matter for further study. This study will need to explore the full range of asymmetries that might arise between progressive and regressive harmony. These could include asymmetries in blocking, in which harmony is blocked in one direction and not the other. These could also include asymmetries in triggering, potentially affecting conditional triggering in one direction and not the other.

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