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Langues possibles et impossibles : Naturalité, facteurs tiers, et phonologie sans substance à la lumière des règles folles

Alexander Marx Chabot

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THÈSE DE DOCTORAT

Langues possibles et impossibles
Naturalité, facteurs tiers et phonologie sans substance à
la lumière de règles folles

Alexander Marx CHABOT

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du grade de docteur en Sciences du langage

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LANGUES POSSIBLES ET IMPOSSIBLES

NATURALITÉ, FACTEURS TIERS ET PHONOLOGIE SANS
SUBSTANCE À LA LUMIÈRE DE RÈGLES FOLLES

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Langues possibles et impossibles: Naturalité, facteurs tiers et phonologie sans substance à la lumière de règles folles

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December, 2021

ABSTRACT

This thesis is about phonological computation and its status as cognition. It asks what phonological computation is like, how possible linguistic sound patterns are constrained by facts about the physical world, and to what extent those facts are recapitulated in phonology itself.

The world's languages exhibit a variety of dynamic phonological patterns. Some are relatively common and recur frequently across language families. Other patterns are less common, occurring rarely or in isolated cases. The formal notation used in phonological theories—meant to embody something real happening in human brains—can be used to express both rare and frequently recurring patterns of alternation. They can in principle be used to express still other kinds of alternations which seem to never occur, or even alternations which are impossible in human language. One of the most important questions in phonological theory, asked for example by Reiss (2003: 335), is *what is a possible rule?* Or, going beyond phonological grammars, what is a possible language?

This thesis explores these questions in the light of phonetically arbitrary alternations, known as *crazy rules* (Bach & Harms 1972). Phonological alternations are a universal property of natural human languages; while many—perhaps most—phonological alternations are easily stated in phonetic—typically articulatory—terms, crazy rules seem to obey no principles of articulatory phonetics. In computational terms, crazy rules are arbitrary because from any input \mathcal{X} , any output \mathcal{Y} can be produced.

This thesis provides an overview of *naturalness* in phonological theory—a tool employed with the ambition of providing phonological theory with explanatory and predictive power. A survey of 34 crazy rules suggests that there is no naturalness in phonology. Further, the survey allows for an important observation to be made: crazy rules are only ever segmentally crazy. While there are patterns of alternation that are phonetically arbitrary, there is no crazy pattern of alternation that depends on syllabic or other suprasegmental structure. The thesis then considers phonological theory in the light of crazy rules. It argues that formal naturalness faces serious conceptual and empirical issues, making a number of false predictions about possible and impossible languages. It suggests a possible explanation for the rarity of crazy rules that does not rely on naturalness or other constraints built into the formal theory, but on facts that lay outside of phonology—facts about human articulation, perception, and language change.

Excising naturalness, the thesis argues that Substance-Free Phonology (Hale & Reiss 2008) provides a promising way of conceptualizing inquiry into the computational properties of phonology. Closing out the theoretical portion, the thesis proposes a substance-free analysis

of an intricate pattern of alternations in Campidanese Sardinian. The model makes profitable use of a distinct melodic domain and a distinct suprasegmental domain. In the former, craziness is possible and thus so are arbitrary melodic computations. In the latter, craziness is impossible and lenition and fortition are perfectly regular phonological processes, even in a substance-free model where phonetic scales can not be used to reliably measure them.

The thesis also proposes a review of Artificial Grammar Learning experiments used to test the learnability of phonological rules: especially those which are unnatural. While there is substantial evidence of a complexity bias in phonological pattern learning in laboratory settings, there is much weaker evidence of a naturalness bias. Finally, this thesis outlines a protocol for EEG experiments which can be used to sound alternations and compare them to phonological computation. The study has a double ambition: to see if neurobiological activity in Artificial Grammar Learning experiments is comparable to neurobiological activity of natural language phonology, and to see if neurobiological activity is similar across natural, complex, and arbitrary alternations in natural-language production.

ABSTRACT

Cette thèse porte sur la computation phonologique et son statut en tant que cognition. Elle demande à quoi ressemble une computation phonologique, comment les motifs possibles de sons linguistiques sont contraints par des faits du monde physique, et dans quelle mesure ces faits sont récapitulés dans la phonologie elle-même.

Les langues du monde présentent une variété de motifs phonologiques dynamiques. Certains sont relativement courants et se reproduisent fréquemment dans toutes les familles linguistiques. D'autres motifs sont moins fréquents, se produisant rarement ou dans des cas isolés. La notation formelle utilisée dans les théories phonologiques—censée incarner quelque chose de réel qui se passe dans le cerveau humain—peut être utilisée pour exprimer des schémas d'alternance et rares et fréquemment récurrents. Elle peut en principe être utilisés pour exprimer encore d'autres sortes d'alternances qui semblent ne jamais se produire, ou même des alternances qui sont impossibles dans le langage humain. L'une des questions les plus importantes de la théorie de la phonologie, posée par exemple par [Reiss \(2003: 335\)](#), est *qu'est-ce qu'une règle possible?* Ou, au-delà des grammaires phonologiques, *qu'est-ce qu'une langue possible?*

Cette thèse explore ces questions à la lumière d'alternances phonétiquement arbitraires, appelées *règles folles* ([Bach & Harms 1972](#)). Les alternances phonologiques sont une propriété universelle des langues humaines naturelles; tandis que beaucoup—peut-être la plupart—des alternances phonologiques sont facilement énoncées en termes phonétiques—typiquement articulatoires—les règles folles semblent n'obéir à aucun principe de phonétique articulatoire. En termes de computation,

les règles folles sont arbitraires car à partir de tout input \mathcal{X} , tout output \mathcal{Y} peut être produit.

Cette thèse fournit un aperçu de la *naturalité* dans la théorie phonologique—un outil utilisé avec l’ambition de fournir à la théorie phonologique un pouvoir explicatif et prédictif. Une étude de 34 règles folles suggère qu’il n’y a pas de naturalité en phonologie. De plus, l’enquête permet de faire une observation importante : les règles folles ne sont jamais folles sauf au niveau segmental. Bien qu’il existe des motifs d’alternance phonétiquement arbitraires, il n’existe pas de motif d’alternance folle qui dépende de la structure syllabique ou d’une autre structure suprasegmentale. La thèse considère ensuite la théorie phonologique à la lumière de règles folles. Elle soutient que la naturalité formelle est confrontée à de graves problèmes conceptuels et empiriques, faisant un certain nombre de fausses prédictions sur les langues possibles et impossibles. Elle suggère une explication possible de la rareté des règles folles qui ne repose pas sur la naturalité ou d’autres contraintes intégrées dans la théorie formelle, mais sur des faits extérieurs à la phonologie—des faits sur l’articulation, la perception et l’évolution des langues humaines.

Excluant le naturel, la thèse soutient que la Phonologie Sans Substance (Hale & Reiss 2008) fournit un moyen prometteur de conceptualiser l’enquête sur les propriétés computationnelles de la phonologie. Clôturant la partie théorique, la thèse propose une analyse sans substance d’un motif complexe d’alternances en sarde campidanais. Le modèle utilise à bon escient un domaine mélodique distinct et un domaine suprasegmental distinct. Dans le premier cas, la folie est possible et donc les computations mélodiques arbitraires le sont aussi. Dans ce dernier, la folie est impossible et la lénition et la fortification sont des processus phonologiques parfaitement réguliers, même dans un modèle sans substance où les échelles phonétiques ne peuvent pas être utilisées pour les mesurer de manière fiable.

La thèse propose également une revue des expériences d’Apprentissage de Grammaire Artificielle utilisées pour tester l’apprenabilité des règles phonologiques : en particulier celles qui ne sont pas naturelles. Bien qu’il existe des preuves substantielles d’un biais de complexité dans l’apprentissage des modèles phonologiques en laboratoire, il existe des preuves beaucoup plus faibles d’un biais de naturalité. Enfin, cette thèse présente un protocole d’expérience EEG qui peut être utilisé pour sonder les alternances et les comparer à la computation phonologique. L’étude a une double ambition : voir si l’activité neurobiologique dans les expériences d’apprentissage de grammaire artificielle est comparable à l’activité neurobiologique de la phonologie de langue naturelle, et voir si l’activité neurobiologique est similaire à travers des alternances naturelles, complexes, et arbitraires dans la production du langage naturel.

*To my mother, who gave me language
and to my father, who gave me curiosity*

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ACRONYMS

AGL	Artificial Grammar Learning
BP	Brazilian Portuguese
CS	Campidanese Sardinian
CVE	Central Virginia English
CR	Computational-Representational
ECP	Empty Category Principle
EEG	Electroencephalography
ERP	Event-Related Potentials
FL	Faculty of Language
FLB	Faculty of Language—Broad Sense
FLN	Faculty of Language—Narrow Sense
fMRI	Functional Magnetic Resonance Imaging

FP	Formal Phonology
GP	Government Phonology
GrP	Grounded Phonology
GMP	Granularity Mismatch Problem
LSG	Linguistically Significant Generalization
LP	Lexical Phonology
MEG	Magnetoencephalography
MMN	Mismatch Negativity
NP	Natural Phonology
NGP	Natural Generative Phonology
OIP	Ontological Incommensurability Problem
OT	Optimality Theory
PET	Positron Emission Tomography
RF	Raddioppimento Fonosintattico
SFP	Substance-Free Phonology
STG	Superior Temporal Gyrus
SPE	The Sound Pattern of English
UG	Universal Grammar

INTRODUCTION

This thesis is about phonological computation and its status as cognition. It asks what phonological computation is like, how possible linguistic sound¹ patterns are constrained by facts about the physical world, facts about domain-general mechanisms like categorization, and domain-specific restrictions inherent in the formal system, and to what extent those facts are recapitulated in phonology itself.

The world's languages exhibit a variety of dynamic phonological patterns. Some are relatively common and recur frequently across language families. Other patterns are less common, occurring rarely or in isolated cases; still others are absent from the record or look so completely implausible that most phonologists would say they are in fact impossible. A fundamental question for phonological theory asked for example by Reiss (2003: 335), is thus: *what is a possible rule?* Or, from the point of view of phonology, what is a possible language?

In past and current approaches to phonology, the answer to this question implicitly or explicitly relies to a great extent on naturalness: a process is possible if it is natural, it is rare or inexistent if it is unnatural. Naturalness thus serves as a way of providing phonological theory with explanatory and predictive power. This thesis provides an overview of naturalness in phonological theory (Chapter 2): what counts as (un)natural, how is naturalness defined, how is it used to constrain phonological theory?

Following Anderson (1981), the goal of this thesis is to show that there is no naturalness in phonology. Naturalness is a property of phonetics, which may be carried into phonology when phonetic precursors are grammaticalized (phonologized). But phonology itself does not know what natural or unnatural things are: (phonetically) natural patterns in phonology are due exclusively to what is called third factors in the minimalist perspective (Chomsky 2005), which include physical factors such as phonetics, but also domain-general cognitive mechanisms, such as a bias against computational complexity.

Since Anderson (1981), the absence of naturalness in phonology has been emphasized—particularly in Substance-Free Phonology (starting with Hale & Reiss 2000b). This thesis explores an understudied phenomenon in order to show that phonological computation is not constrained by naturalness, known as *crazy rules* (Bach & Harms 1972). Crazy rules describe alternations that make no phonetic sense. While

¹ Though I use the term “sound” here, it is infelicitous. There are also phonological patterns in signed languages (see Stokoe 1960 [2005]; Sandler 1993, 2012, 2014; Brentari 2011; Marshal 2011). For the time being, this infelicitous use of terminology will serve as a useful shorthand for externalized language, although this thesis considers both signed and spoken languages to be in the remit of phonological theory. That is, phonology is modality independent: what is true of oral speech is true of signed speech as far as phonology is concerned.

most alternations have a phonetic motivation in terms of both the structural changes effected ($p \rightarrow f$) and the contextual trigger ($p \rightarrow f / V_V$), crazy rules seem to not be subject to any phonetic motivation ($p \rightarrow r$, or $p \rightarrow f / \#_$). If it can be shown that crazy rules are real, i.e. instantiate true phonological computation (rather than allomorphy, lexicalized patterns, analogy, etc.) and are synchronically active, the idea that phonology imposes naturalness is refuted.

This perspective is first substantiated by a survey of crazy rules that have been reported in the small literature concerning the subject (Chapter 3): an inventory of 34 cases is studied in detail, evaluating whether the pattern is regular, synchronically active, and phonological in nature. A relevant empirical generalization is that crazy rules are only ever segmentally crazy. While there are patterns of alternation that are phonetically arbitrary, there is no crazy pattern of alternation that depends on syllabic or other suprasegmental structure.

Based on this insight, Chapter 5 proposes a substance-free analysis of an intricate pattern of alternations in Campidanese Sardinian. Below the skeleton, craziness is possible and thus so are arbitrary melodic computations. By contrast, at and above the skeleton, craziness is impossible and lenition and fortition (which are syllabic in nature) are perfectly regular phonological processes, even in a substance-free model. The argument is that the Campidanese pattern meets all criteria for being the result of true phonological and synchronic computation, but it cannot be made sense of if naturalness is active.

Chapter 6 proposes a review of Artificial Grammar Learning experiments used to test the learnability of phonological rules: especially those which are unnatural. While there is substantial evidence of a complexity bias in phonological pattern learning in laboratory settings, it is found that there is much weaker evidence of a naturalness bias.

Finally, Chapter 7 proposes an experimental study that seeks to use EEG recordings to show that the alternations in Campidanese are phonological and synchronic in nature—work that unfortunately was made impossible by the pandemic. The chapter instead lays out the experimental setup and protocol, as well as the language material used.

Part I

THEORY

Language is not, as we are led to suppose by the dictionary, the invention of academicians or philologists. Rather, it has been evolved through time, through a long time by peasants, by fishermen, by hunters, by riders. It did not come from the libraries; it came from the fields, from the sea, from rivers, from night, from the dawn.

Thus, we have in language the fact (and this seems obvious to me) that words began, in a sense, as magic.

BORGES

WHAT PHONOLOGY IS AND WHY IT SHOULD BE

Only mind sees, only mind hears, all
else is deaf and blind.

EPICHRMUS OF KOS
as translated by Karl Popper

The position adopted in this thesis is that phonology is an innate cognitive capacity, the genetic endowment of *Homo sapiens*. I will argue that this cognitive capacity is purely symbolic in nature, having only an indirect relationship with the physical world exterior to cognition. The thesis explores how such a symbolic phonology interacts with the real world, and how its architecture limits the set of possible phonological processes. It develops a model of phonology which allows for predictions to be made about sound patterns of possible and impossible languages.

So that the model developed herein can be fruitfully compared to other models of phonology, the ambition of this first chapter is to make explicit the pretheoretical assumptions underlying the arguments in later chapters. It proceeds as follows:

Section 1.1 provides an overview of the notion of the *Faculty of Language*, a cognitive capacity shared by all human beings, a genetic endowment which allows for the understanding and production of limitless linguistic expression. It argues that phonology is the domain of faculty of language which constitutes the knowledge speakers have about the patterns of sound in the languages they speak. It argues that phonology is a computational system, built from basic representational units which can be manipulated by operational processes to produce spoken language.

In Section 1.2, I argue that the full predictive potential in a model of phonology does not come from an investigation of neurobiological activity, but from understanding phonology as a property of human minds. It is argued that it is through perceptual cognition that human beings understand and build knowledge about the real world outside of the mind; in this way phonology is like perception in that it allows humans to acquire knowledge about linguistic sound from the real world.

Finally, a model of mental architecture known as *modularity of mind* is presented in Section 1.3. The modular view, here, constitutes a first sketch of a phonological architecture that, it will be argued, provides an explanatory account of possible and impossible phonological grammars, and is put to fruitful use in laying the foundational pieces of a theory of phonology in Chapter 4.

1.1 PHONOLOGY AS A NATURAL OBJECT

1.1.1 *The Faculty of Language*

The object of inquiry in this work—the human phonological capacity—is an aspect of the biology of *Homo sapiens*. A fundamental pretheoretical assumption adopted here is not just that language happens in human brains, but that human brains are built with dedicated architecture for the acquisition and use of language (Anderson 2008; Chomsky 1980; Jackendoff 2002; Lenneberg 1967). In this view, language is a natural object, a distinctive species-specific capacity that ultimately emerges from the genome of human beings¹.

While it is certain that language acquisition is in part the product of environment—one learns Saigon Vietnamese or Mexican Spanish as a function of being born into a community of speakers of Saigon Vietnamese or Mexican Spanish—beginning with the work of Saussure (1916 [1967]) it has been a long-standing foundational pillar of linguistics that there is a fundamental distinction to be made between *langue* as a property of a speech community, such as Saigon Vietnamese or Mexican Spanish, and *langage* as an abstract object independent of that community. An explicit characterization of *langue* depends on all sorts of factors external to *langage* itself since its form is a factor of historical events, the sociopolitical structure of a language area, sentimental nationalism, and so forth.

Language defined as a cultural artifact is typically an abstract and arbitrary grouping of languages by social categories: states (Chinese, Dutch), tribes (Comanche, Guaraní), ethnic or racial groups (Serbian, Black English), social classes (London working-class English, upper-class Tamil). It is, for example, unclear what we mean when we talk about “Chinese”, because Chinese is a vague term used for any number of diverse languages spoken in China. When we talk about “Serbo-Croatian”, we are making a distinction based on political lines more than objectively based linguistic ones. We may talk about “French” but the object in question looks quite different depending on if we are referring to the language spoken in France, Québec, or Côte d’Ivoire. There is linguistic variation at all analytic levels even in very small speech communities, and the variation only increases the coarser the definition of the speech-community becomes.

The Saussurian distinction between the external object of *langue* and the internal object of *langage* is a bright line between language as a social phenomenon and language as a mental phenomenon—it is the latter which is of interest here. The use of *langage* by an individual is based on a Faculty of Language (FL), which is a product of nature, and not of nurture (Saussure 1916 [1967]: 25). Though a language is conventional and acquired through exposure, FL is that shared capacity in human beings to acquire and use natural language (Anderson 2008; Chomsky

¹ See Crain & Pietroski (2001) for an overview of what has come to be known as the *innatist position*.

2002a)—what Haspelmath (2020) calls “linguisticity”. FL is conceived of as a cognitive capacity endowed by biology which—in contrast to learning chess or how to play the piano—allows human beings to rapidly and effortlessly acquire a language with no explicit instruction upon exposure to linguistic stimuli (Anderson 2008; Jackendoff 2011; Rizzi 2004). In this sense, *capacity* means a product of “appropriate external conditions” which needs no explicit instruction or training to be used, and is not dependent on general cognitive metrics such as intelligence (Chomsky 1980: 4). Crucially, FL operates according to domain-specific principles which determine not only how language is acquired, but how it is used (Chomsky 1980); that strictly delimitable set of principles determines the possible forms languages can take.

Thus, the basic position of the program of generative linguistics is that the study of language is not the study of the externalization of language as an abstract phenomenon or social artifact (Jackendoff 1997: 2). Rather, it is the study of an object that exists in the minds of speakers and is instantiated in human brains. Every individual human being—barring cases of serious pathology or gross abuse and neglect—speaks a language that can be studied in isolation from the sociocultural context from which it emerges. This is the basis for the distinction made by Chomsky (1986: 20ff.) between *External language* or *E-language*—a construct “understood independently of the properties of the mind/brain”—and *Internal language* or *I-language*—an “element of the mind of the person who knows the language, acquired by the learner, and used by the speaker-hearer.” I-language is the object of inquiry for theoretical linguistics (Chomsky 1986; Volenec & Reiss 2017, 2020).

I-language, then, is a product of FL, conceptualized as an internal mental phenomenon and amenable to a realist, rationalist approach to inquiry—one in which linguistics is a branch of cognitive science and linguistic theory is a theory of human cognition (Chomsky 1986: 4). This conception of I-language as an element of mind/brain makes linguistic a part of psychology and ultimately biology (Chomsky 1986). From an appropriately abstract perspective, the principles which underlie FL can be isolated from other cognitive functions (Anderson & Lightfoot 2002): FL can be conceptualized as having distinctive characteristics in the way that any other biological system does (Boeckx & Piatteli-Palmarini 2005; Chomsky 2002a). For example, Chomsky (1980: 39) argues that, as in other biological systems, the brain is structured with a differentiated architecture rather than being a homogeneous multi-tasking computer with no specialized functions (see §1.3). In this sense, FL can be compared to a “mental organ” (Anderson & Lightfoot 2002; Chomsky 1980; Jackendoff 1997), an analogy to any biological system which is physically indisassociable from an organism but which is conceptually isolable.

The mental organ metaphor can be profitably used to distinguish between those properties, recurrent in language after language, which are due to the distinctive properties of FL and those which are external to it (Anderson 2008: 805). While a language looks the way it does

due to both environmental factors as well as FL, the set of cognitively possible languages that can be generated by FL is distinct from incidental properties related to speech production. A theory of language is thus a theory of the set of principles which emerge from FL, independent of the myriad different forms of language specific to times, places, cultures, and societies.

A more granular distinction for FL has been argued for by Fitch et al. (2005); Hauser et al. (2002), where Faculty of Language—Narrow Sense (FLN) are those aspects of language which are unique to FL and unique to *Homo sapiens*, and Faculty of Language—Broad Sense (FLB) are those aspects of FL shared by other cognitive domains or other species. The usefulness of this conceptual dichotomy is that it allows for the features of language which evolved *only* in humans to be identified². Here, FLN encompasses everything that is innate and specifically dedicated to language; essentially the computational mechanism of syntactic recursion and the mapping to the interfaces (Fitch et al. 2005: 182).

In the view of Fitch et al. (2005) and Hauser et al. (2002) phonology is a part of the sensory-motor system, the function of which is to map between the symbolic output of syntax and the output of phonetics, and thus a part of FLB (see also Carr 2000); in the words of Samuels (2009: 355), phonology is “an afterthought.” Jackendoff & Pinker (2005); Pinker & Jackendoff (2005), however, argue that phonology must be a property of FLN since its constituent structures and principles, as well as the precise nature of its mapping properties, are in fact specific to human language. I return to this question in §4.4.5.2. For the time being, it will be instructive to consider those aspects of phonology which are indeed shared by other cognitive domains, in particular perception (see §1.2.2).

1.1.2 Linguistic knowledge

That phonological theory as an element of a theory of FL means adhering to a philosophy of scientific realism is evident from the fundamental distinction made by Chomsky (1965: 3) between the principles underlying the structure of language and the actual act of speech production:

Linguistic theory is concerned primarily with an ideal speaker listener, in a completely homogeneous speech-community, who knows its language perfectly and is unaffected by such grammatically irrelevant conditions as memory limitations, distractions, shifts of attention and interest, and errors (random or characteristic) in applying his knowledge of the language in actual performance.

² Boeckx (2013); Martins & Boeckx (2016); Waciewicz (2012) argue that the distinction between FLN and FLB is not useful; in part because it is not entirely clear what the difference between novel capacities unique to *Homo sapiens* and those which have been modified over the course of human evolution might be (Boeckx 2013: 68ff.).

The production of language in real-life situations may be constrained by all sorts of non-linguistic factors: an individual's attention, energy levels, whether their mouth is full or they have just had dental surgery, and so on—this is known as *performance*. In contrast, linguistic *competence* represents the knowledge speakers have about the structure of their language, and is the “fundamental factor” in performance (Chomsky & Halle 1968: 3). This distinction is comparable, though not the same, to the one Saussure (1916 [1967]) makes between *langue* and *parole*, where what is produced through the act of speech is dependent on many factors that are unrelated to the knowledge underlying that speech act.

Competence is the system of rules that accounts for the combinatoriality of language (Chomsky 1980: 90); that combinatoriality is a conceptual necessity (Jackendoff 1997: 3). That is, at a minimum, a theory of language needs to account for the fact that speakers can construct and understand an unlimited number of sentences in their language(s) (Jackendoff 2011: 586). To speak a language is not just to acquire a repeatable list of overheard utterances (see Chomsky 1959), rather language is a system of *knowledge* that, among other things, allows the construction of an infinite set of grammatical sentences as well as the identification of ungrammatical sentences (Chomsky 1957 [2002]). In this sense, *grammatical* utterances are those which are a product of a *grammar*: an intensional system which can generate an infinite number of meaningful expressions from a finite set of discrete units (Chomsky et al. 2019) (see also Halle 1962: 54).

Chomsky (1986: 3) views knowledge of language as individual grammars, which are theories “of the state of the mind/brain of the person who knows a particular language.” A grammar, then, is a description of an I-language, a formalized expression of a speaker's linguistic knowledge. A theory of language must be a theory of the units and combinatorial principles stored in human brains that generate the boundless set of grammatical sentences. Going a step further, to have any explanatory value, it should tell us if there are grammars which speakers *cannot* learn—impossible languages (see Moro 2016). In phonological terms, knowledge is of the system of relations between physical sounds and their cognitive representations, both in static and dynamic terms. A phonological grammar, in turn, is a model of an I-language state of those relations.

The ambition of a theory of phonology is to be a theory of knowledge *qua* competence, not of performance, where linguistic knowledge reveals the architecture of FL (Anderson 2008: 802). In order to make observations relevant to linguistic knowledge, however, an appropriate level of abstract idealization that allows for those structures to be isolated, analyzed, and explained must be adopted (Chomsky 1980). Since this knowledge is instantiated in finite human brains, it must be encoded in combinable, finite terms, and that encoding constitutes a speaker's knowledge of their language (Jackendoff 2011: 587). That is, linguistic knowledge is not the knowledge of a single, unitary object, but rather knowledge of a system of distinct components which

interact with each other in specific ways; knowledge of language is explained in terms of mental structures, systems of *rules* and of *representations* which reflect particular instances of knowledge (Chomsky 1980).

1.1.3 Universal Grammar

Chomsky (1986: 25) argues that FL has an initial state common to all human beings, S_0 . This initial state is genetically determined, and itself determines the possible states FL can assume (Chomsky 2004: 104). The theory of FL in this initial state S_0 , prior to any linguistic experience, is known as Universal Grammar (UG) (Chomsky 1986, 1995, 2002a). UG is the innate, biologically-endowed machinery for encoding linguistic *knowledge*, which we have seen is formalized as a *grammar*. UG is not the grammar itself, but it makes available the *computational procedure for human language* that generates expressions (Chomsky 2002a: 100). Upon exposure to an ambient E-language, S_0 develops into a stable steady state S_S , which is the grammar of an I-language. UG is what is common to all human beings in the form of S_0 , but not to every I-language S_S . In this sense, a theory of phonology is a theory of S_0 of the phonological component of UG.

We can thus speak of a phonological UG which gives rise to phonological I-languages upon exposure to an ambient language, which in turn can be formalized as phonological grammars. Since, as argued by Chomsky (1995: 169), UG determines the class of possible languages, a theory of phonology *qua* architecture of UG is a theory of possible languages. Theories of phonology may differ as to the predictions made regarding the sets of possible and impossible languages, but all generative theories share certain basic assumptions about the basic processes and operators of phonology: rules³ and representations.

The basis of generative grammar is the “inverted-T” model (Chomsky 1965): the relation between sound and meaning is mediated by syntactic structure as when the morphemes in *un+sustain+abil+ity* are interpreted separately as sound and as meaning. It is the phonological component of a grammar which interprets morphemes as sound, as in Figure 1.1. Morphemes must be learned individually and stored

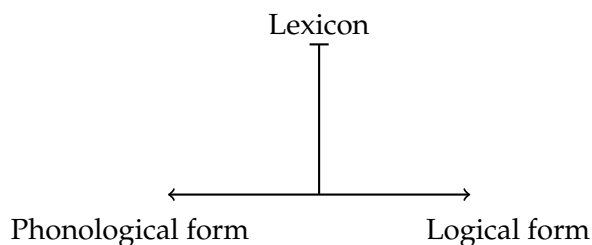


Figure 1.1: The inverted-T model of generative linguistics (Chomsky 1965).

³ In Optimality Theory (OT) (Prince & Smolensky 1993 [2002]) rules are replaced by constraints, see §2.3.3.5.

in the lexicon, an element of long-term memory. The lexicon contains only idiosyncratic properties of words which cannot be predicted, they thus allow morphemes to be distinguished, one from another: *cat* is not *cap*. Those idiosyncratic properties constitute lexical representations, interpreted as sounds.

A phonological grammar, in turn, is built out of phonological rules which assign structural descriptions to the sentences of any given language (Chomsky & Halle 1965: 97f.). That is, the abstract objects built by syntax are given phonetic expression by phonological rules which map between mental objects and physical objects. Chomsky & Halle further argue that the grammar thus conceived represents a “fundamental aspect” of what a speaker knows about their language. Thus expressed, formal phonology is a model of observable, systematic behavior underlying speech sounds and the cognitive functions and abstract structures from which that behavior arises (Purnell 2018: 140).

Rules are the computational aspect of *UG*, the range of variation in possible rule forms is circumscribed by *UG*’s architecture. Rule forms and what kind of changes are permitted by rules are a central theme of this thesis, and a subject I will discuss in Chapters 2 and 4. For now I will provide a brief overview of the motivation and evolution of rules in phonological theory, as well as the symbolic objects rules operate over: phonological features.

1.1.3.1 *Phonological rules*

Trubetzkoy (1969: 31) articulated a position that constitutes a central tenet of structuralism:

One thing can be distinguished only from another thing: it can be distinguished only insofar as it is contrasted with or opposed to something else, that is, insofar as a relationship of contrast or opposition exists between the two. . . Oppositions of sound capable of differentiating the lexical meaning of two words in a particular language are *phonological* or *phonologically distinctive* or *distinctive oppositions*.

That is, for a given linguistic sound to be distinguishable from any other linguistic sound, it must be *distinctive*, and that distinctiveness presupposes *opposition*. The primacy of sound as an oppositional unit means that the physical attributes of a sound are less important in linguistic terms than its function as a distinctive unit.

Saussure (1916 [1967]: 166) makes this clear: “dans la langue il n’y a que des différences.” A physical description of linguistic sounds in terms of acoustics or articulatory facts does not explain their function, rather linguistic sound is understood as a systematic relationship between the sounds of a given language which stand in opposition to one another—what Sapir (1925: 39) characterizes as a “psychological aloofness” necessary to their status as “symbolically utilizable counters.” This is what Sapir means by a *sound pattern*—the relation of distinct sounds in a language relative to each other.

Sound patterns are characterized by the contextual variation internal to languages. That is, “what is felt by speakers to be the ‘same’ sound has perceptibly different forms” as the phonetic context varies (Sapir 1925: 42). Rather than being categorized in terms of its psychical attributes, a sound is categorized as a phoneme—a symbolic, *mental* representation of contrast. In this sense the phoneme is abstract (cf. Twaddell 1935), but Sapir (1933) argues that it has “psychological reality” for speakers; as such it is a real object, an example of *knowledge*. As an example, consider the following words as pronounced in Central Virginia English (CVE) (1):

- (1) [t^h]oo[t̚]
 [t^h]oo[r]ing
 s[t]oop

In these words, the distribution of /t/ is contextually dependent: it is realized as [t^h] with aspiration when word initial; as *checked* [t̚] when word final; as a *flap* [r] when between two vowels; as [t] when it is the second element of an s+C cluster. Speakers of CVE do not notice the physical differences of each sound, but instead reduce all four sounds to a single symbolic representation, noted as the phoneme /t/. Sapir (1933) argued that these objective differences go unperceived because they do not correspond to anything significant in the language’s sound pattern: no words are distinguished based on the difference between [t], [t^h], [t̚], and [r]. In fact, the different realizations of /t/ in the various contexts of (1) are not contrastive; rather they are predictable based on the position of /t/ in its immediate context (2):

- (2) Word initial: [t^h]
 Word final: [t̚]
 Between two vowels: [r]
 Following /s/ in an s+C cluster: [t]

As argued, lexical entries contain just enough information to maintain contrast and to determine phonetic form in each context. Systematic generalizations of the kind in (2) represent linguistic knowledge. This knowledge not as a property of the lexicon, but as the property of a *phonological rule*, which applies to every lexical item which conforms to the the rule’s requirements and formalize knowledge of alternations (Chomsky & Halle 1965, 1968).

Any phonological rule has a number of structural properties (Kisberth 1970). The first is the *structural change* performed by the rule, which is an account of what the rule does. The class of possible structural changes is only determined by examination of the empirical record. The second structural property of a phonological rule is the *structural description* of the rule, a formal account of the conditions which trigger the rule, such as “before a nasal obstruent” or “in a syllable coda”.

Thus, the variation in (2) can be formalized as a series of rules (3):

- (3) $t \rightarrow t^h / \# _$
 $t \rightarrow t' / _ \#$
 $t \rightarrow r / V _ V$

The exact formalization of the rules depends on details of the theory, for now it is sufficient to say that rules capture systematic generalizations representing speaker knowledge, and that rules apply to representations when their structural conditions are met. The nature of rules characterizes and explains the kind of surface patterns which are attested in natural languages. Their form determines, in part, what kinds of mappings are possible between the objects stored in speakers' memories and how those objects are expressed in physical terms.

1.1.3.2 *Phonological representations*

It is important to note that the phoneme is not the basic unit of phonological computation. As [Trubetzkoy \(1969: 67\)](#) points out, it is not phonemes themselves which are central to phonology, but the distinctive oppositions inherent in the phonemes. An opposition is based not only on the properties which distinguish two objects, but also on the properties common to those objects. A set of phonemes then, can be understood as a set of properties which are common to its members and properties which distinguish between them—sub-phonemic properties into which phonemes may be decomposed. [Jakobson et al. \(1952: 3\)](#) make this explicit when they say that within a given language, every opposition “has a specific property which differentiates it from all others. . . between the presence and absence of a certain quality, such as voiced vs. unvoiced, nasalized vs. non-nasalized, sharpened vs. non-sharpened (plain).” Those specific properties are known as *distinctive features*, for [Jakobson et al.](#), “the ultimate distinctive entities of language,” atomic and undecomposable into smaller units.

As an illustration, consider the [CVE](#) words *pit/bit*, *tomb/doom*, and *cut/gut*. It is obvious to speakers of [CVE](#) that these word-pairs all begin with different phonemes: /p b/, /t d/, /k g/, respectively. What is less obvious, although clear upon reflection, is that the pairs p/b, t/d, and k/g are all different in the same way: each pair shares exactly the same lip, tongue, and teeth articulatory configurations, but the second member of each pair is accompanied by vibrations of the vocal cords. This vibrating of the vocal cords is a minimal difference between each member of the pairs, and constitutes a *phonological feature*⁴, which is the minimal representational unit used by phonological theory ([Chomsky & Halle 1968](#); [Kenstowicz 1994](#)).

[Jakobson & Halle \(1956\)](#) explicitly conceive of contrasts between phonemes as being based not on the phonemes themselves, but rather on the features of which they are composed. Combined into a simultaneously occurring bundle known as *segments*, features are the

⁴ See the volume edited by [Clements & Ridouane \(eds.\)](#), especially [Cohn \(2011\)](#) for a discussion of features, and [Durand \(2005\)](#) for a general overview of phonological primitives beyond the narrow conception of features.

atomic units of phonology. Like Sapir's notion of the phoneme, features serve to abstract away from irrelevant and predictable facts of physical realization, and capture generalizations based on contrasts, rather than the physical properties of speech sounds (Anderson & Lightfoot 2002). Thus, what is central in phonological representations is not the phoneme, but rather the oppositions between them, inherent in features.

Features subserve phonological computation in several respects. Chomsky & Halle (1965, 1968) attribute a classificatory role to features, using them to define subsets of sounds which pattern together, thus formalizing the notion of *natural class*. That is, they define classes of sounds and how they pattern together in phonological rules (Ladefoged 1971: 3). In this sense, features encode *sameness* (Hall 2007): they are the common element, to the exclusion of all those which are non-relevant, in sets of segments which are subject to specific phonological computations.

As a demonstration, consider Navajo (Na-Dené), a language in which there are four fricatives subject to contextual voicing, /z ʒ γ l/, as in (4)⁵:

- (4) a. [náhá lá:ʔ]
 /ná h i lá:ʔ/
 'up-SER.PERF3P' 'gather objects'
 'he gathers them, picks them up'
- b. [náháʃ ʔá:h]
 /ná h jɪʃ ʔá:h/
 'up-SER.IMP1P' 'gather objects'
 'I gather them, pick them up'

In (4), the morpheme /-lá:/ 'gather objects' is analyzed with an underlying voiced /l/. When it follows a morpheme that ends in a voiceless consonant, as in /-jɪʃ/ in (4b), it is realized as [-ʔá:]. That is, the voiced fricative /l/ is realized as voiceless [ʔ] when it follows a voiceless consonant. This is not a process limited to /l/: /z ʒ γ/ are all subject to this contextual voicing, realized as [s ʃ x] respectively. This set of fricatives thus constitutes a natural class, since they all share a property are targeted by a single process, contextual voicing.

They also share the property of being voiced fricatives, their unity formalized with the shared features [+voice] and [+continuant]. Since all the other consonants in Navajo are sonorants or stops, together [+voice] and [+continuant] formalize the sameness of the class of segments targeted by contextual voicing, and the difference between that class and the segments not targeted by contextual voicing. The alternation can then be formalized as in (5):

$$(5) \begin{bmatrix} +\text{continuant} \\ +\text{voice} \end{bmatrix} \rightarrow \begin{bmatrix} +\text{continuant} \\ -\text{voice} \end{bmatrix} / \begin{bmatrix} -\text{voice} \end{bmatrix}_-$$

5 Data adapted from McDonough (2003: 53).

The rule in (5) uses features to characterize the target, the computational change, and the output. Natural classes then are characterized by the features used to define them (see also §4.4.4 and §4.4.2.3).

In sum, FL is that unique human capacity to learn and use language, instantiated as UG. In terms of phonology, UG defines the nature of phonological rules, and phonological rules determine in part the set of phonologically possible languages. One of the central questions of this thesis is what possible forms phonological rules can take, principally focusing on the role of phonetic naturalness in UG and rule formalism (see Chapter 2).

1.2 PHONOLOGY AS COGNITION

1.2.1 *The biological foundation of phonology*

At the heart of this thesis is the idea that *phonology is cognition*. That is, phonology is an activity which occurs in human brains, in real time, for which the brain is endowed with specific architecture. As humans, our experience of the external world is removed, since our percepts are the product of mechanical and chemical limitations and of cognitive processing—all three are factors in what and how humans perceive. However, if we wish to understand the cognitive aspect of phonology, phonology's cognitive properties must be distinguished from the mechanical and chemical mechanisms inherent in a holistic view of Language.

Perception of speech begins with rapid, sinusoidal changes in air pressure, characterized as a continuous and gradient sine wave (Warren 2008). Sound waves arrive at the outer ear and move down the ear canal to the ear drum, which vibrates on contact with pressure changes. The vibration of the eardrum in turn causes the vibration of three small bones—the ossicles—which transmit the vibrations to the liquid-filled cochlea. In the cochlea vibrations in the liquid stimulate the movement of small hair cells, which stimulates neuronal activity in the form of *action potentials*—electrical changes across cell membranes (see Barnett & Larkman 2007)—in the cochlear nuclei, located in the brain-stem (Gazzaniga et al. 2014; Warren 2008).

The transformation of the sound waves into action potentials is a kind of *transduction*, “the bridge from the physical to the symbolic” Pylyshyn (1984: 84); after the moment of transduction, all perception is cognition. Once in the form of action potentials, auditory stimuli are sent to Heschl's gyri where the primary auditory cortex is located. The primary auditory cortex performs a number of tasks including locating sounds in space and identifying the content of an acoustic stimulus (Barton & Brewer 2016; Gazzaniga et al. 2014). Sound stimuli relevant to speech are shunted towards anterior and posterior regions of the Superior Temporal Gyrus (STG), which is primarily responsible for processing of phonological information (Burton 2001), though not exclusively (Gazzaniga et al. 2014: 483). These regions show activity

responses to speech-like stimuli which has no semantic interpretation, implicating a pre-lexical stage of processing (Monahan et al. 2013).

Monahan et al. (2013) report findings that show that regions of STG exhibit activity associated with more than just acoustic differences in speech stimuli, meaning that STG is not only activated by complex sounds but also by phonologically meaningful distinctions. Monahan et al. further report on evidence suggesting STG is accessed during speech production as well as perception, even when production is covert. Moving up, the STG interfaces with conceptual systems through a network in posterior inferior temporal regions of the cortex (Hickok & Poeppel 2004).

To account for the distinct tasks associated with different brain regions, Ullman (2004) proposes a model of phonological architecture called the *declarative/procedural* model which implicates declarative memory in the interface between phonology and the lexicon, and procedural memory in the operation of phonological computation. This system involves activity in a network of frontal, basal-ganglia, parietal, and cerebellar structures. Hickok & Poeppel (2004) identify the ventral stream, with its connections to medial temporal lobe and the limbic system as a broadly conceived “what” system for audition where sensory information is converted into a format suitable for linguistic computation: it handles multiple levels of acoustic-phonetic processes, the interface with long-term memory in the form of the lexicon, and the interface with non-phonological linguistic computation in the form of syntactic and morphological operations. In sum, Hickok & Poeppel suggest that this pathway is responsible for the transition from sound to meaning, where linguistic sound is identified and encoded into phonological representations.

With the neurobiological structure of phonological processes thus broadly sketched, it is important to recognize that not much about phonological knowledge is revealed. The identification of language-specific neuroanatomy is not likely to yield an understanding of language in neurobiological terms (Hickok & Poeppel 2004: 69). The reason is that language processing is dynamic, involving memory and mapping between inputs and outputs. Phonology *qua* inquiry into the sets of possible and impossible languages cannot be conducted in purely neurobiological terms: the mere observation of physical events in the brain tells us very little about what it means to perceive those physical events and what they tell us about the external world.

Gazzaniga (2010: 298) for example argues that understanding neuron functions tells us “absolutely nothing about how the brain manufactures a mental state.” The reason for this pessimistic assessment is articulated by Gallistel & King (2009: 171): “[n]euroscientists do not know with any confidence the answers to even the most basic questions about how computations are carried out in neural tissue. There is, for example, no consensus about what the primitive computational operations are, out of which other computations are constructed.” This is not just a problem for linguists, since cognitive scientists in general do not have a good understanding of how mind and brain are related

(Boeckx 2013: 65). In short, “we have no idea” how cognitive capacities come about through the details of neurobiological structure (Jackendoff 2011: 588).

Functional studies whose primary ambition is the localization of brain regions associated with any domain of language, even if they make fine-grained distinctions, are typical of “top-down” approaches to investigation, which seek to designate the parts of a system without inquiry into the mechanisms by which those parts function; as a consequence top-down theories cannot be used to understand or explain the neural mechanisms which underlie language (Arbib & Caplan 1979: 452). Lenneberg (1967: 61) argues that there is, in fact, no evidence for “absolute” language areas, but rather the functional architecture of language implicates regions which are “very frequently” involved in speech and language, and others which are “never” involved. Further, since phonology is modality independent and can depend on more than one brain region, ancillary cortical regions involved in the perception of acoustic signals are not germane to the cortical activity of phonological activity.

Rather than focusing on cortical geography, a more fruitful approach lies in describing neurobiological activity related to speech perception and production. Such an approach involves two aspects: methods of observing cortical activity, and an understanding of how the representational and algorithmic systems underlying language are encoded in the brain Poeppel & Embick (2005). Before looking at cortical activity, however, explicit hypotheses about what representations look like are needed (Philips 2001). For example, Philips (2001: 724) cites evidence for neurological correlates for discrete categories, which are the hallmark of phonological representations in terms of features. That is, phonological theory drives inquiry into the neurobiology of phonology—we need a theory of what to look for before we can begin to search for it.

Poeppel & Embick (2005) identify two issues which must be addressed in order to derive explanation for linguistic patterns from neurobiology:

1. The Granularity Mismatch Problem (GMP): Linguistic theory operates on the basis of fine-grained distinctions and explicit computational operations, while neurobiology operates in terms of broad conceptual distinctions.
2. The Ontological Incommensurability Problem (OIP): The basic units of linguistic computation are incommensurable with those of neurological computation.

The GMP makes explicit the “conceptual granularity” mismatch of basic notions in linguistics and in neurobiology. While the former are detailed (*phonological feature, syllable, noun phrase*, and so forth) the latter are relatively much larger (*dendrites, population, cortical column*), and inspecting them using current neurobiological techniques does not reveal the theoretical structures of linguistics. The two ontologies seem

to be built out of different vocabularies, and Poeppel & Embick (2005) argue that this mismatch prevents the construction of linking hypothesis between neuroscience and linguistics which are both theoretically motivated and biologically grounded.

The OIP is a consequence of not considering how neurological structures are specialized to perform the specific types of computation in linguistic theory; the result is that the primitive objects of linguistic theory do not compare to the fundamental biological units of neuroscience. Each set of objects, linguistic and neurobiological, are posited in order to capture generalizations in their respective domains, but the generalizations are not of like-kind. The GMP and OIP are interface problems faced by any study of cognition, including phonology (Poeppel & Embick 2005).

1.2.1.1 *The biolinguistic program*

Conscious of the issues raised by Poeppel & Embick (2005), the biolinguistic approach to phonology is primarily concerned with how phonological knowledge is encoded in brains (Monahan et al. 2013). Inquiry into the cortical basis for phonology provides a way to link cognitive science with neurobiology, providing a mapping from the physical properties of the real world to cognition—abstract representations of those objects. In the biolinguistic view, “linguistics is part of biology at a suitable level of abstraction” (Boeckx & Piatteli-Palmarini 2005: 462). The biolinguistic approach views language as a natural object, and adopts methodological practices from the natural sciences (Boeckx & Piatteli-Palmarini 2005; Rizzi 2004), seeing linguistics as a cognitive science whose principle concern is uncovering the biological underpinnings of FL (Boeckx 2013).

Explanations for linguistic observables can in principle be derived from formal theories which are agnostic to biological concerns (Boeckx 2015a: 129). However, since human language is instantiated in human brains as linguistic knowledge, that knowledge must take the form of structures and processes which actually occur in brains. It will not do, for example, to propose theories which bear no relation to what evolutionary biology tells us can come about in organisms or what neurobiology tells us happens in brain tissue. The ambition of the biolinguistic program is to investigate what the faculty of language is, what its primitives are, and how those primitives are instantiated in brains (Martins & Boeckx 2016: 1). In effect, the biolinguistic approach takes seriously the idea that FL is an organ of the brain, and can be studied like any other biological aspect of the species (Boeckx & Grohmann 2017).

That is, there is not one set of mechanisms behind FL and a substantially different set of mechanisms behind other disparate domains of biology (Martins & Boeckx 2016); instead, the mechanisms behind FL, and the means for studying it, are valid for all of biology (Chomsky 2005). Lack of understanding of the biological correlates of phonology impedes progress in understanding the range of plausible phonological

computations that can be instantiated in the nervous system (Poepfel & Embick 2005); the brain itself serves as a constraint on the sets of possible and impossible languages since what cannot be computed in the brain is an impossible language. On the other hand, if a formal theory of phonology makes neurobiological sense, then there is no *a priori* reason to assume it is not a realistic model of phonology *qua* cognition, even if it makes surprising predictions about possible languages.

In its strongest sense, biolinguistics represents an effort to provide explanation for linguistic theory through insights from biological sciences—evolutionary biology, genetics, neurology, psychology—in the manner set forth by Lenneberg (1967). In order to understand the structural requirements imposed on FL by biology, linguists are confronted with questions of cognitive specificity and ontogeny, among others (see Boeckx & Grohmann 2017: 3). A theory of linguistics integrated with a plausible theory of the structure and function of mind/brain is a basic desideratum of theory construction (Jackendoff 2011: 590). Ultimately, taking a biolinguistic view seriously means that the primitives posited in the theories formulated by linguists are to be scrutinized in the light of biology (Martins & Boeckx 2016: 10).

Concerning phonological knowledge, one of the principle lines of research in biolinguistics is how I-language is instantiated in human brains. This question framed in more broad terms applied to linguistic knowledge in general has come to be referred to as “Humboldt’s problem”⁶ (Boeckx 2015a; Boeckx & Grohmann 2017; Chomsky 1986; Jenkins 2000). Biolinguistics as a research problem is not just concerned with Humboldt’s problem, but it is relevant to the present thesis since it is concerned with the construction of theories of phonology, in particular with the role of phonetic knowledge in formal theory and how *it* is instantiated in human brains.

Neuroscience is directly relevant to the study of phonology and thus in principle informs the construction of phonological theory (Jackendoff 1997). Indeed, Jackendoff (2011: 604) argues that a theory of language necessarily must integrate FL into the rest of mind/brain in order to have biological plausibility. This is because biology constrains any good theory of FL: “what doesn’t make sense in biology cannot make sense in a theory of language” (Martins & Boeckx 2016: 10). One advantage of examining theories through this lens is that biologically implausible theories—say for example one that says humans store every single sentence they ever hear in long term memory—can be eliminated. More prosaically, considering phonological theory through the lens of neurobiology may serve as a means of restricting generative devices and thus UG. In turn, reducing UG in scope reduces what must have occurred in the evolution of *Homo sapiens* to give rise to UG (Chomsky 2005).

Thus, while crude examinations of neurobiological activity does not allow for a very sophisticated understanding of phonology at the

⁶ After Wilhelm von Humboldt, who viewed language as a process that allowed for infinite creativity from finite means (Chomsky 1986).

present, phonological theory and neurobiological observation can mutually inform each other. A theory of phonology can then be used to explain how the brain represents and computes language by telling us how neurobiological structures and response patterns correlate with the set of computations and representations; what Embick & Poeppel (2015: 360) refer to as *correlational neurolinguistics*. For example, knowing that features are an appropriate level of description for neurobiological correlation (Monahan et al. 2013: 236), we can then begin looking for their substrate in neurobiological activity. Such an approach has been shown to be fruitful by Idsardi & Monahan (2016: 149), who provide neurobiological correlates for what they argue are the core aspects of phonological theory: “features, segments, syllables, abstraction, and laws of form” which are crucial to an eventual explanation in neurolinguistics (see also Friederici 2006 for a general overview of neural correlates for various phonological processes beginning very early in life).

Neurobiology may also be used to profitably inform the construction of phonological theory. Beginning at a very low level, the neuron is the basic unit of neurobiological computation. This follows from the *single neuron doctrine* as articulated by Barlow (1972: 380), embodied in Barlow’s first “dogma” of cognition:

(6) *Barlow’s First Dogma*

A description of that activity of a single nerve cell which is transmitted to and influences other nerve cells, and of a nerve cell’s response to such influences from other cells, is a complete enough description for functional understanding of the nervous system.

In this view, neurobiological understanding of cognition happens at the cellular level, in interactions between neurons; single elements of the brain can be shown to have a distinct function related to perception or cognition (Barlow 1972; Marr 1982). Levine (2005) suggests that this may be too microscopic a view: functional units may be coincident with *cohorts* of neurons, perhaps organized into *cortical columns*, in which groups of neurons share functional properties (Mountcastle 1997, 2003).

Neuronal activity is carried out through action potentials in the form of sequences of voltage pulses, known as *spikes* (Rieke et al. 1999: 1). Gallistel & King (2009: 88) consider the neural spike to be the “universal currency” for the transmission of information in neural tissue. The importance of spikes in interpreting information in the brain is made clear by Rieke et al. (1999: 1):

When we see, we are not interpreting the pattern of light intensity that falls on our retina; we are interpreting the pattern of spikes that the million cells of our optic nerve send to the brain. When we hear, we are not interpreting the patterns of amplitude and frequency modulation that characterize the acoustic waveform, we are interpreting the patterns of spikes from roughly thirty-thousand auditory nerve fibers. All the myriad tasks our brains perform in the

processing of incoming sensory signals begin with these sequences of spikes.

Spikes begin with the action of a neuron or group of neurons and then are propagated through neural tissue by triggering electrical changes in other neurons. An important property of spikes is known as the “all-or-none” principle (see [Adrian 1914](#); [Frank 1994](#))—nerve impulses are the same size no matter the strength of the stimulus which triggers them. Crucially, neurons have excitation thresholds which must be exceeded in order to trigger an impulse. The ability of a spike to propagate does not depend on the stimulus which triggers it: they either propagate to neighboring neurons or do not, there is no intermediate stimulus ([Rieke et al. 1999](#)).

The “all-or-none” principle led [McCulloch & Pitts \(1943\)](#) to represent the activity of neurons as a series of logical propositions, essentially binary operators for “true” and “false”. While not meant to be a model of biophysical activity⁷, they do allow for the understanding of cognitive activity: neurons are discrete, they either fire or they do not. [Abraham \(2003\)](#) shows that this abstraction of neuronal activity is a useful tool, allowing the construction of formal, symbolic models with clearly defined properties and empirical content. [Gallistel & King \(2009: 24\)](#) also argue that information transmission and processing in the brain is digital: “information is carried by a set of discrete symbols”, where symbols are “physical entities in a physically realized representational system” ([Gallistel & King 2009: 72](#)). Spike trains, then, represent the continuous properties of the real world encoded into discrete sequences of neuronal activity.

This is exactly what a model of phonology with discrete, symbolic features predicts—minimal neurobiological units functioning as discrete, symbolic operators. Such a model defines the ontologies and processes of phonology in computational terms which are appropriately abstract such that they can be performed by specific neuronal populations ([Poeppe & Embick 2005](#)). This brief review of the neurobiology of phonology provides a rough outline for the sorts of properties that we should expect in a theory of phonology: symbolic operators, discreteness, and binary operations that either happen or do not.

1.2.1.2 *Phonology as a mental organ*

Though obviously the product of neurobiology, the properties of phonology *qua* mental organ can be studied independently of neurobiological structure. Indeed, from a correlational perspective, this is a prerequisite to understanding language in neurobiological terms. The set of attested phonological patterns, as a manifestation of I-language, is a reflection of speaker/hearer knowledge. This conception of I-language as a cog-

⁷ There is some gradient activity in the brain, and cells that send signals across short distances where signal decay is less of an issue—such as in the retina—operate with graded voltage responses ([Rieke et al. 1999](#)).

nitive object commits phonologists to a mentalist stance: phonology is cognition and happens in the human mind⁸.

In order to avoid any Cartesian incoherence the consequence of this stance is that, like all other kinds of cognition, phonology is ultimately a neurobiological phenomenon. However, while all mental processes must have a physical basis, it is not an examination of those physical processes which leads to understanding of the mental processes they give rise to (see Nagel 1974). Marr (1982: 27f.) makes a very apt observation to this point:

[T]rying to understand perception by studying only neurons is like trying to understand bird flight by studying only feathers: It just cannot be done. In order to understand bird flight, we have to understand aerodynamics; only then do the structure of feathers and the different shapes of birds' wings make sense. More to the point, as we shall see, we cannot understand why retinal ganglion cells and lateral geniculate neurons have the receptive fields they do just by studying their anatomy and physiology. We can understand how these cells and neurons behave as they do by studying their wiring and interactions, but in order to understand *why* the receptive fields are as they are—why they are circularly symmetrical and why their excitatory and inhibitory regions have characteristic shapes and distributions—we have to know a little of the theory of differential operators, band-pass channels, and the mathematics of the uncertainty principle...

Marr (1982: 15) asks if neurobiology can answer any questions regarding *how* or *why* the activity of neurons gives rise to cognitive processes, suggesting that to understand cognitive processes, they must be conceptualized in a way that is independent of specific mechanisms and structures in brains.

To this end, Marr (1982: 25) describes three levels of explanation in understanding information processing as related to the neurobiological function of perception, reproduced in Figure 1.2. Each level can be described independently of the others, although the answer to the first level is a prerequisite for the second level, and the answer to the second level is a prerequisite for the third. Marr argues that each level must be understood in order to have an explanatory theory of perceptual cognition in neurobiology.

The most basic form of understanding of perceptual cognition in the brain then is the *computational level*—the “complex computations constructed from the composition of elementary features” which the

⁸ Searle (2004: 113ff.) argues that mind can be understood as conscious states which have no ontological status independent of neurobiology, but which exist at a higher level than that of neurobiological activity. While individual neurons are not conscious, in Searle's words “portions of the brain system composed of neurons are conscious.” Consciousness is a subjective, first-person state of interpreting the world—for Searle it is “causally reducible” to neurobiology, but not “ontologically reducible.”

Figure 1.2: The three levels of perceptual information processing according to Marr (1982).

1. Computational theory	2. Representation and algorithm	3. Hardware implementation
What is the goal of the computation, why is it appropriate, and what is the logic of the strategy by which it can be carried out?	How can the computational theory be implemented? In particular, what is the representation for the input and output, and what is the algorithm for the transformation?	How can the representation and algorithm be realized physically?

brain uses to extract the information it needs to make sense of the world (Gallistel & King 2009: 59). Embick & Poeppel (2015: 360) identify the computational level with the domain of theoretical linguistics, and the algorithmic level with the real-time properties that are the domain of psycholinguistics. In terms used in this thesis the first level can be identified as *competence* and the second as *performance* (see §1.1.2); the levels can be profitably applied to an understanding of phonology as cognition both as perception and as production. This thesis is primarily concerned with the first level as it applies to phonology.

Marr (1982) argues that a computational theory has two important aspects: 1) it specifies what is computed and why and 2) the operation is defined by the constraints it has to satisfy. Regarding the theory of visual processes, he argues that “the underlying task is to reliably derive properties of the world from images of it” (Marr 1982: 23). For Marr, a computational theory characterizes a mapping from one kind of information to another, with precise definitions for the mapping, which demonstrates its appropriateness and adequacy for its task.

The third level is the domain of neurobiology. The relative independence of each level means that the computational theory (what is being computed by the brain) can be abstracted away from the algorithmic (how that thing is realized) and the hardware (where in the brain that thing is). This independence also entails that to know *how* or *where* phonological computation is instantiated in brains, we need an explicit theory of *what* phonological computation is. This, Marr (1982) argues, makes it possible to make explicit statements about what is being computed and why, thereby providing explanation. For example, Abraham (2003) shows the abstract theory of the neuron developed by McCulloch & Pitts (1943) allows for an understanding of neuronal activity not available from neurobiological observation alone.

A model of phonology, then, is a model of mental processes which are a property of *mind*. That is not to say that phonological theory is just an abstraction or useful fiction; following Odden (2013: 250) phonologists

have an “ontological commitment” to describing a natural object which exists; phonological theory makes *true* statements about what human language is, and should have the ambition of “exactly describing the nature of language.” A theory of phonology, then, should be a theory of something which can actually be instantiated in human brains, but it does not rely on direct observation of human brains (see also Poepfel & Embick 2005). The mind is a theoretical object in the sense of Carnap (1966)—it is not directly observable, its temperature cannot be taken, it cannot be weighed, its color cannot be described. Its existence is justified through a *rationalist* approach to scientific inquiry: science is an effort to understand the *principles* of how things work (see Scheer 2011a: 502).

A model of mind serves as a supporting theoretical structure which is needed to make sense of neurobiological observations. It is well recognized in science that theory precedes observation: we cannot see anything if we do not have any expectation about what we will observe (Popper 1935 [1992]). What is needed to make sense of data is a *paradigm* in the sense of Kuhn (1962)—a general consensus on what constitutes a fact and what can be considered data. Linguistic data can only be judged in the context of a well-articulated theory (Halle 1975: 529). This is in part because knowledge about raw data from the physical world is “cooked”, as put by Hammarberg (1981: 262). Theory, then, drives inquiry; in rationalist science theories are constructed to explain phenomena whose effects can be detected, even if the objects themselves are not immediately or directly detectable. In turn, the theoretical objects described exist by virtue of their explanatory power.

The hypothesis-driven method of practicing science is what Weinberg (1976), borrowing from Edmund Husserl, refers to as the *Galilean* style of scientific methodology. Chomsky (2002b: 98) characterizes the Galilean style as the recognition that abstract systems represent principles that provide “deep insight into why” things are the way they are, even in the face of apparent empirical contradictions. Galileo was convinced that the Earth was not stationary, but rather moved around the Sun—not because this was directly observable from the Earth itself, but because his theory eliminated all other possible celestial configurations (see Feyerabend 1976: 106ff., who argues that new scientific theories are frequently in conflict with established scientific facts).

As stated by Wisan (1978: 14), Galileo’s method “was not that of the mathematician who derives true conclusions from true principles but that of deriving conclusions from hypotheses, confirming the conclusions by observations and showing that all alternative hypotheses which are proposed must fail.” Wisan goes on to note that for Galileo, theoretical principles represent the truth, more so than empirical confirmation: if experience does not agree with the theory, there must be some explanation for the incongruity which does not invalidate the theory. The theory, then, must be conceived of independently, or even *regardless* of data. The theory itself represents the truth, and where phonology is concerned it precedes the neurobiological explanation.

Hypothesis-driven science has made important contributions to our understanding of the real world (see Carnap 1966: 240ff.). This is true of cognition as it is of other domains. Theory provides an explanation which allows for understanding, what Feyerabend (1976: 32) calls a dream world” which “we need in order to discover the features of the real world we think we inhabit.” For example, the mechanisms of color perception were worked out by Helmholtz, Hering, Hurvich, and Jameson *before* the underlying physiology was understood (Palmer 1999: 111). This was done by starting from an abstraction and working towards the physical implementation of an algorithmic theory. Palmer (1999: 111) argues that without functional theories which serve as guides to interpret results, “biological data can be accumulated, but their theoretical meaning is unclear.” In sum, a theory of phonology as a product of mind has epistemological value with explanatory value that cannot be provided by a purely neurobiological account.

1.2.2 Perception

For Searle (2004: 259) one of the “chief functions” of the mind is to “relate us to the rest of the world.” Phonology is at the boundary between the real world of physical phenomena and mind-internal aspects of linguistic computation, a singular position in language cognition. For example, the ultimate product of syntax is a hierarchical structure which has no direct physical correlate—its existence is mental and purely symbolic. In contrast, the output of phonology *does* have a direct correlate in the real world: phonological symbols are expressed as sound waves or signs. In this sense, phonology is *different* from other aspects of language. As Bromberger & Halle (1989: 53) put it:

Phonology... is primarily concerned with the connections between surface forms than can serve as input to our articulatory machinery (and to our auditory system) and the abstract underlying forms in which words are stored in memory. Whereas syntax is concerned with the relations among representations that encode different types of information requiring different types of notation, phonology is concerned with the relationship between representations that encode the same type of information—phonetic information—but do so in ways that serve distinct functions: articulation and audition on the one hand, and memory, on the other.

In this view, phonology serves as a mapping between the mind and input to the articulatory system and between phonetic phenomena back to the mind—it tells us about the world external to our minds. For Gallistel & King (2009: 43), “communication between the world and the brain” is a “mapping from states of the world to representations of those states.” The mapping between states is *perception*, the source of virtually everything we know about the physical world outside of our own bodies (Pomerantz 2003).

Perception happens when physical energy from the world external to our minds triggers specialized nerves in sensory organs, and is converted to neural signals through transduction—any process by which energy from the real world is converted into neural activity (Levine 2005). More generally in cognitive science, transduction is the process by which objects in one vocabulary are translated into another vocabulary (see §1.3.2.1). Those neural signals give rise to conscious experience; perception is the interpretation of information about the world brought to us by sensory receptors (Pomerantz 2003). Levine (2005: 25) argues that perception is “organizing a comprehensible internal representation of the external world.” In this regard, phonology is like other sensory systems such as vision, audition, and olfaction (Hawkins 2010): it is a product of sensory stimuli processed in the brain and perceived in the mind⁹.

Pomerantz (2003) specifies eight critical principles underpinning perception:

1. Perception is limited: we perceive only a portion of the information in the real world.
2. Perception is selective: our perception of the real world is limited by attention.
3. Perception refers to the distal stimulus, not the proximal stimulus: stimuli are perceived as properties of objects, not as properties of the sense organs.
4. Perception requires time: perception happens with a slight lag relative to the actual event.
5. Perception is not entirely veridical: perception is not fully accurate or faithful but depends on both mechanical and cognitive limitations.
6. Perception requires memory: perception relies on information stored in memory.
7. Perception requires internal representations: perception relies on internal representations of the percept.
8. Perception is influenced by context: stimuli are perceived in a context of other co-occurring stimuli.

These eight principles serve as a useful initial framework for understanding phonology as cognition. Especially pertinent to the discussion of phonetic naturalness in phonology is its non-veridical nature, and

⁹ Perception is not usually thought of as having output like phonology does. Pylyshyn (1999: 362) however notes that vision, for example, “provides a means for the immediate control of actions and sometimes does so without informing the rest of the cognitive system that is responsible for recognizing objects...” That is, vision interfaces with motor systems (i.e. reaching and grasping) to produce cognitive output (Hickok & Poeppel 2004: 68).

the requirement of internal representations. To understand these principles, consider the visual system, a relatively well-understood cognitive system (Hawkins 2010; Palmer 1999; Pylyshyn 1999).

1.2.2.1 *Perception is non-veridical*

The first critical principle of visual perception is its non-veridical nature—visual stimuli cannot be perceived as percepts faithful to the objects that give rise to them, as seen in Figure 1.3—they are subject to mechanical distortion and cognitive interpretation. The mechanical distortion is due to the properties of the eye’s optics: an object reflects light waves which are focused by the lens onto the retina. In the process, the image is projected “upside-down”, and since the retina is functionally flat, the image is reduced to two dimensions.

Vision is a process by which complex patterns of light on a two-dimensional surface are perceived as three-dimensional objects in a three-dimensional visual scene (Palmer 1999: 9). This implies that the two-dimensional projection is subject to interpretation by the brain. In addition, the optic nerve has no photoreceptive cells and leaves a “blind-spot” on the visual field, although this is invisible to perception, filled in by cognition. Thus, we do not perceive a “high-fidelity” external world as it is—we perceive a reproduction of it, a cognitively-interpreted world.

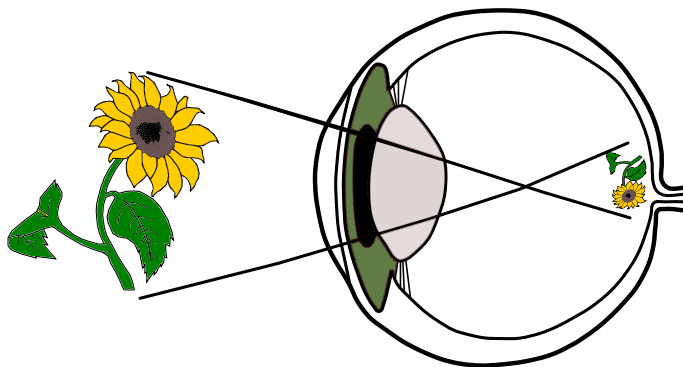


Figure 1.3: A representation of the mechanical aspects of vision.

As in phonology, in a full account of vision the mechanical and chemical aspects as well as the cognitive elements have to be described. The mechanical and chemical aspects of vision—the laws of optics, the lens and the muscles that manipulate it, the material of the eye, the shape of the retina, and the light-sensitive cells on the retina—are not relevant to a theory of the cognition of visual perception, since in principle any number of engineering solutions could do just as well.

More generally, Gallistel & King (2009) survey the current state of cognitive science and suggest that cognition is an information-processing task. Real-world phenomena act on sensory organs, which transform that information in neural signals, which are in turn processed by the brain to extract that information and contribute to an organism’s internal reconstruction of the real world. For percepts (e.g.

blue, or taste of cumin, or smell of the sea), the perceived sensation must not be the same kind of thing as its real-world referent: there are no volatile molecules of cumin in brain tissue. Thus the real-world phenomena are not interpreted as they are, but rather as the neural signals they give rise to in sensory organs—as symbolic objects which represent real-world phenomena in the mind but are not of like-kind with their proximate stimulus. The symbolic objects are *representations*: “a relationship that holds between two systems, a representing system and a represented system” (Gallistel & King 2009: 60).

Representations are then subject to rule-governed *computations*, giving rise to the experience of reality. This conception of mind as an information processing device is known as a Computational-Representational (CR)¹⁰ theory of cognition (Embick & Poeppel 2015; Gallistel & King 2009; Poeppel & Embick 2005; Pylyshyn 1984), (see Thagard 2005 for an overview of the history of CR models of cognition.). The CR theory constitutes an explanation for how the brain experiences real-world phenomena. Poeppel & Embick (2005) do not view the notion of computation as abstract, rather the question of what computations are performed in the brain constitutes the research program in cognitive science. Thus we come back around to the central question of this thesis: what kinds of phonological computations are performed in the brain?

Crucially, an appropriate CR theory of phonology tells us what kind of objects are computed by phonology, and correlates for *those and only those* can be sought in neurobiological activity. Gallistel & King (2009: 219) argue that CR approaches to cognition lead to a more biological conception of learning, where learning “reflects the computational aspects of the problem of extracting a given kind of representation from a given kind of data.” In turn, the CR theory of language can be compared to other domains of cognition with the dual aims of refining the linguistic theory and extending the explanatory power of theories of cognition in general.

Visual cognition will again serve as an illustrative example of more general principles that can be applied to phonology. In visual cognition, the computational system is complex and involves several subsystems working over several different sub-domains, including edge detection, shape detection, and movement detection (see Marr 1982; Palmer 1999, 2003; Pinker 1984; Pylyshyn 1999 for discussion). A simple illustration of visual computation comes from optical illusions¹¹. Optical illusions

10 The use of *computational* here is not to be conflated with the computations of a digital computer, but rather refers to computation in the sense of Turing (1950): explicit step-by-step instructions for accomplishing a task.

11 Optical illusions are of two kinds: those due to perceptual cognition and those due to the effects of optics. The former kind are the subject of the present discussion, and are the result of computation in the perceptual/cognitive system which arise when a computation is not suited to the external world (Gregory 1991). A classic example of the latter is a stick plunged into water, which appears to bend at the waterline. This is due to the effect of light being refracted by water, and not an effect of cognition. Presumably an osprey, whose survival crucially depends on being able to compensate for refraction so that it can hunt fish under the surface, has the necessary cognitive

due to perceptual cognition show that objects which do not exist may be perceived.

For example, in Figure 1.4, a lattice with colored axes is laid onto a white background. Although each color does not extend beyond the lines of the lattice and there is only white space in the axes, the brain perceives colored shapes extended around each colored axis. The effect in Figure 1.4 is known as neon color spreading, described by van Tuijl (1975), in which color seems to spread out from colored segments resulting in the percept of a tinted shape around the axes. Neon color spreading is the result of a computational process in the brain that is not perfectly suited to the situation in the real world, giving rise to a non-veridical percept: the illusion of perceptually created shapes and colors which exist only in the mind.

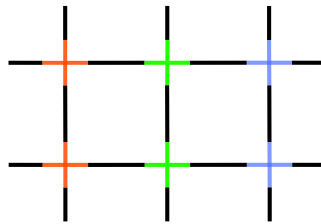


Figure 1.4: Neon color spreading of perceived shapes; image based on Kitaoka et al. (2001).

Another example are the well known Kanizsa triangles (Kanizsa 1955), where shapes are extrapolated from angles and incomplete edges by the construction of contours. In Figure 1.5 the angles in the three circles give rise to the percept of a triangle, although the line segments do not actually join up into one. In this version, a neon-spreading effect is obtained by tinting some line segments and sections of the circles. Although there is only white space between the colored line segments and the colored sections, the brain perceives a blue tint at the angles of the triangle. Typically, even once aware of the illusion, the colors remain in perception: conscious knowledge of the effect is not enough to dissipate it.

Descriptively, the effects in Figure 1.4 and Figure 1.5 show the brain creates lines and “spreads” color, resulting in a perceived triangle where there is none, and a perceptual blue tint where there is fact only white space. These percepts are created by the brain at an early stage of visual processing (Veuilleumier & Landis 1998), before conscious attention can even be brought to bear on the image, suggesting that the computations are basal and a fundamental part of the cognitive architecture.

1.2.2.2 Perception requires representations

The second critical principle of perception is that it requires internal representations—visual percepts are not of like-kind with their stimuli.

adaptations but the human visual system has had no need to develop perceptual strategies to overcome the effect of refraction.

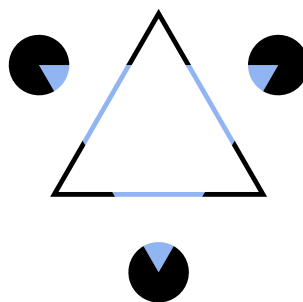


Figure 1.5: Perceived contours of a triangle tinted by blue; image based on Ware (1980).

To see this, consider the case of categorical color perception. The retina of the human eye is covered in two kinds of photoreceptive cells—known as rods and cones—each containing billions of light-sensitive pigment molecules which change shape upon contact with photons, altering the flow of electric current and giving rise to action potentials and the neural activity of cognition (Palmer 1999).

Color is a perceptual effect that arises from the effect of the wave properties of visible light, a narrow band of the electromagnetic spectrum with wavelengths of between approximately 400 nm and 700 nm (Palmer 1999); everything shorter or longer than those wavelengths is not registered by the mechanical sensors of the human eye, and so not perceptible by the brain¹². The spectrum of color is gradient and continuous: wavelengths can be measured with great precision, one is only limited in the precision of measurements by one's instruments and patience. In principle very precise wavelengths—for example 435.027071986 nanometers—can be measured, and in the spectrum of visible light there is a specific wavelength which corresponds to any measurement of any precision. Human beings, however, do not perceive the continuous nature of the color spectrum. Instead, it is segmented by the perceptual system into discrete categories, which correspond to relatively more or less coarse terms such as *red*, *green*, *blue*, and so forth.

One critical aspect of cognition in general is its translational nature: physical phenomena are gradient and continuous¹³, while cognition trades in categorical and discrete phenomena. Division of the continuous phenomena in the real world into discrete symbols is the result

12 The fact that human beings do not perceive some bands of the electromagnetic spectrum—ultrasound, ultraviolet light, magnetic fields, etc.—though bats, bees, and sharks, respectively, do, is above all a matter of physiology, not of cognition.

13 Casey Tomlin (p.c.) has pointed out to me that the treatment of the real world as the domain of continuous phenomena depends on the level of description. A sound wave, for example, is propagated by individual molecules that make up the atmosphere. In this sense, sound is a discrete phenomenon; there is no waveform. A rationalist stance, however, reveals the existence of the waveform by virtue of its usefulness in characterizing and explaining phenomena in the real world. Certainly, phenomena are continuous in human perception: the ear canal is a resonance chamber (Warren 2008: 7), amplifying the frequency of waveforms, while color perception depends on the wave properties of light (Palmer 1999). See Mainzer (2019) for discussion.

of a process known as *categorization* (see Harnad 2005 and Ashby & Maddox 2011, *inter alia*). Categorization is the process by which variable input are treated as invariant input, giving rise to a single kind of output. Essential to perception is the creation of categories; for color, the continuous and gradient electromagnetic scale is cut up into a set of discrete categories and precise measurements have no meaning since there are only type-members of a category.

This is not only true for vision, however, and is also applicable to phonology. In fact, Hawkins (2010: 61) argues that a fundamental assumption in cognitive science is that “brain processes are fundamentally similar regardless of sensory modularity.” As such, categorization is a domain general property of cognition: it works to create symbolic categorical objects that abstracts out variable phenomena across sense modalities. Thus, a basic model for perceptual cognition consists of computational processes which operate over discrete categories—and this model can be extended to phonology to provide a rough first approximation of what a model of phonology looks like in the light of correlational neurolinguistics.

1.2.2.3 *Linking hypotheses*

The advantage of such a perspective is the potential it has for explaining why possible languages are as they are. Embick & Poeppel (2015); Poeppel & Embick (2005) suggest that if cognitive neuroscience thus conceived—a dialogue between neurobiology and the CR theory of mind—reveals restrictions on the sorts of computations the brain can perform, this may lead to explanation for the properties of language; in turn it may provide explanation for the sets of possible and impossible languages. For example, because of the limited storage power of memory, it is biologically impossible for a language to be built entirely from sentences stocked in long-term memory.

On the neurobiological side, CR models identify the representational primitives and operations of perception that correlate with neurobiological activity. For Embick & Poeppel (2015); Poeppel & Embick (2005); Poeppel & Monahan (2008), the primary analytical question in neurolinguistics is *how* computations are implemented in biology; an explanatory theory that responds to this question is what they refer to as a *linking hypothesis*, a theory that unites cognition and neurobiology. In such a perspective, neurobiology and cognition are on an equal footing—their integration leads to a joint perspective of function and structure, providing greater understanding of elementary mental operations in both mind *and* brain (Posner 2001).

In turn, neurobiological inquiry can improve CR models of language: Monahan et al. (2013: 233) argue that “knowledge about how basic auditory information is represented and processed in both humans and animals is more likely to provide important insights into how phonological information could be represented and processed.” CR theories explain *what* the computations and representations used in cognition are while neurobiology explains *why* those particular computations

and representations are used (Embick & Poeppel 2015: 358). Phonological theories should be built out of operations which can be easily translated to precise algorithms which can be associated with neurological activity (Bale & Reiss 2018).

In sum, CR theories make specific claims about the primitive objects of computation and representation used in grammars which can in turn be correlated with specific neurobiological structures. Embick & Poeppel (2015) propose an approach in which CR theories do not eclipse neurobiology, but rather are given equivalent epistemic status, supporting study of computation in the brain. They argue that the computational primitives of an appropriate CR theory of language can serve as a linking hypothesis between cognition and neurobiology.

1.2.3 *Phonological perception*

In many respects, the CR model as applied to perception is appropriate when applied more narrowly to phonology. Phonology, like vision, is non-veridical and requires internal, categorical representations. In fact, much of the information that potentially could be extracted from an acoustic signal is not relevant to language—a speaker’s age, gender, state of health, physical condition, emotional state, how fast or loud they are speaking, whether or not they are a heavy smoker, and any number of performance factors impact the acoustic qualities in a speech signal without being relevant to its phonological status. The speech signal, in the form of sound waves, is richly-detailed, variable, and in constant flux—across speakers as much as for individual speakers.

Speakers, however, do not perceive a speech signal as continuous and gradient, characterized by variability, but rather as a sequence of invariable, discrete, categorical units (Cohn 1998; Keating 1996). Measuring the physical properties of a speech signal does not provide understanding of the signal in linguistic terms, since it contains an unlimited number of points in time and there is potentially no limit to the parameters by which it could be measured (Anderson & Lightfoot 2002). In phonological terms, the continuous speech signal is cut up into segments—discrete units which correspond to the distinct categories listeners perceive in the continuous, gradient waveform of speech (Sapir 1925). Hammarberg (1976: 355) maintains that speech segments do not objectively exist in acoustic or articulatory terms, since there is no way to segment the physical speech continuum into the discrete units said to correspond to segments:

The segment has no physical existence of the kind demanded by those who would base science on pure objective observation. Nor can segments be inferred from the speech signal or the articulatory movements without resorting to the host of phonological suppositions. . . The ontological status of the segment is, and has always been, a fundamental problem in the the study of phonetics and phonology. But

it should be perfectly obvious by now that segments do not exist outside of the human mind.

Segmentation of the speech signal is a theory of its structure, an appropriate idealization that leads to explanation and understanding of the properties of speech (Anderson & Lightfoot 2002). It is, above all, a mental concept—a property of human cognition. As in visual perception, segmentation of the speech signal results in discrete symbolic representations of physical objects; as Tattersall (2019: 2) puts it, resulting in a cognitive world that is “not only as it is directly perceived by the senses, but as it **might** be”, and imposing discreteness on what is in reality continuous.

In phonological terms, the difference between the continuous and the categorical is stark, as can be seen in Figure 1.6, which represents the two different levels of description of a single utterance, between which there is an inherent difficulty in identifying correspondences between objects (Kingston 2019: 359). Hammarberg (1981: 265) points out that the relationship between the cognitive object “language” and its “physical surrogates” is unclear, arguing that there is nothing in an acoustic speech stream that clearly corresponds to the invariable, discrete units of categorical perception. The correspondence between mental objects and physical signal then, is non-veridical.

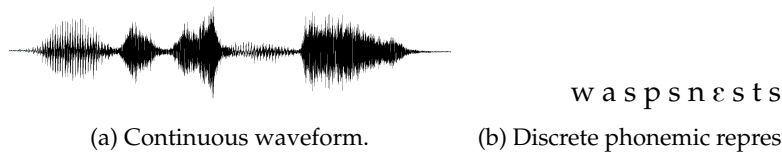


Figure 1.6: Acoustic and phonemic representations of the words *wasps' nests*.

This non-veridical relationship entails a fact about auditory percepts: they are not faithful to acoustic substance (Reiss 2007: 74). The consequence of this ontological gap is that phonology cannot be the study of physical objects since they cannot directly tell us about what is happening in the mind. That is, linguistic categories are imposed on acoustic signals, they are not a property of the signal itself. There is, after all, a significant amount of non-linguistic information carried in the speech signal (performance factors, coughs, the environmental conditions acting on the speaker, ambient sounds such as wind in the trees, cars passing in the street, other speakers in the background, etc), which needs to be filtered out by the brain.

Given the difference between the physical and the mental, there must be a kind of cognitive arbitration between the two, which translates between dynamic objects that exist on a physical and temporal plane and static objects imposed over a continuous stimulus (Cohn 1998). Those static objects are the symbolic categories of phonology, and it is phonology which provides that cognitive arbitration. A number of phonologists have argued that phonological theory is a theory of representations in the form of symbolic objects, and a theory of computations over those objects (Embick & Poeppel 2015; Hale & Reiss 2000a; Kaye

1989; Odden 2013; Poeppel & Embick 2005; Volenec & Reiss 2017, 2020). Conceived of as a kind of cognition described by a computational theory, phonology—like generative linguistics writ large—is a branch of cognitive science, in particular a form of theoretical neuroscience (Bale & Reiss 2018: 3ff.).

1.3 COGNITIVE ARCHITECTURE

1.3.1 *Modularity: a model of cognition*

In the view of Fodor (1983), any cognitive process which is independent and distinct from central processes such as attention, belief, judgment, and problem solving is known as a cognitive *module*. A module is a specialized functional unit which accomplishes a specific task and operates at a subconscious level. In the words of Scheer (2011a: 520), modules “do their job fast, well, they are very reliable, and they are mandatory: humans cannot decide to switch them off.”

Modularity erects firewalls between domains which delimit their purview and limit their interaction with each other while making explicit their common architecture and isolating them from top-down, conscious control. Fodor (1983) and Nakayama (2005) identify any cognitive system which brings in information from the outside world as being modular in nature: it performs a specific function and operates in a specific way with specific symbolic objects. The result of modular computation is available to central processes, but the computation itself and the symbolic objects over which the computation is performed are not.

Fodor (1983: 47ff.) elaborates nine features which collectively characterize modular systems:

1. They are *domain specific*: they are specialized in function such that their computations they perform are *idiosyncratic*, they operate over a constrained range of information and no others.
2. They are *mandatory*: their operation is not voluntary from the perspective of the perceiver, but rather they are constrained to apply whenever presented with an appropriate stimulus.
3. There is *limited access* to the modular computations: only the final computational result of the module is available to central processing, any intermediate levels of computation are not.
4. They are *fast*: the specialized tasks that modules perform are among the fastest of psychological processes.
5. They are *informationally encapsulated*: the process of modular computation is impenetrable to the perceiver and insensitive to information the perceiver may have access to in other domains.
6. They have *‘shallow’ outputs*: the product of modular computation is very simple and does not result in complex beliefs, but rather

in simple outputs which can be parsed either by other modules in the form of basic vocabulary and then built up or by horizontal faculties such as memory.

7. They have a *fixed neural architecture*: modules have a biological substrate in that they are associated with neurological structure.
8. They exhibit *characteristic and specific breakdown patterns*: damage to the neural architecture of modules results in specific cognitive pathologies, not in random or surprising pathologies.
9. Their ontology exhibits a *characteristic pace and sequencing*: the developmental course of cognitive modules is endogenously determined and uniform across individuals.

Of these properties of a modular system, two are especially important to the present discussion because they bear directly on the nature of phonological representations and computations: *domain specificity* and *informational encapsulation*.

1.3.1.1 *Domain specificity*

Domain specificity makes the specialized aspect of a “mental organ” explicit. A module operates according to specific principles that apply only to it: they are deaf and blind to the internal functioning of other modules. Symbolic representations are a kind of proprietary vocabulary particular to a given module, and the computations which work over that vocabulary only make sense in the context of that module: the vocabulary of one module is uninterpretable by another.

Recall from §1.1.3 that **UG** provides the set of basic symbolic representations out of which a grammar is constructed. Phonology traffics only in phonological objects: symbolic representations relevant to phonology are not parsable by other cognitive domains, linguistic or otherwise (Hale & Reiss 2008; Reiss 2007; Scheer 2011a). Thus phonology *qua* cognitive system is insensitive to real-world properties such as acoustic waveforms and facts about human articulatory physiology as well as non-phonological linguistic objects such as NPs—any information not encoded in the phonology-specific vocabulary of the phonological module is uninterpretable by phonology (Iosad 2017; Scheer 2011a).

1.3.1.2 *Informational encapsulation*

Informational encapsulation is related to domain-specificity, and makes explicit the bulkhead between a given module, other modules, and central processes such as belief. It says that modules cannot see or be affected by information in other modules: during modular computation, no information which was not present in the input can play a role in determining the output. Recall the examples of optical illusions from §1.2.2. The perception of the illusory shapes and colors is not a function of an individual’s knowledge, since even if they know that what they are seeing is the effect of an optical illusion, the effect remains

persistent. Knowledge plays a prescribed role in the output of visual computation.

In turn, modules cannot produce partial outputs intelligible to other modules, only completed computations can produce output which can be transmitted to other modules (Scheer 2011a). By maintaining the modular bulkhead, we have a principled explanation for why gustatory information is not interpreted in phonology, and why auditory computations do not work over visual representations, and so forth. For the faculty of vision, Pylyshyn (1999) argues that encapsulation (what he calls *cognitive impenetrability*) is of prime importance in understanding what Marr (1982) refers to as *early vision*. Globally, vision cannot be considered to be modular since a full understanding includes the nature of physical stimuli as well as mental knowledge not strictly limited to vision, including expectations and experience of the world (Hawkins 2010; Pylyshyn 1999). The computational primitives underlying vision, however, can be considered in a modular framework and understood as an isolated part of the whole cognitive apparatus.

Computation works in cognition, as we have seen, by mapping from inputs to outputs. Individual modules are characterized by what kinds of input and output they deal in, and what the mappings are like: computation over domain-specific vocabulary. In this way, the purview of a theory of phonology, as argued by Reiss (2007: 55), is restricted to “a component that involves computations over discrete symbols.” As such, a complete theory of phonology is a complete account of phonological computations (feature deletion, tone spreading, epenthesis, etc.) and phonological symbols (feature, nucleus, etc.), but nothing else, *in principle*. It is, then, entirely formal (see §4.4).

1.3.2 Modular phonology

In the monumental *Grundzüge der Phonologie*, Trubetzkoy (1969) laid out the central tenets of a linguistic theory which viewed phonetics and phonology as being two distinct objects of inquiry. On the one hand are the physical properties of sounds, and on the other are the properties of the symbolic objects within a linguistic system. Thus, we have a sharp distinction between two ontologically different realms. The conception of FL as a “mental organ” suggests that that FL is in a sense autonomous in terms of cognitive function, operating independently from general cognition and other perceptual systems; in short, as a module.

In fact, FL is divisible into discrete parts on the basis of function—minimally, morphology, syntax, semantics, and phonology, as in the inverted-T model (§1.1.3.1). Each domain operates according to representational and computational principles that do not apply to the others. For example, while objects such as DETP and \bar{X} are basic functional units in syntax, they have no existence in phonology. The different computational systems are in effect self-contained worlds that do not communicate with each other; phonology cannot “look inside” other modules and no information is available to phonology which is

not directly inputted into it (Reiss 2007: 74). This is the basic insight of Zwicky & Pullum (1986): syntactic processes never refer to phonological features (cf. Jackendoff 2000: 13; Newell 2018 and Scheer 2016). In this thesis, phonology is considered from a modular perspective

A modular approach to phonology places the emphasis on phonology as a cognitive process, rather than as a simple behaviorist description of stimuli and responses (Scheer 2011a). Cairns & Raimy (2009: 1) suggest that the modular approach allows “larger questions” of phonology to be broken down into smaller ones:

What components are responsible for the facts at hand?
Which aspects of the behavior are directly due to operations within components and which emerge from interactions between components? Rough answers to these questions help develop more precise questions about the individual components and the architecture that houses them.

Indeed, the modular approach places the emphasis on the properties of the CR system which underlies phonology, making explicit the distinction between competence and performance. Thus, it allows a better understanding of what is phonology and what is not phonology (Reiss 2009).

Adopting a modular approach then has consequences for the structure of phonological architecture, the form of phonological theory, and its remit. The principal distinctions to be made are between phonology and phonetics on the one hand, and phonology and morphology on the other, what Bermúdez-Otero (2012: 8) refers to as “the division of labor” between phonology and adjacent domains of inquiry. The remit of phonology theory, then, becomes restricted to phenomena which are phonological, not facts about phonetics or morphology. Since, in this thesis, the ontological status of crazy rules is one of the principal topics of discussion, determining the division of labor is crucial: while crazy rules are unlikely to be confused with phonetic processes, they may in principle be excluded from phonology by shunting them into morphology.

Discussion of how phonology relates to phonetics and to morphology is thus a prerequisite to the discussion of crazy rules and what they mean for theories of phonology, since they can in principle be recast as non-phonological artifacts. This section then serves as a preliminary discussion of how phonologists can recognize a generalization that is due to phonology as opposed to one which is spurious or due to phonetic facts or morphological computation. This demarcation of turf is a part of any scientific endeavor—an astrophysicist must be able to tell the difference between stars, planets, and moons before they can talk about the organization of the Solar System. A full theory of the division of labor would be equivalent to an answer to the question “what is the nature of linguistic computation?”—a complete model of syntax, morphology, phonology, phonetic implementation, and interfaces (David Odden, p.c.). For the time being, we shall have to be content with arguments bearing on the nature of phonological computation

and how it differs from phonetic implementation and morphological computation.

1.3.2.1 *Interfaces*

Informational encapsulation and the domain-specific nature of modular vocabulary means that modular output must be translated in order to be accessible by other modules. Morphosyntactic information, for example, must be translated into phonological vocabulary before it can be used by phonology (Newell 2018). Hale & Reiss (2000a, 2008); Volenec & Reiss (2017, 2020) refer to this process as transduction—the translation of one kind of domain-specific vocabulary into another.

Transduction is an edge-property of modules, a specific function carried out by *transducers*, which are strictly translational and do not perform any computation (Pylyshyn 1984: 153f.). In phonological terms, the computational system maps inputs to outputs by manipulating phonological vocabulary, as in [+voice] → [-voice]. Transduction maps between vocabularies as in /ʔ/ ⇔ [muscular instructions for the production of a glottal stop]. The former is an example of computation, where an input is modified as a function of an independently stored algorithm, while the latter is a look-up function.

Hale & Reiss (2000a: 170) and Reiss (2007: 74) argue that once acoustic signals are transduced in perception, it is only the formal properties of phonological symbols that are relevant to phonological computation—the acoustic and articulatory properties of speech sounds are irrelevant. Jackendoff (2000: 14) also argues that phonological structure is “neither auditory nor motor,” since auditory and motor signals are continuously varying and phonological symbols are discrete. The continuous auditory and motor signals do have cognitive representations, but the modular firewall means their formal representations are not a part of phonology. Those continuous representations are instead the properties of phonetics. Transduction between phonology and phonetics is handled by what has been called the phonology-phonetics interface (Boersma & Hamann 2008; Hamann 2011; Kingston 2019; Scheer 2014; Scobbie 2007), the mechanism by which phonetic representations are turned into phonological symbols, and phonological symbols into phonetic representations. The interface and its nature will be further developed in §4.4.5.

The principle consequence of a modular architecture with transduction is that the properties of other modules as well as effects introduced by transduction are not in the remit of phonological theory. As a consequence, phonological theory is reduced to a model of the computational properties provided by FL (Reiss 2007). This reduction in the scale of phonology has concomitant effects in both morphology and phonetics.

1.3.2.2 *Phonetics*

Phonetics is the broad domain of the acoustic and articulatory properties of speech, whether it be oral or signed; phonetics is what is physical.

In contrast, the cognitive realm of phonology is the organizational principles of speaker knowledge concerning those speech units. These two realms are ontologically distinct, but since phonologists make observations relevant to their domain of inquiry principally through the veil of phonetics, the division of labor is not necessarily obvious. In addition, the descriptive categories of each domain often share vocabulary (Hyman 2001); phonological and phonetic descriptors may overlap, such that terms like *nasalization*, *voicing*, *rounding*, can be used in either domain (see Vennemann & Ladefoged 1973 for discussion).

As a result, the border between phonetic phenomena and phonological phenomena is murky, and it is not always clear what kinds of phenomena should be accounted for by phonological theory and what kinds should be left to the realm of phonetics. The similarities between phonetics and phonology has led some scholars to obscure the difference between the two, or even to argue that there is no difference between phonetics and phonology and that they are in fact the same thing; Flemming (2001: 9) is especially explicit on this point, arguing that “[p]honetics and phonology are not obviously distinguished by the nature of the representations involved, or in terms of the phenomena they encompass.” In particular, Flemming notes that coarticulation is in many respects similar to assimilation, suggesting that phonetics and phonology may be so intertwined as to be functionally indistinguishable.

This is an example of what Scheer (2010b) refers to as a *scrambling trope*: phonetics and phonology are handled indiscriminately by the same system of rules or constraints. The scrambling trope is characteristic of the tack adopted in approaches where phonetics and phonology are indistinct (Flemming 2001; Kirchner 1997, 1998). In such a view, there is no place for crazy rules in phonology, since by their nature crazy rules cannot be reduced to mere phonetic descriptions (such descriptions would be nonsensical or at best unenlightening).

However, this reductionism is not always actionable, since there are cases where phonetic phenomena and phonological phenomena exhibit distinctness. For example, Cohn (1998) demonstrates the existence of “phonological doublets”—cases where a phonetic phenomena may be manifest in different ways. In the case of nasalization, for example, a vowel may be nasalized in either a gradient or a categorical way depending on the context. Cohn (1990) shows that in French—where vowel nasalization is contrastive on the surface—sequences of consonants followed by nasal vowels show a distinct and rapid transition in nasal airflow from none to a steady-state over the vowel articulation period, thought to reflect the surface vowel’s specification for [+nasal].

In contrast nasality in vowels in English—a non-contrastive property even on the surface—is realized as a variable cline. This suggests that nasalization in English vowels is a fact about phonetic implementation: they have no specification for the feature [nasal] (Cohn 1990: 139f.). For nasal vowels in both French and English, while the descriptor *nasality* is valid, the language-dependent manifestation of *nasality* as either a

categorical or a variable phenomenon suggests that a distinction is to be made between phonology and phonetics.

Solé (1992) provides experimental data reinforcing this view¹⁴, showing that in Spanish nasalization of vowels preceding nasal consonants begins at a stable time before the onset of the consonant, meaning there is an oral phase as well as a nasal phase, not a categorical specification valid for the entire duration of the production of the vowel. Solé (1992) concludes that nasalization in Spanish vowels is a purely mechanical effect of coarticulation.

While there is at present no silver bullet that allows for distinguishing between phonetics and phonology, developing explicit criteria for describing phonological output can cleave between the two (Hamann 2011). For example, in step with the arguments made by Solé (1992) and Cohn (1998), it has been argued that phonetic processes do not involve categorical or distinct features (Anderson 1975; Janda 1987; Sommerstein 1977). Phonological rules, on the other hand, do make direct reference to phonological categories, and operate over features which are phonologically distinctive (see also the discussion in §1.1.3.1). This suggests that phonetic processes and phonological processes operate over distinct and independent vocabularies. In this view, phonetics is the implementation of phonological features or the changes made to those features by phonology (Kingston & Diehl 1994). To illustrate, it will be useful to briefly examine two well-studied phenomena: phonetic coarticulation and phonological assimilation.

For Hammarberg (1976: 357), *coarticulation* is “a process whereby the properties of a segment are altered due to the influences exerted on it by neighboring segments. . . Thus, for example, we find rounded *k*’s before rounded vowels, front *k*’s before front vowels, back *k*’s before back vowels, and so forth.” In turn, McCarthy & Smith (2003: 4) describe *assimilation* as “a phonological process in which a segment changes to resemble its neighbors more closely.” From the descriptions given, it is not at all clear what the difference between coarticulation and assimilation might be. In fact, for Ohala (1993), *coarticulation* and *assimilation* are synonyms; in this view, there is no distinction between phonology and phonetics and phonology is subsumed into phonetics.

However, Cohn (2007: 6) warns against conflating “*explanation of the source* of the patterns and the account of the *patterns themselves*.” While assimilation may be the phonological reflection of coarticulation, she maintains that the two kinds of processes belong to two different and distinct domains. While a segment is a physical manifestation of a mental object, coarticulation is merely a physical artifact of the process of articulation and is not the product of any mental process other than the execution of commands (Hammarberg 1976: 361); that is, coarticulation is a phonetic effect resulting from facts about human

14 The results reported by Solé (1992) are compatible with the gradient effects of phonetic implementation, though she concludes, for quite different reasons, that nasal vowels in English are in fact [+nasal], a result that is incompatible with the argument made by Cohn (1990). I leave this aside here, wishing only to show how gradient phenomena are thought to be artifacts of phonetic implementation.

articulatory anatomy and assimilation is a phonological computation resulting from facts about UG.

While patterns of coarticulation are similar to patterns of assimilation, they are not the same. The difference lies in how they are manifested: as categorical effects when phonological and as gradient effects when the phonetic expression of phonology (Cohn 2007). A phenomena whose output is gradient and variable, as in the case of English vowel nasalization, is not phonological. In this view, only categorical changes which neutralize or feed other phonological rules are phonological (Anderson 1975; Scobbie 2007), phonetic phenomena do not affect categorical features. That is, a bright line can be drawn between phonological computation and phonetic phenomena by distinguishing between gradient and categorical effects—a widely accepted distinction (Anderson 1975; Chitoran & Cohn 2009; Cohn 2007; Janda 1987; Keating 1988, 1996; Pierrehumbert 1990; Scobbie 2007) (see Hamann 2011; Myers 2000, and Kingston 2019 for informed overviews). Another way of making this distinction is by viewing as phonological any alternation which refers to a phonological category (by nature discrete), either in its structural description or in its structural change.

Categorical effects are sensitive to “gross patterns of timing,” (Cohn 1998: 32); for example, all or part of a segment, but never in terms of “absolute or raw duration.” Myers (2000: 245) suggests that categorical patterns are expressed in relative terms of category labels like “short” or “long”, with discrete membership in categories; objects belong to a given class or do not, there is no gradience. In the case of geminate consonants, for example, it is not absolute duration that constitutes the phonological percept, but rather the relative duration of the two consonants. As such, phonological patterns are not sensitive to quantitative information: speaking rates or style, differences in vocal tract anatomy, and other gradient patterns have no effect on phonological status (Myers 2000).

In contrast, gradience is expressed with real numbers and mean measurements, with objects exhibiting more or less of a given phonetic quality depending on conditions imposed on articulation from outside of phonology—facts about articulatory physics, fatigue, speaking rate, and so on (Myers 2000: 246). The distinction is pithily summarized by Kingston (2019: 361):

Phonological representations are in the mind, where they constitute a part of speakers’ and listeners’ implicit linguistic knowledge, differences between them are qualitative, and the rules and constraints that specify phonological well-formedness are syntactic, in specifying combinations and structural arrangements of discrete, symbolic categories. Phonetic representations are events in the world, differences between them are quantitative, and the gradient relationships between their constituents are expressed in calculus.

In a modular view of phonology features do not encode acoustic or articulatory correlates, since they are phonological symbols and are deaf to the properties of the real world (Reiss 2003). As such phonology does not model articulation, acoustic structure, or auditory input, since the only place phonology intersects with those domains is at the interface as the input to articulation (Purnell 2009: 341). In other words, as the output of phonological computation. If phonetics and phonology constitute ontologically distinct realms of inquiry, then there is no *a priori* reason to assume that phonetics plays a role in phonological computation. This leaves the modular bulkhead intact, and opens up the logical possibility for the existence of phonetically-arbitrary phonological computations—for crazy rules.

1.3.2.3 Morphology

At the frontier of phonology with the rest of grammar is morphology, the grammatical system which joins together pieces of meaningful content from the lexicon into words (§1.1.3.1). Morphological computation can produce surface alternations, as in cases of suppletive allomorphy in English strong-verb paradigms which are inflected by stem allomorphy, for example in *sing/sang/sung* or *tell/told/told*. In morphological alternations, changes in sound and meaning originate in the lexicon and are not the product of phonological computation.

While suppletive allomorphy's status as a lexical property is secure, many alternations admit a certain amount of analytic flexibility, where the role played by the lexicon and phonological computation is not determined on pretheoretical grounds but by the theory of grammar (Bermúdez-Otero 2012). In classical phonemic theory, the scope of rule-governed generalizations was limited by surface contrast (Anderson 1982). In contrast, Chomsky & Halle (1968) extended the scope of phonology to allomorphy by incorporating grammatical information in the form of morphological vocabulary and surface-syntactic structure into the rule-based formalism (Kenstowicz & Kisseberth 1977: 77ff.). The result was a class of morphologically conditioned phonological rules.

Two principle issues arise from this extension of the phonological domain. The first is that if a given alternation can be accounted for in many different ways the task of building a target grammar is rendered more difficult for a learner (Bermúdez-Otero 2012). The second is directly relevant to the modular model of cognition: allowing phonology to traffic in morphological vocabulary breaks down the modular bulkhead between domains. Thus, a theory of grammar must delimit the realms of phonology, morphology, and the lexicon, in particular by explicitly defining how phonology interacts with morphosyntax. In the most strict sense, allowing rules to reference morphosyntactic information makes them something other than phonological (Bermúdez-Otero 2012; Kaye 2014; Janda 1987), making eliminating reference to morphological categories a desideratum for phonological theory (Anderson 1992).

As a means of establishing the principles governing morphological alternations and how they are distinct from those governing phonological processes, consider two patterns of alternation in German: Ablaut and Umlaut. Ablaut in German refers to the limited class of lexical items (between 170-180 according to [Wiese 1996](#)) in which verb stems show a vowel alternation in the past-tense or past-participle form (7):

(7)	Present tense	Past tense	Past participle	Gloss
	<i>lauf-</i>	<i>lief-</i>	<i>ge-lauf-en</i>	'run'
	<i>sauf-</i>	<i>soff-</i>	<i>ge-soff-en</i>	'drink, excess'
	<i>find-</i>	<i>fand-</i>	<i>ge-fund-en</i>	'find'

Like English strong verbs, Ablaut is an idiosyncratic and unpredictable process, a property of the lexicon not controlled by any productive grammatical computation ([Wiese 1996](#)). In [Wiese's](#) view, Ablaut is a cover term for a variety of different patterns all found within the restricted domain of verbal morphology; it is well outside the scope of phonology.

In contrast, the superficially similar pattern of vocalic alternation known as Umlaut has been the subject of a turf war between phonology and morphology, with some arguing for its phonological status ([Wiese 1996, 2000](#)), and others arguing against ([Anderson 1992; Janda 1987; Pöchtrager & Kaye 2014](#)). In German Umlaut, pairs of words which are morphologically related exhibit a pattern of alternation in which non-front vowels in stems alternate with a fronted vowel or diphthong in derivational morphology, illustrated in (8)¹⁵:

- (8) a. /u:/ ~ /y:/
Huhn 'hen-SG.' *Hühn-er* 'hen-PL.'
Gruß 'greeting-MASC.' *grüß-en* 'greet-V.'
- b. /ʊ/ ~ /ʏ/
dumm 'silly-ADJ.' *dümm-lich* 'silly-ADJ.GRAD.'
Hund 'dog-MASC.' *Hünd-in* 'dog-FEM.'
- c. /o:/ ~ /ø/
hoch 'high-POS.' *höch-st* 'high-SUPERL.'
Vogel 'bird-SG.' *Vögel* 'bird-PL.'
- d. /ɔ/ ~ /œ/
Glocke 'bell-N.' *Glöck-chen* 'bell-N.DIM.'
Holz 'wood-N.' *hölz-ern* 'wood-ADJ.'
- e. /a:/ ~ /ɛ:/
Europa 'Europe-N.' *europä-isch* 'Europe-ADJ.'
(ich) sah '(I) saw-IND.' *säh-e* '(I) saw-SUBJ.'
- f. /a/ ~ /ɛ/
Stand 'stand-N.' *ständ-ig* 'continuous-ADJ.'
lach-en 'laugh-V.' *läch-el-n* 'laugh-V.ITER./DIM.'

15 Data from [Wiese \(1996\)](#).

- g. /aʊ/ ~ /ɔʏ/
 (ich) *lauf-e* '(I) run-1S.' (er) *läuf-t* '(he) runs-3S.'
saufen 'drink-, excess-V.' *Säuf-er* 'drinker-N.'

Some properties exhibited by the Umlaut data suggest that the alternation is phonological, as its presence in a large number of morphological contexts makes it hard to define what its morphological function is. In fact, [Wiese \(1996: 128\)](#) argues that Umlaut is an element of both derivational and inflectional morphology, and can only be considered a morphological marker in a very abstract sense since it only marks the presence of a derived category. [Wiese](#) also sees Umlaut as being a homogeneous and local process, lending further support to its analysis as a product of phonological computation. [Wiese](#) views the vowel alternation as being triggered by specific morphological contexts, but rather than being a product of lexical allomorphy, it is a process of phonological linking, where a floating [+front] feature provided the morphological object spreads to the umlauting vowel in the stem. Those lexical stems which do not show the alternation simply have no place for the floating feature to attach.

On the other hand, several authors have argued that whatever its morphological function, the incontrovertible fact that Umlaut depends on morphological information makes the phonological position untenable ([Anderson 1992](#); [Janda 1987](#); [Kaye 2014](#); [Pöchtrager & Kaye 2014](#)). Two additional properties of the alternation—the arbitrary relationship between the context and the process and its numerous exceptions—are pointed out by [Pöchtrager & Kaye \(2014\)](#), who argue that no true phonological process shares those characteristics. In this view, Umlaut is a process by which allomorphs stored in the lexicon are selected according to the morphological context.

The criteria used by [Pöchtrager & Kaye \(2014\)](#) to establish the non-phonological basis of Umlaut then provide one of the more explicit frameworks for distinguishing between phonological and morphological processes.

- (i) Phonological processes are non arbitrary in that there is a direct relationship between a phonological process and its environment ([Kaye et al. 1990: 195](#)), and all phonological phenomena can be described in terms of putting things together or taking them apart ([Kaye 1989: 111](#)).
- (ii) Phonological processes apply without exception wherever their conditions are met ([Kaye 1992: 141](#)).
- (iii) Phonological processes are semantically transparent in that forms with an common underlying stem will share the semantics of the stem (cf. [Lightner 1978](#)).
- (iv) There are structural limitations on phonological events (see §4.4.3).

In the light of modularity, an important distinguishing property of a phonological rule is the lack of morphological vocabulary in its structural description. In turn, [Bermúdez-Otero \(2012: 44, 50\)](#) articulates

the corresponding hallmark of morphological processes in the *Morph Integrity Hypothesis* (9):

(9) *Bermúdez-Otero's Morph Integrity Hypothesis*:

The representational currency of morphology is the morph; morphology does not reference phonological representations such as features, segments, nodes, or association lines.

The consequence of (9) is that morphosyntactic features are not relevant to phonology (see [Newell 2018, 2021](#)). The advantage of placing modular restrictions on phonology and morphology is that the resultant constrained theory makes predictions about possible languages by ruling out a large number of storable grammars. Modular restrictions also provide a scaffolding for the construction of theories which allow for a deeper understanding of both phonology and morphology. As put by [Bermúdez-Otero \(2012: 48\)](#):

When confronted with a morphologically conditioned phonological alternation, modular frameworks rule out large sets of logically conceivable analyses for the simple reason that those analyses require modules to communicate in ways which are not permitted. . . Moreover, modular frameworks are themselves amenable to empirical evaluation: a modular framework fosters a progressive research program if most apparent counterexamples are eventually resolved, and particularly if they are resolved in ways which reveal previously unnoticed structure in the data; conversely, a modular framework leads to a degenerating research program if it accumulates unresolved problems or solves them only by weakening its empirical content. . .

An illustrative example of apparent counterexamples to (9)—the careful examination of which lead to new discoveries concerning phonological structure—comes from [Compton & Drescher \(2011\)](#), who describe a process of palatalization in the North Slope dialect of Alaskan Iñupiaq (Eskimo–Aleut), where alveolar consonants undergo palatalization after some instances of [i], but not others (10)¹⁶:

(10)	Stem	Gloss	'and a N'	'N OBL.PL'	'like a N'
a.	iɣlu	'house'	iɣlu-lu	iɣlu-nik	iɣlu-tun
b.	iki	'wound'	iki-ɬu	iki-ɲik	iki-sun
c.	savik	'knife'	saviɣ-ɬu	saviɣ-ɲik	savik-sun
d.	qimmiq	'dog'	qimmiv-ɬu	qimmiv-ɲik	quimmi-sun
e.	ini	'place'	ini-lu	ini-nik	ini-tun
f.	kamik	'boot'	kamiɣ-lu	kamiɣ-nik	kamik-tun
g.	aiviq	'walrus'	aiviv-lu	aiviv-nik	aiviq-tun

¹⁶ Data adapted from [Kaplan \(1981: 81f.\)](#).

The word form in (10a) has a stem ending in /u/, and is followed in each derived form by a morpheme beginning with an alveolar consonant. The forms in (10b-d) all show palatalization of the suffix-initial consonant triggered by [i]. Finally, in (10e-g), another set of forms demonstrates that not all realizations of [i] trigger palatalization. The same pattern of alternations is present in verbal suffixes. The two /i/s then exhibit a disjunction: the palatalizing /i/ is known as strong *i* and the non-palatalizing as weak *i*.

Since, on the surface, there is no phonetic property to distinguish between the palatalizing strong [i] and the non-palatalizing weak [i], there is *a priori* no way to describe the palatalizing process in phonological terms, since a rule $l n t \rightarrow \lambda \mu s / i_$ makes the correct predictions for (10b), but not for (10c). An obvious solution is to suggest that the palatalization pattern is morphological, where each allomorph is selected as a function of the lexical stem: some stems get a non-palatalized allomorph, and some get a palatalized one. In this view, the alternation is not conditioned by any phonological properties, but is a function of the lexicon.

However, Compton & Drescher (2011) argue for a phonological analysis of the pattern in (10) that does not make any reference to morphological information by suggesting that the representational structure of palatalizing and non-palatalizing forms is distinct. In their account, strong *i* is marked by a feature [coronal] which the non-palatalizing weak *i* lacks¹⁷. This feature has no direct phonetic correlate, but marks the class of palatalizing strong *is* and creates the context for palatalization. Thus, the analysis of Compton & Drescher simultaneously avoids invoking morphology to account for a phonological pattern while revealing a new fact about phonological representations in North Slope Iñupiaq that is not obvious from an inspection of its phonetics (see §4.4.2).

With morphological vocabulary excised from phonology, a potential assay of phonological status is available for examining crazy rules. If a crazy rule crucially depends on morphosyntactic information in its structural description, then it is not a phonological process, and rather is an effect of morphology or of the lexicon. Alternatively, if a crazy rule can be accounted for in purely phonological terms, or if apparent morphosyntactic conditions can be shown to be the reflection of phonological structure, then its status as a phonological process is more sure.

1.3.3 *The architecture of phonology*

The modular architecture has a number of consequences for phonological theory. Principle among them, it reduces the scope of phonology, removing phonetic effects and morphological information from its remit. Further, it places an analytic emphasis on phonological representations

¹⁷ See also Gussmann (2007: 56ff.) for a comparable representational account of [ɛ] in Polish.

to explain patterns that seem superficially to make reference to objects or domains which are not phonological (see Faust et al. 2018; Lowenstamm 1999; Passino 2013; Raimy 2009; Scheer 2009 for examples). This results in parsimony within phonological theory at the same time as it allows for the unification of seemingly disparate phenomena.

The discussion thus far suggests a phonology that is distinct from phonetics and insensitive to morphosyntactic information. In the terms of Embick (2010), morphological and phonological activity are *localist*, and not the product of a singular, *global* computational system. That is, any phonetic or morphosyntactic vocabulary must first pass through the appropriate interface with phonology and be translated into phonological vocabulary, limiting their respective influence inside of phonology.

Concerning morphological effects in phonology, Smith (2001, 2011) provides a survey of cross-linguistic phonological differences in nouns and verbs, which frequently exhibit distinct phonological behavior. For example, whether or not stress is fixed or free, or how hiatus repair is effected. Where noun and verb differences are concerned, in every case the differences are based on suprasegmental or prosodic properties, not featural ones (Smith 2011). There are no effects where nouns are realized with vowel rounding while verbs are not. This is an example of what Scheer (2016) calls “melody-free syntax”, suggesting that morphological information and phonological features are *incomunicado*. Scheer argues that allomorphy is insensitive to melodic properties because melodic properties are the input to phonological computation. The output of that computation is structural, and can be directly transduced into vocabulary that is visible to and parsable by morphosyntax.

That is, not all phonological information is invisible to morphology: structure built by phonological computation (phonological output), such as syllables, is available to morphological computation. Since morphosyntactic information is not parsable by phonology, phonological patterns which exhibit evidence of morphosyntax must be due to properties of transduction and phonology proper (Newell 2018). There is no morphology in phonological computation, but phonological output is translated and shunted to morphology through the interface. This exchange at the interface can result in apparent phonological and morphosyntactical mingling, but is not a product of either phonological or morphological computation itself (see §4.3.3 for the effect of phonetics at the interface with phonology).

Thus, the modular framework distinguishes phonetics from phonology, and phonology from morphology, and establishes an architecture in which the output of any module can be transmitted to the adjacent module through an interface. That morphology is “melody-free” but sensitive to the structures built by phonological computation (Scheer 2016) suggests that phonology itself is organized in a modular fashion, with higher-order structures such as syllables mediating between melody and morphosyntax, but with no way for melody and morphosyntax to interface.

It is thus necessary to distinguish between basic phonological vocabulary that is melodic in nature and those structures which are built by phonological computation. This distinction forms a fundamental principle in phonological architecture: melodic information is not treated by the same system as structural information. This implies that the inverted-T model (Figure 1.1) is too coarse, and phonology itself is composed of different sub-systems (cf. Archangeli & Pullyblank 1994). Cairns & Raimy (2009: 8) use data from Southern Paiute (Uto-Aztecan) to argue for separate modules for syllables and metrical feet; two modules which “operate independently of each other,” each with “its own computational and representational resources.”

Thus, melodic phonology at the level of features and prosodic phonology at the suprasegmental level are not the same: they are distinct modules. Since modules operate according to domain-specific vocabulary and are informationally encapsulated, it follows that melodic phonology and prosodic phonology can also each be characterized by their own proprietary vocabulary and modular bulkhead. In addition, there is an interface between phonological structure and morphosyntax, but not between melody and morphosyntax. In contrast, there *is* an interface between melody and phonetic vocabulary, but not between melody and morphosyntax. This architecture will be further discussed and put to profitable use in §4.4.5.2.

1.4 CONCLUSION

This chapter outlined the basic assumptions underlying the rest of this thesis. Namely, that phonology is a part of an innate, genetically-endowed mental organ, uniform across the species and circumscribed by UG. Crucially, phonology is a kind of cognition and thus a property of *mind*. Central to a theory of phonology is the notion of phonological rules, which formalize the computational mapping between lexically-determined distinctive cognitive objects and contextually-determined segments which are realized as physical objects in the real world.

I argued that phonology, like other kinds of perceptual cognition, is necessary in order to map between gradient and continuous phenomena in the physical world and the mind, which operates in discrete, symbolic units—a function of neurobiology which is discrete. Phonology is a non-veridical CR system composed of primitive computations and representations. While those computations and representations are instantiated in human brains, they are not best understood through the examination of neurobiological activity, but rather through a theory of phonology that represents cognition in human minds.

The basic architecture of phonology is modular in nature. It is built out of at least two computational systems, one which operates over melodic objects at the segmental level, and one which operates over prosodic objects at the suprasegmental level. Each computational system is distinct from the other, with its own computational properties and interfaces with adjacent modules; the segmental level inter-

faces with phonetics, and the suprasegmental level interfaces with morphosyntax.

The following chapter will discuss in detail the nature of phonological rules, in particular the role of naturalness in theory construction and the consequences of naturalness for the empirical remit of phonology, especially as relates to crazy rules.

ON PHONOLOGICAL INQUIRY: THE POSSIBLE
AND THE IMPOSSIBLE

On the metaphysics of linguistics
there are two extreme positions,
which may be termed (and have
been) the “God’s truth” position and
the “hocus-pocus” position.

HOUSEHOLDER

Chapter 1 was a treatment of phonology *qua* natural object: “concrete mental events and states that occur in real time, real space, have causes, have effects, are finite in number” (Bromberger & Halle 2001: 21). There, I reviewed some of the basic claims of the generative program; notably, that phonology is the product of *mind*, in particular a Computational-Representational (CR) system known as Universal Grammar (UG). This chapter will treat phonology *qua* theory, a rational model of a natural object which allows for the understanding of the essential properties of that natural object.

The first portion of the chapter reviews some questions concerning what the principle desiderata of a phonological theory are, what kinds of facts can be rallied to make conclusions about phonology, what explanation looks like, what prediction looks like, some problems with generative formalism, and efforts to remedy those problems. This portion serves a dual purpose: the first is that it is seen as a necessary preliminary step before theories can be meaningfully compared, the second is that many of the issues highlighted served as the impetus for the introduction of naturalness in phonological theory, one of the principle topics of this thesis.

Naturalness is the subject of the second portion of the chapter. In the period directly following the publication of Chomsky & Halle (1968), various solutions to several formal problems inherent in The Sound Pattern of English (SPE) formalism were explored (§2.2.3). Naturalness was one of the most potent and most enduring; it is also the most difficult to reconcile with the notion of crazy rules. Beginning with §2.3.3, naturalness and the role it has played in theory construction is discussed, with particular attention on its consequences for inquiry into crazy rules and possible languages.

The overview shows that theories which formalize naturalness eject crazy rules from the remit of phonology—they become a product of the lexicon or of morphology. As a consequence, the set of possible phonological operations is restricted, which in turn limits the set of possible languages to those with phonetically natural phonological grammars.

2.1 ON PHONOLOGICAL THEORY

2.1.1 *The ambition of phonology*

Baudouin de Courtenay, speaking in St. Petersburg in 1870, argued that linguistics was a science which “generalizes the phenomena of language and looks for the forces operating in language and for the laws that govern its development, its life” (Baudouin de Courtenay 1870 [1972]: 55). That is, linguistics seeks to describe the essential properties of human languages by deriving generalizations from empirical observations of linguistic data; for phonology, this naturally means generalizations over phonological data (Chomsky & Halle 1968; Hurford 1971) in the form of alternations, as distributional regularities (Harris & Lindsey 1993), or more broadly, as “recurrent sound patterns” (Blevins 2009: 325). The ambition of a theory of phonology, then, is to account for those sound patterns in human language.

Baudouin de Courtenay (1870 [1972]: 54) makes clear that this goal is not equivalent to collecting patterns and arranging them taxonomically, saying the “*descriptive* approach, an extreme empirical one, which sees its task in gathering facts and generalizing from them in a purely external manner, without attempting to explain their causes. . . reduces science to a purely empirical endeavor, to some sort of meaningless game.” Thus, the principle ambition of linguistic theory is *explanation* through the discovery of the nature of the representations and computations underlying the patterns themselves (Odden 2013).

Theoretically-derived generalizations form the basis for predictions in phonology (Pierrehumbert 2016: 34). Generalizations about what possible phonological rules are like allow for unattested—but possible—rules to be predicted. Further, since by their nature impossible rules will never be attested, phonological theory is the only means of conceptualizing such rules. Phonological theory, then, is a tool used to reveal facts both about speaker knowledge as well as what languages are like. Ultimately, beyond language itself and the organization of the lexicon, it tells us something about the natural object, UG (Kenstowicz 1994: 57):

When generative linguists study the phonology of a language, they try to discover three kinds of generalizations. They look for regularities that help to define the language’s inventory of phonological elements: its vowels, consonants, syllables, tones. They determine patterns in the distribution of these elements in the language’s representations: may they appear or are they banned from initial, medial, final positions in the word from stressed/unstressed syllables?; may an element of type *a* immediately precede/follow an element of type *b*?; and so on. Finally, they investigate alternations in the shapes of morphemes composed of these elements within the word and variant pronunciations of words within the sentence. The regularities that emerge from such study are assumed to be the joint product of the

principles and parameters of Universal Grammar and the rules and representations that develop through the course of language acquisition.

As a collection of butterflies does not by itself reveal anything about the principles of butterfly construction, which is understood rather by a theory which explains why butterflies are as they are, the principles underlying recurrent sound patterns are only revealed by a theory of **UG** that reveals the essential properties of phonological computation. Accordingly, the goal of linguistic theory is to characterize what universal properties underlie language (**Morley 2015a**: e40); not simply to generalize patterns, but to categorize computationally possible phonological patterns (**Hale & Reiss 2008**: 171). An emphasis on explanation over simple description leads to the construction of theories with predictive power; a substantially more profound kind of understanding than mere taxonomic categorization.

2.1.2 *On prediction and falsifiability*

The classic assay by which **Popper (1935 [1992]: 48)** argued scientific inquiry could be distinguished from pseudo-scientific inquiry rests on the notion of falsifiability:

In this formulation we see that natural laws might be compared to ‘proscriptions’ or ‘prohibitions’. They do not assert that something exists or is the case; they deny it. They insist on the non-existence of certain things or states of affairs, proscribing or prohibiting, as it were, these things or states of affairs: they rule them out. And it is precisely because they do this that they are *falsifiable*.

In linguistics, Popperian falsifiability has been held as a desideratum of theories (see **Morley 2015b**: 22 for example), but as argued by **Kuhn (1962: 146 f.)** the real power of a theory comes not from its vulnerability to anomalous phenomena, but rather from its power to make predictions. A theory is not a single hypothesis meant to perfectly account for all facts, but instead is a series of related hypothesis about the world; a research program that **Lakatos (1978: 5)** argues makes “dramatic, unexpected, stunning predictions”.

In this way, a scientific program leads to the discovery of novel facts about the world. In the construction of linguistic theories, the emphasis is on predictive power, as when **Ladefoged (1980: 498)** argues that “[l]inguists, like any other group of scientists/observers, should seek explanations for the regularities they observe; but they should not be worried if their explanations are merely predictive of future observations and not otherwise testable.” Equally, **Basbøll (1980: 101)** argues that a theory should be *prognostic*, making refutable predictions about things beyond the set of narrow facts used to to build it. In fact, it is only by making predictions that a scientific theory can be judged to have been falsified, because to be interesting or falsifiable,

a theory of grammar must make predictions about human language (Vaux 2008: 30).

2.1.3 *On the remit of phonological theory*

If phonological theory is, in part, a theory of possible phonological rules, this entails that it is a theory not limited to the set of attested languages. The set of attestable languages, after all, is surely larger than the set of attested languages, and the set of possible languages larger still. Impossible languages obviously cannot be found in the linguistic record. Hale & Reiss (2008: 3) provide an illustration of this set-hierarchy constituting possible phonological inquiry (11):

- (11) ATTESTED \subset ATTESTABLE \subset HUMANLY COMPUTABLE \subset STATEABLE
- a. Attested: Sicilian, Russian, Australian English
 - b. Attestable: Nissart in the 14th century, Sentinelese, Maltese in 300 years
 - c. Humanly computable: $p \rightarrow s / _r$
 - d. Statable: $V \rightarrow V$: in prime numbered syllables

Hale & Reiss identify (11c) as the set of languages in the purview of phonological theory; the set of attested languages is a subset of the set of *possible* languages. I follow Hale & Reiss in viewing the remit of phonology as being humanly computable languages, but this classification raises issues which must be addressed. It is not clear that $p \rightarrow s / _r$ actually constitutes a humanly computable language, since it is, at present, unattested in the typological record.

Hale & Reiss (2008: 206) argue that the possibility of unattested processes being humanly computable is highly likely, since language is the product of a complex interaction between various cognitive and physiological systems which can conspire to produce or suppress patterns. This is certainly true, and echoes an argument made in functionalist camps that unattested languages may be unattested due to properties inherent in learning or general cognition; they may be improbable, but not impossible (Haspelmath 2008: 92). If such functional factors are the only limits to the set of humanly computable languages, however, then UG has no role in limiting the set in (11c). In turn there is no real distinction to be made between (11c) and (11d), since there is no principled means by which to determine if a statable language is humanly computable or not. For example, while it may be obvious that an impossible language is one in which all consonants are realized as [z] if in the presence of bees, it is somewhat less obvious why a language should not lengthen vowels in prime numbered syllables.

Where unattested patterns are concerned, Archangeli & Pullyblank (1994: 433) establish two classes: *accidental gaps* are patterns predicted to exist but not yet discovered and thus possible; *systematic gaps* are patterns excluded by formal theory and thus impossible. One of the

tasks for phonological theory is to exclude systematic gaps without confounding them with accidental gaps and thereby unnecessarily excluding unattested languages. To do this, there must be a principled way of discriminating between accidental and systematic gaps, if this cannot be done then there is no way of making real predictions about what a possible language is like. In principle an accidental gap may be a computationally possible language which simply has not been found yet and so is unattested in the typological record (see Haspelmath 2004, 2008; Kiparsky 2008b; Scheer 2019b for relevant discussion. This issue will be developed extensively in Chapter 4).

Crazy rules are an interesting lens through which to consider predictive power in phonological theory. A number of phonological theories are built on axiomatic notions of phonetic naturalness, and *a priori* exclude crazy rules from the remit of phonology (see §2.3.3). These theories make falsifiable predictions, because they make firm predictions about what kinds of languages we expect to find in the sets of possible languages. Theories which do not include naturalness, in contrast, predict a different set of languages (12):

- (12) a. $\{\ell_1, \ell_2, \ell_3, \ell_4, \ell_5 \dots \ell_m\}$
 b. $\{\ell_1, \ell_2, \ell_3, \ell_4, \ell_5 \dots \ell_m \dots \ell_n\}$

(12a) is the set of possible languages predicted by theories built with naturalness. (12b) is the set of possible languages agnostic to naturalness, and is consequently larger; one of them is a better match of the set of possible languages which could be instantiated in human brains. The role of naturalness in formal theory is crucially important to any discussion of crazy rules, since a naturalness filter may preclude them from being the product of phonological grammars—in order to determine the ontological status of crazy rules, the role and extent of naturalness in the formal theory must be clearly articulated.

One way of establishing a class of impossible languages is by directly incorporating formal filters into phonological theory such that the set of grammars generated by the formal system hews closely to the set of attested language grammars. Since many phonological rules are explainable through recourse to articulatory or perceptual factors, instantiated as *formal naturalness* such factors serve to filter out phonological grammars which generate unnatural patterns (see §2.3.3). In this way, naturalness serves as the arbiter of possible and impossible languages. An advantage of a theory with formal machinery tooled to recapitulate phonetic naturalness is that it constrains the set of possible languages. The theory predicts that certain processes which do not satisfy naturalness will be impossible for speakers to learn—they are impossible languages. In contrast, *ceteris paribus*, the set of possible phonological grammars predicted by a theory of phonology which has no formalized notion of naturalness is much larger—and consequently so is the set of possible languages.

Thus, the issue of naturalness relates directly to the status of crazy rules: if crazy rules are in fact within the remit of phonological theory

and the set of possible languages corresponds to (12b), the function of naturalness as a predictive tool in phonology becomes essentially nil. Admitting crazy rules into the remit of phonological theory means that, potentially, phonological grammars can generate *any* kind of alternation. If this is the case, then there may be no such thing as UG after all, since the acquisition of phonological patterns would be unconstrained except for what is possible in general cognitive terms (Haspelmath 2011, 2020). In order to make useful predictions regarding impossible languages, the generative power of formal grammar must be constrained by other means. To this end, Chapter 4 proposes a means of constraining phonological theory independent of phonetic naturalness.

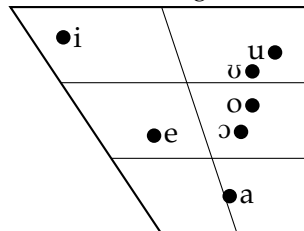
2.1.4 Possible and impossible languages

To understand the distinction between systematic and accidental gaps, consider patterns of harmony. Systems of vowel harmony are cross-linguistically well attested, as in the following set of related word-forms in Halh (Khalkha) Mongolian (13)¹:

(13)	DPST	CAUS	POTENTIAL	GLOSS
	it-ᠵe	it-uᠵ	it-xuic ^h	'eat'
	tu:ᠵ-ᠵe	tu:ᠵ-uᠵ	tu:ᠵ-xuic ^h	'jump'
	og-ᠵo	og-uᠵ	og-xuic ^h	'give'
	c ^h o:r-ᠵo	c ^h o:r-uᠵ	c ^h o:r-xuic ^h	'decrease'
	xuŋ-ᠵa	xuŋ-uᠵ	xuŋ-xuic ^h	'pleat'
	u:rɸ-ᠵa	u:rɸ-uᠵ	u:rɸ-xuic ^h	'evaporate'
	ɔr-ᠵo	ɔr-uᠵ	ɔr-xuic ^h	'enter'
	c ^h ɔ:r-ᠵo	c ^h ɔ:r-uᠵ	c ^h ɔ:r-xuic ^h	'be pierced'

In Halh Mongolian there is a process of *vowel harmony* whereby the frontness or backness of the vowel that appears in certain suffixes is predictable based on the frontness or backness of the vowel in the root. The vowel system of Halh Mongolian consists of seven basic phonemic vowel segments, as in Figure 2.1², representing a sagittal view of the vowel space. This harmony process can be understood in articulatory

Figure 2.1: The vowels of Halh Mongolian (Svantesson et al. 2005).



terms as an artifact of the relatively retracted position of the tongue

1 Data adapted from Svantesson et al. (2005).

2 Each vowel contrasts with a corresponding long vowel, but this contrast is distributionally limited to the first syllable in a word, and is not shown here.

root in the realization of the vowels [ʊ a ɔ], resulting in vowels that are *pharyngealized*—vowels that are realized with a narrowing of the pharynx (Ladefoged & Maddieson 1996). The vowels [i u e o] are not realized with a retracted tongue root, and do not trigger the harmony process. This generalization can be expressed as in (14):

$$(14) \quad V \rightarrow V[\alpha \text{ pharyngeal}] / V[\alpha \text{ pharyngeal}] C_0__$$

(14) says that a vowel will take the pharyngeal quality of a preceding vowel, with any number of intervening consonants.

Halh Mongolian has another kind of vowel harmony, reflecting a different aspect of vowel articulation: *rounding harmony*, as in the words in (15)³:

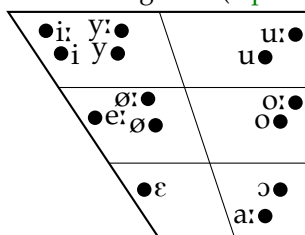
- (15) RFL. / -E /
 pi:r-e 'brush'
 su:ɣ-e 'tail'
 te:ɣ-e 'gown'
 poi:r-o 'kidney'
 c^ha:s-a 'paper'
 xɔ:ɣ-ɔ 'food'

In this harmony, the open, rounded vowels [o a ɔ] cause the vowel of the following suffix to be realized round as well (16):

$$(16) \quad V \rightarrow V[\alpha \text{ round}] / V[\alpha \text{ round}] C_0__$$

In both kinds of Halh vowel harmony, (14) and (16), articulatory properties of the triggering vowel are spread to the target vowel. In fact, harmony processes are attested operating over a number of different articulatory features. Consider the pattern of vowel harmony in Hungarian, which is one of frontness and backness of the harmonizing vowels. The frontness/backness distinction can be seen in the sagittal vowel chart of Hungarian in Figure 2.2, where it can be seen that the vowel space is divided along a front and back axis.

Figure 2.2: The vowels of Hungarian (Siptár & Törkenczy 2000).



As in Halh Mongolian, Hungarian vowel harmony is *stem controlled*, which means that it is the quality of the vowel in the stem of a word which is the trigger for harmony which targets vowels in affixes. In Hungarian, it is always suffixes which are subject to harmony, and

³ Data adapted from Svantesson et al. (2005).

harmony works across a single stem and any number of affixes (Siptár & Törkenczy 2000). Although there are some exceptions and additional details, this is a close approximation of the pattern (Siptár & Törkenczy 2000: 63 ff.); consider now the word forms in (17)⁴:

- (17) juh 'sheep' juh-a:sz 'shepherd'
 kert 'garden' kert-e:sz 'gardener'
 eger 'mouse' eger-ke 'little mouse'
 leány 'girl' leány-ka 'little girl'
 bika 'bull' bika-nak 'to the bull'
 tűz 'fire' tűz-nek 'to the fire'
 mos 'wash' mos-at 'make wash'
 küld 'send' küld-et 'make send'
 ad 'give' ad-atik 'be given'
 kér 'beg' kér-etik 'be begged'

In each related word form in (17), the vowel in the suffix is a function of the quality of the vowel in the root: it is front [e] if the root vowel is front, and back [a] if the root vowel is back. This is expressed in the rule in (18):

- (18) $V \rightarrow V[\alpha \text{ front/back}] / V[\alpha \text{ front/back}] C_0__$

The front/back distinction in Hungarian is phonemic: the contrast between /y/ and /u/ is a function of each vowel's relative position in the vowel space; every vowel in Hungarian is phonologically either front or back. The contrastive function of this distinction can be seen

Figure 2.3: Hungarian vowel phonemes (Siptár & Törkenczy 2000).

	FRONT		BACK	
	UNROUND	ROUND	UNROUND	ROUND
HIGH	i i:	y y:		u u:
UPPER MID	e:	ø:		o:
LOWER MID		ø		o
UPPER LOW	ɛ			ɔ
LOWER LOW			a:	

in Figure 2.3 where another aspect of the Hungarian vowel system is made explicit: each vowel has corresponding long/short phonemes, if the differences in height between some pairs, such as /e:/ and /ɛ/ are abstracted away.

While the phonological quality of frontness/backness harmonizes in Hungarian, the phonological quality of length never does. Consider the words in (19):

⁴ Data adapted from Siptár & Törkenczy (2000).

- (19) a. ha:z-unk 'our house'
 ha:z-hoz 'to the house'
 ha:z-ban 'in the house'
 b. kert-ynk 'our garden'
 kert-hez 'to the garden'
 kert-ben 'in the garden'

In both (19a) and (19b) the affixes are realized with vowels which harmonize with the backness or frontness of their stem, but in (19a) it can be seen that the long vowel in the stem has no effect on the length of the suffix. This is not a property of the suffix, since suffixes in Hungarian can be realized with long vowels, as in (20):

- (20) ha:z-to:l 'away from the house'
 ty:z-tø:l 'away from the fire'

In (20) it can be seen that suffixes can be long independently of the length of the stem vowel, and that harmony applies independently of length.

The lack of length harmony represents an interesting cross-linguistic asymmetry in harmony patterns. There are numerous cases of harmony systems which target consonants—dental harmony in Nilotic languages, sibilant harmony in Navajo, nasal harmony in many Bantu languages, and laryngeal harmony in Zulu. Or, as we have seen, they may target vowels; there is round harmony in Turkish, height harmony in Kisa (Bantu), and even complete harmony, in for example Kashaya (Pomoan) (see Anderson 1980; Archangeli & Pulleyblank 2007; van der Hulst & van de Weijer 1995; Rose & Walker 2011 for overviews). Rose & Walker (2011: 256) note that vowel harmony “occurs for all of the primary vowel place characteristics, affecting backness, rounding, height, and tongue root advancement retraction.” To be explicit, harmony systems, whether they target consonants or vowels, always involve the configuration of the articulators—the temporal dimension seems to be invisible to harmony processes; Krämer (2003: 17) specifically remarks on the unattested status of length harmony, but does not make further comment as to *why* there is no length harmony.

There is an asymmetry in that among all the harmony patterns exhibited in the world’s languages: *length never harmonizes*. There seems to be no language in which a long vowel causes another vowel to be realized as long⁵. While length is different from other articulatory properties such as backness or roundness in that it is a temporal property, there is no obvious reason for temporal properties to be excluded from harmony processes.

There seems to be something special about length that is not obvious from a mere description of harmony processes. That fact that is unattested despite the breadth and frequency of other harmony processes,

5 Though see Hyman & Udoh (2002) for a discussion of Leggbó, an Upper-Cross language spoken in Nigeria that exhibits an intriguing surface pattern of vowel alternations that looks much like length harmony, but that is also analyzable metrically as a property of prosodic phonology.

means that it may be an impossible phonological process—a characteristic of an impossible language. If this is the case, then there must be some principled explanation which accounts for this systematic gap.

2.2 EXPLANATION IN PHONOLOGY

2.2.1 *Explanatory Adequacy*

As discussed in §2.1, the ambition of phonological theory is not just to classify, but to explain. Chomsky & Halle (1965) (see also Chomsky 1964, 1965, 1986) argue that linguistic theories can be classified in terms of *levels of adequacy*. The most basic level is *observational adequacy*, and makes empirically-true observations accounting for the primary language data that a language learner is exposed to without making any hypothesis about how that data is structured. Observational adequacy is not a theory or a grammar. Rather it is a reflection of produced patterns as attested in the linguistic corpus—a description of an E-language (see §1.1.1). Observations concerning linguistic data may not function as a unified whole—each description can be *ad hoc* and adapted for each observation.

The next level is *descriptive adequacy*, and is embodied in a theory which makes a Linguistically Significant Generalization (LSG) (Chomsky 1965: 40 ff.). An LSG is a fact about language and reflects a speaker's linguistic knowledge (Prideaux 1971; Hurford 1977); not all facts about language are LSGs. In order to determine what constitutes a LSG, any theory of phonology must make explicit claims about the kinds of observations that are within its remit, and those which are not. In order to do so, a phonological theory makes explicit a set of principles that give rise to an analysis. As such, a theory which makes a LSG is an account of the underlying structure of a language and gives a formal description of a coherent whole.

A descriptively adequate theory constitutes a theory of I-language in that it gives a correct account of a speaker's knowledge and captures basic generalizations in a linguistic corpus (Rizzi 2016). In so doing, a descriptively adequate theory describes an I-language extensionally, one that is generated by a CR system. For Chomsky & Halle (1965: 103) since a descriptive grammar is a description of speaker knowledge, it may be right or wrong in its description, and evidence can be presented for or against it⁶. As such, attaining descriptive adequacy is the minimal desideratum for a linguistic theory.

A descriptively adequate theory has an advantage over observational adequacy in that it makes make claims about patterns, going beyond mere recapitulation of attested data; they may in principle be able to explain why impossible patterns are impossible. Recall the example of length harmony from §2.1.4: while there are many attested

6 In some ways, this approach marks a break from so-called “taxonomic linguistics” in the style of Leonard Bloomfield, which has been argued by generativists to be neither right nor wrong, making no predictions and saying nothing about knowledge. See however Goldsmith (2008) for a more nuanced view.

cases of harmony, length harmony is unattested—a lacuna that has no significance in mere descriptions of harmony patterns with no explanation of the content of those patterns.

A theory which merely attains descriptive adequacy, however, is not sufficient. It makes explicit claims about explananda, but no claims about the explanans for those explananda. There are potentially an infinite number of grammars which may describe a body of linguistic data. Hyman (1970: 50) rightly points out that among the infinitely many possible grammars, there is a correct grammar, which he refers to as “psychologically real”; that is, a grammar may rise to the level of descriptive adequacy without being an actual description of speaker knowledge instantiated in speakers’ brains (see also Cena 1978). The ontological commitment in Odden (2013) requires that for a theory to describe facts about the natural world, it correspond to this correct grammar.

In order to describe a “psychologically real” grammar and to provide an explanation for why languages are as they are, Chomsky (1964: 29)—echoing Baudouin de Courtenay—argues that a grammar can be said to meet the level of *explanatory adequacy* when it provides a principled basis for favoring it over other descriptively adequate grammars. A theory with explanatory adequacy explains *how* the descriptively adequate grammar comes about from the primary language data (Chomsky & Halle 1965; Chomsky 1986). The level of explanatory adequacy goes beyond the brute empirical facts, since the grammar with greatest explanatory adequacy may contain objects that are not directly observed in the data from which the grammar is built (Chomsky 1964: 33); thus it makes predictions (Dinnsen 1980: 172), telling us what possible and impossible languages are like.

To attain the level of explanatory adequacy, a grammar must provide a set of explanantia, or principled reasons why language is as is. Principled reasons may, as noted by Anderson (2016: 3), follow from the nature of the computational system itself, and thus from the architecture of *UG*⁷, or from properties that lay outside of *FL*, as argued for notably in the work of John Ohala (Ohala 1974; Ohala & Lorentz 1977; Ohala 1983, 1987, 1990) (but see also Blevins 2004; Chomsky 2005; Hale & Reiss 2000a, 2008). The ultimate use of this distinction between descriptively adequate and explanatorily adequate theories is that the latter make explicit claims about what kinds of phonological patterns are the direct consequences of the structure of the grammar.

Recalling the discussion of the levels of explanation in Marr (1982) from §1.2, this question can be framed as one of levels of explanation: is explanatory adequacy an aspect of the computational theory, or of another level of explanation? A theory of phonology with explanatory adequacy, then, takes a stance on where the locus of explanation for

⁷ This is the position argued for by Rizzi (2016), who views explanatory adequacy as a statement about a grammar’s relation to *UG*, a formal property of a grammar. That is, a theory attains explanatory adequacy when the formal system is built out of psychologically-real primitives of *UG*, which can be explained by facts about human cognitive architecture. In this view, explanatory adequacy is a purely formal notion.

a given pattern is to be found—in the formal computational system endowed by UG, or strictly outside of it in facts about non-linguistic cognition, perception, human articulation, the physical world, and so forth. In short, phonological theory must be explicit in defining what kinds of patterns are in its remit. This issue will be taken up again in §2.3.3 with the question of naturalness.

2.2.2 *Linguistic Significance*

In order to discuss the status of crazy rules in phonology, it is first necessary to determine what sorts of facts constitutes generalizations about phonological knowledge. Generalizations are, after all, not strictly speaking empirical observations, since, as argued by Hurford (1977: 578), they are “made at an idealized level somewhat removed from the ‘raw’ data they purport to describe.” That is, they can only be made through the lens of a theory that allows for the conceptualization and description of linguistic data. Different theories may have different sets of relevant empirical facts upon which to base generalizations. Further, it is not immediately clear what constitutes phonological data, how that data can be identified, and what generalizations actually reveal the nature of UG.

This means that prior to formalizing true generalizations about language they must first be discovered (Hurford 1971: 5), as agreement as to what constitutes linguistic data and patterns within that data is a necessary step preceding the comparison of theories and explanations. What is a relevant linguistic datum depends on several factors including what the explicandum is. It is nonsensical to compare a theory of FL to a theory of language as a social or cultural artifact. Explaining why, for example, Romance languages are spoken extensively throughout Europe, Africa, and South America is a question of history—of geopolitical trends and facts—not about the nature of UG. Similarly, it is clear that the fact that Algeria’s northern frontier is Mediterranean coastline is not an observation relevant to FL, since it is not a part of the knowledge speakers have that bears directly on linguistic patterns in Algerian Arabic.

Phonology *qua* cognition is concerned with facts relevant to the nature of UG. But even with a restricted field of inquiry, the choice of theory can have a significant influence on what counts as UG-relevant data. The Gordian knot of phonology is deciding what kinds of generalizations are phonological in nature, and what kinds belong outside of phonology, or even outside of formal grammar (see §1.3.2.2 and §1.3.2.3). For example, the generalization that in French there are nasal vowels is phonological, but the same fact about English is not a part of formal grammar. The generalization in English that the plural morpheme is /-s/ is a fact about grammar, but not phonology, while the fact that /-s/ can be realized as [s], [z], or [əz] is a fact about phonology. This is because patterns in human language reflect interacting forces both from outside grammar, and from the structure of the grammar

itself. Only the former constitute evidence regarding the structure of grammar.

This thesis is a study of crazy rules and their status as a subset of phonologically generated alternations in linguistic data. Patterns of alternations in linguistic data, however, are not always phonological; they may be spurious, or due to phonetics or morphological computation, or artifacts of the lexicon, and so forth. To a certain extent, the choices made in theory construction dictate if a pattern of alternation is in fact an LSG and if so, if it is phonological in nature instead of being, for example, a product of morphological computation or non-computationally derived forms stored in the lexicon.

Ontologically speaking, there are facts about phonology and facts about language which are not about phonology. Phonological theory is responsible only for the former—such facts are reflected in the form of phonological grammars. The latter category includes phenomena which are linguistically significant in that they affect the shape of phonological inventories and the relative frequency of phonological rules, but that are not phonologically significant in that their effect is indirect and they are not reflected in phonological grammars.

Phonological rules are the formal device for representing phonologically significant generalizations. A rule has three principle functions, which Chomsky & Halle (1968) refer to as *conditions of adequacy* in rule formulation (21):

(21) *Conditions of adequacy* (Chomsky & Halle 1968: 330)

A phonological rule must:

- (i) Make it possible to present data precisely and clearly
- (ii) Permit general statements to be formulated about a language which are true and significant
- (iii) Provide a basis for distinguishing these from other generalizations which are false, or which are true but not significant

In SPE style formalisms, rules characterize a native speaker's competence. As such, one way of defining the sets of possible and impossible languages is by formally establishing what a possible rule is and how they are distinct from impossible rules.

In Chomsky & Halle (1968), phonological generalizations are quite broad, engulfing all kinds of purportedly related forms, since phonological rules can be formulated in broad terms and include information which is not strictly phonological, including grammatical information or information such as [+French loanword]. In SPE-based phonology, an LSG can be established on a relatively unrestricted basis, including etymological relationships, semantic relationships, or paradigmatic relationships between sets of word forms.

That generative theory provided no real basis for determining when forms were related constituted one of the primary lines of attack against the theory in the period immediately following the publication of SPE.

The criticism in [Derwing \(1973: 148f\)](#), for example, is pointed: “given that there is no known external (non-linguistic) means to confirm or deny the rules or the base forms which such analysts have entertained in their descriptions, the abandonment of effective constraint on the abstractness of lexical representations has robbed the theory of generative phonology of empirical significance.”

Perhaps the most extreme case of free-wheeling derivational relationships is in the work of [Lightner \(1978\)](#), who maintained that a common underlying form could be established for pairs such as: *eye* and *ocular*, *thunder* and *detonation*, *dental* and *tooth*, *rebel* and *bellicose*, *cardiac* and *heart*, *three* and *third*, *gynecology* and *queen*, *sweet* and *hedonism*. While there is an etymological link between, for example *shadow* and *obscure*, most speakers do not know the etymological history of their language and there is no synchronic reason to assume that etymology is a factor in computation of such disparate forms. However, nothing in the theory excludes such a possibility, since there is no procedure for determining if word forms are related to a common underlying form by a phonological process ([Basbøll 1980](#)). In fact, such analyses may be seen as desirable, since by deriving forms through computation, they reduce the number of lexical items in a language—phonological rules do all the heavy lifting (see [Dresher 1981](#) and [Lass 1984](#) for discussion).

Even alternations of more closely-related word forms, for instance in a shared verbal paradigm, are not by themselves evidence for grammatical processes since they may be the result of historical processes rather than synchronic ones. For example, the word forms may exhibit alternations which are the result of suppletion; that is, every item in the paradigm may have its own lexical form which must be learned and stored as such in long-term memory by speakers. In such cases, there is no online computation, as in the paradigm for the Provençal verb *être* ‘to be’ (22):

- (22) 1s *siáu* 1p *siam*
 2s *siás* 2p *siatz*
 3s *es* 3p *son*

The form for 3s, *es*, is paradigmatically related to all of the other forms, but it is diachronically the result of the collapse of two different verb paradigms for the Latin verbs *stare* and *esse*. While regular verb paradigms in Romance languages can be considered the product of regular morphological computation, verbal paradigms such as that for *être* in Provençal contain the historical residue of verb forms from several paradigms. That is, members of this verbal paradigm are not derived from any computation performed on a base form, but rather are the result of suppletion and must be learned separately.

In English, despite their semantic relationship, [McCawley \(1986: 28\)](#) qualified a putative phonological alternation targeting /t/ in the forms *right* and *righteous* as a “leap of facts” based on the willingness of linguists to allow each other to recognize in such relationships “something for there to be facts about.” [McCawley \(1986: 37\)](#) argues that if linguists-

tics is to be a cognitive science, the data used to make claims about linguistic patterns must have “psychological substance”—that is they must represent speaker knowledge—facts about etymology, semantics, or paradigms are not by themselves sufficient basis for assumptions about phonology.

Similarly, the word-pairs *ear* and *irrigate*, *ink* and *incapable*, or *bear* and *bared* superficially might seem to be related since they share some phonetic qualities; however etymologically and computationally they are unrelated and reveal nothing about grammar or UG. Spurious generalizations such as these are not of much interest in theory construction: there is no reason, paradigmatic, semantic, or phonetic, to assume they represent knowledge of any kind of computational process.

In order to eliminate spurious generalizations, the qualifying criteria of an LSG must be made explicit. This is not a trivial task: Derwing (1976: 38) suggests that rules which are meant to capture systematic variations are contingent upon assumptions made by linguists, and may not represent any kind of psychological productiveness. The question put forth by Derwing is pertinent: how “regular and formally productive” is regular and productive enough to warrant the positing of a rule which is meant to represent actual speaker knowledge? Hurford (1977: 577) takes a particularly gloomy view, saying that instances of LSGs “can only be an informed guess made against the background of . . . acquired impressionistic knowledge of what languages are like.” Indeed, even the choice of what constitutes *evidence* for an LSG depends to certain extent on theoretical assumptions (see Zwicky 1980 and Ohala 1986 for discussion).

For Ohala (1986), experimental evidence is the best method of assaying evidence for LSGs, and thus speaker knowledge. Experimental evidence which demonstrates the productive character of alternations (Berko 1958; Derwing 1976; Cena 1978; McCawley 1986) is taken to reflect speaker knowledge. The classic test for “psychological substance” is the *wug test* (Berko 1958). In a wug test, speakers are presented with nonce words and asked to perform some kind of morphological operation on them so that the novel form is modified, for example by adding a plural morpheme, resulting in a change in a phonological context. In this way, the speaker can be elicited to create a context in which some alternation takes place. If the operation is carried out on the nonce words, then it is said to be productive and the alternation is taken to be the operation of computation—a psychologically real fact about the speaker’s linguistic knowledge. In practice, LSGs are adduced from a variety of methodological principles (see Zwicky 1972 for discussion), and linguistic theory itself is the ultimate arbiter of what constitutes a true alternation (Hurford 1971, 1977).

Establishing a pattern as an LSG, whatever the methodological tack used to derive it, is merely an opening move in a phonological analysis. This is because LSGs can come from outside of phonology, as in the case of morphological alternations. Phonology occupies a position between the lexicon and the real-world of physical phonetic facts; core facts of phonology, such as the existence of processes which map from

underlying segments to surface segments and the existence of features, may be rarely contested but the murkier frontiers are often the place for skirmishes regarding the exact place of LSGs as generalizations relevant to phonetics, phonology, or morphology. A given observation may be consigned to one or the other based on a variety of criteria, and analyses may not agree on which category an observation is to be explained by, rendering the comparison of theories impossible. This has important consequences for the place of crazy rules: they may be ejected from the realm of phonology based on methodological precepts. The theoretical stakes for the ontological status of crazy rules will be further discussed in §2.3.3.

2.2.3 *Overgeneration*

As discussed in §1.1.3.1, an early structuralist notion held that phonological systems cannot be understood in terms of the mechanics of articulatory or acoustic phonetics; rather, they can only be understood as a network of symbolic objects that build contrast, a purely mental phenomenon. Contrast, in turn, has to be expressed as physical objects—sounds or gestures—realized in time and space (Chitoran & Cohn 2009). The basic function of the formal system in Chomsky & Halle (1968) is to map between the symbolic and the physical, and the symbolic nature of phonology has been the basis for the categorical symbol-processing formalism of a number of phonological theories (Scobbie 2007). Crucially, a good theory performs at least two related tasks: it explains why the patterns it describes are as they are, and it makes predictions about unattested—but possible—patterns, and distinguishes between them and impossible patterns. However, it is still unclear how a theory is imbued with explanatory adequacy.

In principle, formal systems can be powerful enough to impose regularity over any data-set. This raw formal power means that the difference between potential spurious generalizations and LSGs can be obscured: generalizations can be made which merely reflect artifacts of the over-powered formal system, not of speaker knowledge. This means that explanatory adequacy is not possible in a pure SPE-style formalism, partly because it leads to *overgeneration*: the formal system has unlimited descriptive power. SPE-style rules that set no bounds on possible computations can describe all attested languages, all unattested languages, and make no distinction between possible languages and impossible languages.

The raw power of the generative system was addressed within SPE itself in the famous⁸ Chapter 9 (Chomsky & Halle 1968: 400):

The entire discussion of English in this book suffers from a fundamental theoretical inadequacy. Although we do not know how to remedy it fully, we feel that the outlines of a solution can be checked, at least in part. The problem is that our approach to features, to rules, and to evaluation

⁸ See discussion in Hale & Reiss (2008); Odden (2017); Scheer (2011b).

has been overly formal. Suppose, for example, that we were systematically to interchange features or to replace [α F] by [- α F] (where $\alpha = +$, and F is a feature). There is nothing in our account of linguistic theory to indicate that the result would be a description that violates certain principles governing human languages.

Sommerstein (1977: 204) argues that phonological rules “can do almost anything”, since underlying representations can be posited without limit, and rules can manipulate them in a similar limitless fashion. Overgeneration is accelerated by structural and computational freedom coupled with the free reference to non-phonological information such as morpho-syntactic information (Scheer 2011b: 404). In terms of structure, the free association of features and feature values into segments results in an explosion of combinatorial possibilities: of all the possible segments the system can compose, only a vanishingly slight fraction are actually attested in natural language. Thus, there is no explanation for why some rules occur and reoccur, and others never occur.

The computational wing is free to overgeneration because there is no restriction on the terms: in a rule $X \rightarrow Y / Z$ any sort of object can instantiate X, Y, and Z. In a world in which languages are arbitrary and phonological computation can follow any rule, there is no real need for a phonological component of mind: everything human beings know about language is the result of a stimulus-response reaction (Moro 2016). Such a system has no problem generating crazy rules, but its unrestricted scope means that there is an expansive gap between attested segments and processes and formally possible segments and processes; in a system that overgenerates there is no distinction between possible and impossible languages.

As an illustration, consider the following data from Brazilian Portuguese (BP) (23):

- (23) a. ba[t]er ‘to hit’
 ba[t]o ‘I hit’
 b. man[d]ar ‘to order, to send’
 man[d]o ‘I order, I send’
 c. ba[tʃ]i do ‘beaten’
 man[ɕĩ]ndo ‘ordering, sending’

In (23) there is an alternation between the coronal obstruents [t d] in (23a) and (23b) and [tʃ ɕ] in the forms in (23c). The consonants in question are a part of the roots of each word, but the concatenation of the past-tense morpheme *-ido* results in their being realized in a specific context: preceding the high front vowel /i/. The alternations in (23) can be generated by the SPE-style rule in (24):

$$(24) \begin{bmatrix} +\text{coronal} \\ -\text{continuant} \\ -\text{distributed} \end{bmatrix} \rightarrow \begin{bmatrix} +\text{coronal} \\ -\text{continuant} \\ +\text{distributed} \end{bmatrix} / _ \begin{bmatrix} +\text{syllabic} \\ +\text{high} \\ +\text{front} \end{bmatrix}$$

(24) takes the feature matrices for /t/ and /d/ as input, and says that when they are realized in front of /i/, they are realized as [tʃ] and [dʒ] respectively. The features specified by each matrix perform several functions. First, the target class /t d/ is denoted by the features [+coronal], [-continuant] and [-distributed] since only /t d/ carry this exact feature specification; every other consonant in BP is irrelevant. The trigger matrix is the high front vowel /i/. The change from /t d/ to [tʃ dʒ] is manifest in the change of the feature [-distributed] to [+distributed]. The shift from /t d/ to [tʃdʒ] preceding /i/ is a typical, well-attested palatalization, which the rule adequately describes.

However, using the same formal system, the opposite of (24) can just as easily be written (25):

$$(25) \begin{bmatrix} +\text{coronal} \\ -\text{continuant} \\ +\text{distributed} \end{bmatrix} \rightarrow \begin{bmatrix} +\text{coronal} \\ -\text{continuant} \\ -\text{distributed} \end{bmatrix} / _ \begin{bmatrix} +\text{syllabic} \\ +\text{high} \\ +\text{front} \end{bmatrix}$$

By simply switching the feature values of [distributed], we can write a rule that deaffricates [tʃ] and [dʒ], resulting in [t d], before front high vowels. This formally comparable rule generates an unattested and surprising process. The process in (25) may even generate an impossible language, but since the formal system provides no way of differentiating between possible and impossible languages, there is no way of knowing. In these circumstances, the difference between (11c) and (11d) is trivialized.

In addition to its raw computational power, a further accelerant of overgeneration in SPE was the fact that underlying representations could be quite abstract relative to their surface realizations⁹. Objections to “the abstractness problem” began to emerge early on (Derwing 1973; Kiparsky 1968 [1973]; Postal 1968) (see Hyman 1970; Kenstowicz & Kisseberth 1979 for discussion). The issue can be articulated as follows: how far removed is the phonological form of a word from its phonetic instantiation? To put it another way, how much work must phonological rules be shouldered with in order to derive related surface forms from underlying forms? Without any means of restricting the form of underlying representations, and with virtually unconstrained computational power, the theory articulated in SPE had no empirical significance (Derwing 1973: 148f.).

2.2.3.1 Antidotes for overgeneration: Lexical Phonology

In the wake of SPE, two lines of attack on overgeneration coalesced: one against abstractness in representations, and the other on the raw formal power of the computational system (Scheer 2011b: 406ff.). The overgeneration spurred by absolute neutralization and abstract forms

⁹ The representation of *nightingale* as /nixt/ingale posited by Chomsky & Halle (1968: 234) in order to account for the non-application of trisyllabic laxing is a classic case of an abstract underlying representation.

identified by Kiparsky (1968 [1973]) lead to a proposal to restrict abstractness by limiting the distance between underlying and surface forms, and to divide the lexicon into derived and underived forms; the former are morphologically complex (e.g. *craft+y*) while the latter are morphologically simplex (e.g. *clever*). Rules, in turn, are limited in the scope of their application, operating only over derived forms.

The notion of levels in phonology eventually gave rise to the program of Lexical Phonology (LP) (Kaisse & Shaw 1985; Kiparsky 1985; Mohanan 1986; Rubach 2008). In LP, exceptions to general rules are a part of the lexicon, where all idiosyncratic information is stored. The lexicon itself plays a role in computation, being structured into different levels, each of which is the domain of a particular phonological or morphological computation. Rules apply in two ways, either in the lexicon itself as lexical rules, or outside of the lexicon as post-lexical rules. The interaction between morphology and phonology in LP meant that the set of alternations which needed to be accounted for by computational rules was reduced. LP aimed at restricting the formal system's power to overgenerate by restricting the scope of computation.

2.2.3.2 Antidotes for overgeneration: The evaluation metric

The second line of attack was directly on the computational power of grammars. Since phonological data can be described by infinitely many grammars statable in formal terms, a crucial desideratum of a theory of phonology is that it describe true, psychologically-real grammars—it must attain the level of explanatory adequacy (§2.2.1). Chomsky (1957 [2002]: 49) distinguishes between “a grammar” of a language ℓ and “the correct theory of this language,” and establishes the necessity for criteria enabling the identification of the correct grammar of ℓ among the set of possible grammars of ℓ . Without a way to choose between descriptively adequate formal theories, there is no way of achieving explanatory adequacy; what is required to differentiate between the true grammar and the infinite set of possible alternatives is a procedure to evaluate the candidate grammars and select the true one (Chomsky & Halle 1968: 330ff.).

This selection procedure is known as the *evaluation metric*¹⁰—a formal mechanism for selecting among possible grammars and identifying LSGs. The problem identified by Chomsky & Halle (1968) in Chapter 9 (§2.2.3) was precisely a problem of evaluation: the formal system allowed for no way to select from among grammars. In Halle (1962) and Chomsky (1965), the evaluation metric was primarily on the notion of the “simplicity” or “economy” criterion: LSGs are captured by virtue of the number of symbols needed to state them. The more symbols needed, the less true the generalization (McCarthy 1981b). For example, a rule which specifies [+voice -cont] as the structural target captures a better generalization than a rule which specifies [+voice -cont -nasal] when the set of targets is /b d g/. Further, this metric

¹⁰ Also called the evaluation measure (Kiparsky 1974).

can in principle be used to conduct valid cross-theory comparisons: a theory which uses simpler formal tools to capture a generalization may be more highly valued than one which requires an elaborate formal system to capture the same generalization.

Building on the simplicity criterion, an early solution to the formal system's shortcomings was provided by Chomsky & Halle (1968: 400ff.) themselves: in order to close the gap between attested patterns and formally possible patterns SPE made use of a notion first used by the Prague school known as *markedness*. In SPE terms markedness was an intrinsic value that served as a way to measure relative complexity in both segments and rules; the more complex a rule as measured by markedness, the less likely it was to represent a true LSG, and thus be a part of a formal grammar or an attested pattern. Complexity, then, was a proxy for naturalness—complexity in representations and computations incurred a cost the grammar was sensitive to thanks to the evaluation metric—intended to reflect natural attested linguistic patterns (see Lass 1975, 1984 for discussion).

Simplicity in the formal sense is a hypothesis about the form of grammar, and in turn about UG: language learners acquire the simplest possible grammar that attains the level of descriptive adequacy. In this sense, formal simplicity is the criteria by which explanatory adequacy is derived (see Rizzi 2016 for discussion). Formal simplicity is also a heuristic by which phonologists can select from among competing descriptively adequate theories of grammars. In this regard it is an application of Occam's razor: parsimony is valued over descriptively adequate theories which introduce extraneous elements.

Formal simplicity in general, and marking conventions in particular, do provide an antidote to overgeneration, but they failed to accomplish the task they were set to for several reasons (Kiparsky 1972, 1974). Prideaux (1971) argues that the evaluation metric has no empirical echo since it is a purely formal notion and makes no reference to anything outside of the formal system itself. That is, the evaluation metric is a theory-internal definition of LSG (McCarthy 1981b: 221). Yang (2017) also sees the evaluation metric as being internal to a linguistic theory, as opposed to a universally applicable notion of simplicity; ultimately, the simplicity criterion is nonsensical outside the bounds of the formal theory. Far from providing true explanatory adequacy, marking conventions constitute a prime example of data-fitting: modifying a theory using *ad hoc* stipulations to preclude the generation of unattested languages (Blaho & Rice 2014; Hale & Reiss 2008).

A further attack on overgeneration was an explicit, across the board reduction of computational power by limiting the expressiveness of the formal notation through the incorporation of functional factors in grammar—*formal naturalness*. Any theory in which phonetic naturalness serves as an explanation and a precondition for rules is presumed to be more constrained (Dinnsen 1980: 171f.). Formal naturalness limits overgeneration by restricting the set of possible alternations which can be computationally generated.

The promise of formal naturalness was multiple. First, it would allow for a phonological theory that closely matched attested languages and reduced overgeneration. Second, it would allow a phonological theory to differentiate between possible and impossible languages by providing explanatory adequacy. Third, it would serve as an arbiter in the division of labor—whatever was unnatural was not phonology. Formal naturalness also has consequences for the ontological status of crazy rules: since they are not descriptively reducible to phonetic principles, their place in the phonological grammar is threatened.

2.3 NATURALNESS IN PHONOLOGY

2.3.1 *Relative and absolute constraints*

Marking conventions ultimately failed to provide explanatory adequacy (Anderson 1974; Schachter 1969; Schane 1972; Vennemann 1971). The ambition of markedness to mirror typological patterns in phonological theory itself, and the debate surrounding the inadequately constrained theory articulated in SPE persisted into the 1970s (see Kiparsky 1968 [1973]). Following the assertion by Postal (1968: 55ff.) that there are natural relations between underlying phonemic segments and their phonetic surface forms, the notion of naturalness seemed an obvious manner by which to develop an evaluation metric that could distinguish between typologically expected processes and rare or unattested ones. Naturalness then, and the idea that frequently attested patterns were *ipso facto* natural, continued to serve as a ready potential limit to the purview of phonological theory.

In fact, typologically universal phenomena were seen as such obvious candidates for an evaluation metric with explanatory power that Schachter (1969: 342) was led to assert with confidence: “[t]he need for incorporating a valid account of phonological universals into a general model, or metatheory, of phonological descriptions may be taken as self-evident.” The self-evidence is the advantage such a metatheory would bring to phonological analysis, allowing typological universals to be incorporated into phonological theory and thus dispensing with the need to restate universals in individual language grammars. Vennemann (1971: 75) suggested that the evaluation metric be supplemented by “linguistic plausibility”, by imbuing linguistic symbols with knowledge about what is possible in human languages; this, he suggested, could be done through a “theory of naturalness, a formal device to incorporate knowledge about linguistic universals into the evaluation procedure.”

The closeness of fit between phonetic patterns and phonological patterns (see §1.3.2.2) began to seep into phonological theory in the period following SPE¹¹, especially as a means of explaining phonetic patterns

11 Though naturalness as a phonological notion is nearly as old as phonology itself, going back at least to Sibawayh’s *Al-Kitab* written circa 800 CE. See Blevins (2008b: 122ff.) for an overview of naturalness in pre-generative phonology.

(Dinnsen 1980: 171). Kenstowicz & Kisseberth (1979: 61) argued that phonetic naturalness could be used to choose between competing descriptively adequate analyses:

[T]he choice between taking x or y as basic can usually be determined by the relative naturalness of the corresponding rules $x \rightarrow y$ versus $y \rightarrow x$. If changing xs to y in the environment b represents a more expected process phonetically than does changing ys to x in the environment a , then the former analysis is preferred. In the majority of cases where the predictability criterion is applicable, the associated rule(s) will be natural as well.

Sommerstein (1977) argued that phonological theory should take up the task of establishing what kinds of phonological processes are natural, why they are natural, and then assigning them a special status in phonological theory. Thus, in the wake of SPE, formal naturalness was deployed to reduce the expressive power of grammar, provide an evaluation metric, and provide explanatory adequacy. If the computational system provided by UG is sensitive to phonetic naturalness, it is only to be expected that the world's languages should be characterized by recurrent sound patterns which align closely with phonetic patterns.

In turn, by limiting the generative capacity of the formal theory, naturalness also provides an explanation for unattested patterns. Constraints on the formal system, jointly with the evaluation metric, formed the basis for explanatory adequacy in early generative theories (Kiparsky 1972: 191f.). Kiparsky suggests that constraints are of two kinds. *Absolute* constraints, derived directly from the formal notation itself, limit the class of possible grammars simply by making impossible rules "unstable in an absolute sense." *Relative constraints*, meanwhile, are imposed through the interplay of formal tools and the evaluation metric; they impose costs on unnatural patterns, making grammars relatively more or less disfavored and reflecting attested patterns. Formally, as discussed in Derwing (1973), two notions in particular were deployed in early generative work to impose relative constraints: the notion of simplicity in formal grammar (§2.2.3.2), and that of naturalness.

Formal naturalness, then, constitutes a kind of relative constraint imposed on grammar which limited the formal system, making unnatural or unattested grammars impossible for phonology to account for, thereby reflecting linguists' intuitions about phonetic naturalness and facts about typology. Beginning with the marking conventions of Chomsky & Halle (1968), this became a recurrent theme in generative thinking. The result was a concomitant reduction in the set of alternations that phonological theory is responsible for and a means of achieving explanatory adequacy: languages may look the way they do, and not some other way, because phonological computation is natural. Crucially, it also meant that the status of crazy rules in phonology was in doubt.

2.3.2 Definitions of phonological naturalness

To a certain extent, all phonology is natural in that it is the product of human biology and not a cultural artifact (Maddieson 2009). In this respect it is as natural as any other part of nature. However, in the context of phonological theory naturalness tends to be the reflection of an observation that some phonological patterns occur and reoccur with greater than expected frequency in the world's languages, and the need for an evaluation metric that would allow phonologists (and children tasked with learning a language) not only to strictly determine the division of labor between phonology and other sources of linguistic patterns, but to justify including a posited rule in a formal grammar (Dinnsen 1980). The term *naturalness* itself has been taken to mean a number of different things in the literature: as a formal aspect of rules which operate over symbolic natural classes as in SPE, as a functional effect of articulation, and as a typological phenomenon (Bermúdez-Otero & McMahon 2006). These three conceptions of naturalness are intertwined, since what is typologically natural tends to be justified by functional pressures and reflected in some formal structure.

The marking conventions in Chomsky & Halle (1968) were essentially the formalization of typological facts as *symbolic* naturalness, meant to recapitulate commonly attested patterns and assure that formal structures which produced such patterns were more highly valued, since they *a priori* were more natural. In this case, symbolic naturalness is inherent in the simplicity metric (Chen 1973); a formal device which could be used to evaluate the naturalness of phonological grammars by counting symbols. Kenstowicz (1994: 21) provides another example of symbolic naturalness which explicitly refers to common elements in the structural description of rules. The class of possible rules, $[x] \rightarrow [y]$ can be constrained if $[x]$ can only become $[y]$ in context $[z]$ where $[z]$ shares one or more features of $[y]$, as in a typical assimilation process. This same limitation could also be imposed on $[x]$ and $[y]$, for example, by limiting the change from $[x]$ to $[y]$ as one of a changed feature value for example. This limits changes and triggering contexts such that both are non-arbitrary (Scheer 2015a: 313).

Naturalness can also be *functional*, manifest in phonetic explanations of phonological rules. Phonetic explanations do not have to be formalized to enter into phonological theories; they may be informally used, as when Keating (1988: 291) notes that phonologists may use phonetic explanations to provide general explanations or bolster specific arguments. They may also look to phonetic correlates that suggest some theoretical construct has a physical basis, or that a proposed rule is plausible, without looking for formalized naturalness (see Cohn 2007; Myers 1997 and Kingston to appear for overviews). In turn, articulatory constraints can take a number of different forms, from a universal pressure towards assimilation or simplification (Hyman 1975), or more general notions such as ease of articulation (Archangeli & Pullyblank 1994; Greenwood 2016; Kirchner 1998; Pierrehumbert 2000; Ohala 2005; Shariatmadari 2006). Alternatively, phonetic explanations may incor-

porated as a formal element of the theory, reflecting the structure of grammar in UG (Archangeli & Pullyblank 1994; Hayes & Steriade 2004; Hooper 1976; Kirchner 1998).

Finally, naturalness may be *typological*, based on the observation that certain phonological patterns are recurrent in human languages, characterizing a number of languages in distinct language families. At the same time, other processes which could be logically conceived of are rare, or never occur. In this view, typological frequency demands an explanation, as it is equivalent to phonological naturalness (Carpenter 2010; Hyman 1975; Maddieson 2009; Moreton 2008; Myers 1997; Ohala 1972; Schane 1972; Schane et al. 1974). Generally, arguments based on typology can ultimately be reduced to arguments based on articulatory plausibility: natural rules are typologically common because they are manifestations of universal articulatory constraints (Archangeli & Pullyblank 1994; Blevins 2004; Greenwood 2016; Hayes & Steriade 2004; Hellberg 1978; Hyman 2001; Myers 1997; Ohala 1972; Schane 1972).

The following section will briefly outline the principle efforts to build the three kinds of naturalness into phonological theory, and the consequences of each of those efforts for the ontological status of crazy rules.

2.3.3 *Naturalness in formal theory*

Although a theoretical role was never attributed to naturalness in Schane (1972), his taxonomy of natural rules constitutes an early program in which naturalness played a central role. Schane argues that naturalness rules are of three kinds:

1. Assimilative rules
2. Preferred syllable structure rules
3. Rules for maximum differentiation

Assimilative rules represent, for Schane, the clearest kind of natural rule—they describe contexts in which two adjacent segments do not share a feature value in their underlying representations, where one segment takes one or more feature values from the other so that both segments have identical values for those features on the surface. In Schane's view, consonant assimilation, lenition, vowel nasalization, and palatalization are all examples of this kind of natural rule. This is a kind of symbolic naturalness in that it is based on formal features and feature values, but the interaction of features implies a notion of naturalness based on functional considerations.

Preferred syllable structure rules come into play when an underlying representation would violate the canonical syllable shape in a language. An example of this second kind of natural rule is the rule of Brazilian Portuguese (BP) which inserts an epenthetic vowel after an underlying consonant which would otherwise result in a closed syllable, as in

ético ‘ethnic’ which is realized [e.ʔi.ni.ku] instead of *[e.t.ni.ku]. This is presented as a natural rule because languages such as BP which prefer open CV syllables are more frequent than languages which allow CVC syllables, and such processes assure the realization of surface CVCV forms. This kind of rule represents a kind of typological naturalness.

Maximum differentiation rules work on both static elements of phonology as well as dynamic ones. Thus a minimal vowel inventory /i a u/ is a natural one because all members of the set are maximally different from each other. Schane (1972) also argues that this principle can be instantiated by rules, such as in rules of final devoicing and liquid gliding, which all serve to enhance saliency between adjacent segments. This kind of rule is a kind of functional naturalness.

There is an important and apparent contradiction in the definitions just given: why do some natural processes (assimilative rules) serve to make adjacent segments more similar to each other, while others (maximum differentiation rules) serve to make them less similar? Schane (1972: 213) says this contradiction vanishes if “clear-cut external explanations are given for each.” That is, according to Schane, assimilative rules are the result of physiological constraints that are articulatory in nature, while maximum differentiation rules are the result of psychological constraints that are perceptual in nature.

The principal ambition in Schane (1972: 214) is to establish a taxonomy of natural rules, while recognizing that the constraints giving rise to these patterns are to be found “outside of phonological theory per se”; nevertheless, Schane (1972: 206) is clear that his taxonomy must “be recognized within phonological theory”, since their status as natural rules is derived from their structure, even if their explanation lies in extragrammatical factors. In order to give the three rules a non-arbitrary theoretical status, Schane outlines conditions for formalizing the three kinds of rules (26):

(26) *Schane’s (1972) Theory of Natural Rules:*

- a. The Theory of Assimilation specifies: which segments are candidates for assimilation, which features are subject to assimilation, and what direction assimilation works in.
- b. The Theory of Preferred Syllable Structure specifies: what the typology of syllable shapes is, what the mechanics of syllabic simplification are.
- c. The Theory of Maximum Differentiation specifies: a set of constraints under which non-assimilatory neutralizations can take place, an exact account of the directions of these neutralizations.

While Schane’s taxonomy does not represent an explicit constraint on formal theory, the conditions are meant to provide a set of rigorous specifications that characterize natural processes by making explicit the “internal linguistic justification for the various categories of natural rules” (Schane 1972: 213)—representing then a programmatic schema for the formal identification of natural rules.

The constraints in (26) allow the analyst to say why a rule is natural, but do not identify or limit impossible rules. Furthermore, (26) has nothing to say about the theoretical role played by naturalness, leaving the notion in a theoretical limbo—is naturalness the reflection of a grammatical property? Or merely a taxonomic classification with no epistemological value? The response to these questions is rather vague: “one would hope to find something in the structure of natural rules which would explain their universal popularity” (Schane 1972: 206).

With the advent of the Natural Theories—Natural Phonology (Donegan & Stampe 1979; Stampe 1973) and Natural Generative Phonology (Hooper 1976; Vennemann 1971)—the notion of naturalness was incorporated directly into the construction of phonological theory, resulting in a concurrent formalization of naturalness as linguistic competence (De Cuypere & Willems 2008; Stausland Johnsen 2012). Since the Natural Theories, the notion that phonetic naturalness is a part of linguistic knowledge with explanatory power and thus should be reflected in formal theory has persisted; the most influential of them will be discussed below.

2.3.3.1 *Natural Phonology*

The program of Natural Phonology (NP) was a direct response to the perceived lack of explanatory power in SPE (Donegan & Stampe 1979). It was not that SPE was not concerned with explanatory power, but rather that it “abandoned the problems it had been proposed to explain...or turned to alternative principles like markedness or other equally unrelated criteria” (Donegan & Stampe 1979: 167). NP embodies functional naturalness, initiated by Stampe (1973) as both a reaction against the formalism of generative grammar and as manner of basing phonology in functionalist terra firma, with aim to place limits on the powerful formal system laid out in SPE.

In many ways, the conceptual break between NP and generativism is stark—where generativism is a theory about what speakers know, NP is a theory about what speakers do. The principal observation is that speakers frequently do not articulate what they intend to articulate, and that in turn listeners do not always perceive the speech signal in a way that relates directly to articulation. NP is a theory of what extra-grammatical factors—articulatory and acoustic—arbitrate between speakers and listeners and can explain the discrepancies between what speakers intend to say, what they say, and what listeners hear.

Naturalness is at the heart of NP; to wit Donegan & Stampe (1979: 127):

This is a *natural* theory, in the sense established by Plato in the *Cratylus*, in that it presents language (specifically the phonological aspect of language) as a natural reflection of the needs, capacities, and world of its users, rather than as a merely *conventional* institution. It is a natural theory also in the sense that it is intended to *explain* its subject

matter, to show that it follows naturally from the nature of things; it is not a conventional theory, in the sense of the positivist scientific philosophy which has dominated modern linguistics, in that it is not intended to *describe* its subject matter exhaustively and exclusively, i.e., to generate the set of phonologically possible languages.

NP explicitly and directly incorporates natural processes into phonological theory, extending the scope of naturalness into a claim that all humans are born with innate phonological processes as a part of their linguistic competence. Those processes, in turn, were explained through recourse to phonetic factors, both through ease of articulation and through acoustics and perception (Donegan 2001).

The basic insight is simple: phonological phenomena are universal because of the universal properties of *Homo sapiens*, common to the species, engenders patterns that are *ipso facto* natural and recurrent. This includes not only biology, but also things such as wishes, plans, and the expectations of speakers. Assimilation, for example, being typologically frequent, is explained by physiological facts about articulation or perception during the production of speech by humans.

Phonology in NP—as in the generative program—is a mental process, but one that is “motivated by the physical character of speech—its neuro-physiological, morphological, mechanical, temporal, and acoustic properties” (Stampe 1973: 6). That is, in NP, the origin and explanation for phonological phenomena lay partially in the extra-linguistic in that they are strategies for coping with the physiological realities of the human vocal apparatus. This means that the conception of naturalness in NP is one of phonetic naturalness which leads to typological naturalness. For instance, the allophonic nasalization of vowels in English in tokens such as *hand* [hæ̃n] is a result of the way humans are built, and the fact that sounds adjacent to sounds articulated with a lowered velum for the production of nasals are nasalized to a certain extent because it is easier for the vocal apparatus to lower the velum in anticipation of the production of the nasal segment, and neighboring segments are innocently caught in the cross-fire as it were, rather than being the target of a nasalization rule.

While in generative thinking phonology was a system which had to be acquired by the learner upon exposure to an ambient language, in NP this order of acquisition was reversed. In the view of Stampe (1973), humans are born with an innate knowledge of what is natural. In languages with final devoicing, for example, speakers know that voiced stops pose specific articulatory problems, and so replace them in final position with voiceless counterparts which do not pose the same problems. As such, final devoicing, like other natural processes, are not merely cataloged, but also explained since they have a functional motivation. Speakers of languages without final devoicing must essentially “unlearn” what they know, overcoming their innate preference for final devoicing.

NP effectively excludes crazy rules from phonology by establishing a dichotomy between *processes* and *rules*. Only processes, which are invariable and phonetically motivated, represent phonology. Rules, instead, are learned by engaging general cognitive competency and may be arbitrary—the represent social conventions and are the opposite of natural. Stampe (1973) argues that rules are subject to exceptions, are never triggered by slips of the tongue, can be repressed consciously, and notably may result in unnatural alternations with no obvious phonetic explanation; as such they are not a part of phonology. An example is the case of velar softening in English: the alternation between *electric[k]* and *electric[s]ity* is not phonology; it is, rather, a property of a distinct ontological space, that of morpho-syntax.

Processes, in contrast, have unique motivations. Segmental processes increase perceptibility or ease of articulation of segments—in this sense all phonology is teleological since it is a means to attain a goal. Processes are innate; or rather are the result of innate constraints imposed by our existence as corporal beings and may be optional. One of the most important arguments for this last point comes from data from child speech. Stampe (1973: 5 f., 16 ff.) uses data from child speech intending to show that rather than learning phonological rules governing alternations, children must learn to suppress natural rules that are not a part of their language¹². The conclusion is that the locus for apparent naturalness in phonology can be found directly in the synchronic grammar: speakers know what a natural process is and what is not, and this knowledge guides them in their choices.

While processes are at the center of the NP program, everything else is outside of the remit of phonology. Rules and other extra-phonological alternations have no phonetic motivation; they are sometimes the historical residue of processes which no longer have phonetic motivation and have become “fossilized” or conventionalized. Where processes lack grammatical function, rules may be morphological or otherwise carry semantic or syntactic information (such as in the case of Umlaut, see §1.3.2.3). Rules, in contrast to innate processes, are learned and as such are conventional. Importantly, rules may not always apply; for instance even though tri-syllabic laxing describes an important generalization about sound patterns in English, the word *obese*, when realized as tri-syllabic *obesity* is not realized with a lax vowel.

The consequences for crazy rules are clear: as phonetically unmotivated alternations they are excluded from phonology. They are a property of the grammar, but, being rules they are a property of the

12 Using evidence from child speech has been criticized; see Blevins (2004) who argues that child speech is subject to constraints imposed by motor and articulator-control issues, not competence issues. Also Newmeyer (2005), who discounts evidence from child speech. De Cuypere & Willems (2008: 13) are similarly pessimistic regarding the value of child speech, noting that “some common sound substitutions in child language prove rarely if ever attested as sound change in adult phonology,” as well as “the fact that different children come up with different solutions to bypass similar phonological intricacies.” The conclusion that natural rules exist in child speech from the very beginning is demonstrably false for a rule of vocalic allophony in Swedish (Hellberg 1978). See discussion in Foulkes & Vihman (2013)

morpho–phonological grammar, even when they make no reference to morphological vocabulary. The ultimate result is that NP defines a set of possible phonological grammars that is relatively reduced compared to the one defined by SPE, and greatly reduced relative to one defined by theories which do not include notions of synchronic naturalness. Crazy patterns may still arise—the naturalness inherent in the phonological grammar proper makes them relatively unlikely, though not impossible.

2.3.3.2 *Natural Generative Phonology*

The origins of Natural Generative Phonology (NGP) are in the work of Vennemann (1971), but the most complete exposition of NGP comes from Hooper (1976). Like NP, it places an emphasis on constraints to the generative power of SPE. In contrast to NP, it is a true generative theory of phonology—a theory of what speakers know. NGP’s primary ambition is to establish what a phonological rule is and what empirical criteria can be employed in order to identify them—that is, how to explain alternations and the relation that holds between alternating forms (Hooper 1976). In NGP, naturalness is functional in nature.

While SPE allowed for highly abstract underlying representations forms, the foundational epistemological principle underlying NGP is the *True Generalization Condition*, which requires that all underlying representations be directly related to surface forms. Based on this principle, Hooper argues that NGP is more concrete than SPE, since abstract rules relating abstract underlying forms to surface forms are not possible—the only true LSGs are surface true; this makes opacity impossible, since the output of all rules must be realized on the surface. Hooper (1976: 14) is explicit regarding the implications of the True Generalization Condition on the empirical domain of phonology: “[t]his theory at the same time makes STRONGER claims about what is a possible natural language because it restricts considerably the number of possible grammars for any given body of data.”

In NGP there is a clear typology of rules: 1) phonetically conditioned rules (P-rules) 2) morphonemic rules (MP-rules) 3) syllabification rules 4) morphological spell-out or word formation rules 5) via-rules. Rule types 3, 4 and 5 are not substantially different from those of more mainstream generative theories. The first two rule types, however, serve to mark the division of labor in NGP, circumscribing and restricting the kinds of grammars it allows.

P-rules serve as a formalization of naturalness in the grammatical computation itself. Here, naturalness is articulatory, as when Hooper (1976: 16) says that P-rules “describe processes governed by the physical properties of the vocal tract”, and serve to describe alternations that take place in contexts which can be identified based only on “phonetic terms” (Hooper 1976: 14). “Phonetic terms” means two things here, both phonological features with intrinsic phonetic content (as in SPE) and phonological boundaries with obligatory and consistent phonetic forms; i.e. syllables and pauses correlated with phonetics and word

and morpheme boundaries with syntactic and semantic correlates. P-rules are automatic rules of phonetic detail or neutralizations, examples being English aspiration and German final devoicing respectively. All rules which contain “only phonetic information” (Hooper 1976: 14) are rules of this kind. From this point of view, as in NP, speakers have knowledge about naturalness hard-coded into their grammars. Indeed, P-rules correspond to the natural processes of NP, but can also variably apply if blocked by social, morphological, or syntactic factors. Further, while in NP there is no requirement that processes be surface-true, P-rules must be.

In contrast to phonetically motivated P-rules are MP-Rules. The distinction between the two kinds of rules is a fundamental tenet of NGP (Hooper 1976: 15). MP-rules perform a similar function to P-rules in that they change features, but instead being cued by phonetic terms, they act on features in environments described in morphosyntactic or lexical terms. These rules refer then to categories such as plural, past tense, noun or verb as well as to lexical items, which is an arbitrary class designated by diacritics. Hooper (1976) gives the example of the rule governing the voicing of certain spirants in certain English plurals: *wife / wives, wolf / wolves, house / houses*, as a rule of this type. These rules are not universal, since they act on arbitrary items, and are thus arbitrary themselves. A synchronically active rule is either phonetically motivated or morpho-syntactically motivated; no other kind of rule can be a part of the phonological grammar.

As in NP, crazy rules in NGP are banished from the phonological component of the grammar, the set of phonological operations is surface-true, phonetically motivated, and exceptionless. If crazy patterns are synchronic, they reside in the realm of MP-rules, being arbitrary in nature; even if, as in NP, they make no reference to morphological vocabulary.

2.3.3.3 Grounded Phonology

Grounded Phonology (GrP) (Archangeli & Pullyblank 1994) is an extension of autosegmental phonology (Goldsmith 1976, 1990) and feature geometry (Clements 1985). For Archangeli & Pullyblank (1994: 3), the principle task for a theory of phonology is “to provide an explicit characterization of the full range of attested representations and rules, but at the same time should be incapable of characterizing many of the imaginable patterns that are not attested in natural language.” As such, the question of what makes an impossible language impossible has a central role in the theoretical foundations of GrP.

GrP addresses this question in part by its architecture: it is a modular theory of language in that it establishes interfaces via which phonology communicates with syntax and morphology. Phonetics, in turn, interfaces with the phonological module but not with syntax or morphology. The phonological module itself is composed of sub-modules, each of which operates according to their own set of formalisms. To constrain the range of possible phonological grammars such that the

relative frequency of both attested and unattested patterns are given explanation each sub-module imposes constraints on representations and computations which interact to make certain configurations disfavored or impossible.

In GrP, the notion of naturalness is present symbolically, functionally and as typology: recurrent attested patterns are taken to represent natural patterns, and plausible phonetic explanations—in both articulation and perception—are given to explain those recurrent patterns. Archangeli & Pullyblank (1994: 167f.) give as an example the fact that certain physical properties are associated with the production of [+nasal] segments, notably voicing. Archangeli & Pullyblank then note that the lowered velum needed to produce nasalization results in an articulatory configuration that is particularly conducive to voicing, and that voiceless nasals pose problems in perception.

Naturalness in GrP is manifest in the phonetic properties intrinsic to features—such as [+nasal]—which are known as *F-elements*. Symbolic naturalness is manifest in the representation of segments, which are composed of F-elements in a hierarchical system of associations—known as *paths*. Following the Grounding Hypothesis, which says that associations must be phonetically motivated GrP grammaticalizes naturalness in phonological theory by making restrictions on paths a part of the formal system. That is, association between features is regulated by the most important set of formal conditions that impose naturalness: the Grounding Conditions, which are derived from the “interaction of the phonetics with phonology” (Archangeli & Pullyblank 1994: 9). In the case of nasals and voicing, the grounding conditions impose a constraint against a [+nasal] segment being realized as [-voice]. The grounding conditions then assure the generation of *well-formed* structures on the surface. A path which potentially violates the Ground Hypothesis, such as [+nasal -voice], is *ill-formed* in the grammar. Ill-formedness and well-formedness are basic notions in autosegmental phonology (Goldsmith 1990), governing the acceptability of representational structures.

Grounding conditions then explain the frequency of attested patterns by placing phonetically-motivated formal restrictions on the number of possible feature associations. Formally, the grounding conditions consist of a series of implicational statements (e.g. *if [+nasal] then [+voice]*). Implicational statements in turn are “grounded in their phonetic correlates”, which may be articulatory or acoustic in nature (Archangeli & Pullyblank 1994: 15). Implicational statements play a direct role in determining what kinds of segments occur in natural languages, Archangeli & Pullyblank in turn argue that these reflect possible languages and make predictions about what kinds of impossible languages cannot exist.

In the computational wing in GrP, the grounding conditions interact with another sub-module, that of Parametric Rule theory, favoring (or disfavoring) both synchronic computation and diachronic rule changes by providing constraints on formally possible rules which are intended to explain the range of possible variation in alternating forms. In the

view of Archangeli & Pullyblank (1994: 285), “if there are no limits on possible rules, there is no theory: anything is an acceptable rule.” In order to avoid this proliferation of rules, GrP restricts the class of possible rules by imposing four binary parameters on rule forms. The parameters place strict limits on what components of rule descriptions can vary, and in what ways, in an effort to reduce the set of possible rules to the set of attested rules (Archangeli & Pullyblank 1994: 285 f.).

Archangeli & Pullyblank (1994: 182 f.) recognize that attested phonological patterns come about from the interplay of formal and substantive factors, and merely assume that most processes are natural, rather than all. Since all paths must be phonetically grounded, when a path is the target or source of a rule, the rule will in turn be phonetically grounded. Notably, one of the four parametric variables limits rules to operating on single F-elements or paths. Since both F-elements and paths are subject to Grounding Conditions, rules are also subject to Grounding Conditions. For example, while rules can insert or delete F-elements or paths, they cannot insert [-voice] to a path with [+nasal] because such an association is ill-formed according to the Grounding Conditions.

Thus, in GrP, crazy rules cannot be generated by the phonological formalism, since phonetic naturalness plays a direct role in determining what kinds of computations can be carried out. Crazy rules are thus ejected from the phonological component of grammar, and presumably are shunted into morph-syntax or the lexicon.

2.3.3.4 *Government Phonology*

The program of Government Phonology (GP) (Charette 1990; Harris 1990; Harris & Kaye 1990; Kaye 1990a; Kaye et al. 1985, 1990) does not directly address the question of naturalness in any of the three guises discussed in §2.3.2; in fact GP maintains that phonological conditioning factors are *never* phonetic, rather they are purely phonological and an alternation which has non-phonological conditioning factors is not phonological in nature. However, GP is in part a response to the formal power of SPE, in particular its arbitrary aspect, in that one of its primary ambitions is to articulate a non-arbitrary theory of phonology where everything happens for a principled reason and the formal apparatus that generates phonological patterns is a reflection of those reasons.

On the representational side, typology is recapitulated via markedness, where the number of marked features in a segment increases a segment’s complexity, such that [æ] is more complex than [a], for example (Kaye et al. 1985). The surrogate for substantive naturalness is specific well-formedness conditions on representations, which in Charette (1990) and Kaye (1990a) take the form of abstract licensing conditions. Representations which do not satisfy the phonological licensing conditions are ill-formed, and must be repaired.

Computationally, GP restricts the set of possible phonological processes according to a set of specific criteria that have repercussions for the status of crazy rules. Kaye (1992: 14) and Kaye (1995: 290) estab-

lish the *Minimalist Hypothesis*, later renamed the *Minimality Hypothesis* (Kaye 2014), which states that phonological processes apply whenever triggering conditions are satisfied; in contrast to LP, there is only one set of computations. Rules apply exceptionlessly and are surface-true. If the conditions are met for a phonological process to happen, it will happen.

A further consequence of the Minimality Hypothesis is that alternations which require statements about morphological structure as a conditioning environment cannot be phonological (Kaye 1995). This idea reaches its apotheosis in Kaye (2014), where alternations limited to specific morphological contexts and never found morpheme internally are excluded from phonology; they are always instantiated by different lexical forms. Another way of considering the Minimality Hypothesis is by viewing it as a condition on what kind of vocabulary is relevant in the statement of phonological rules: only alternations which can be stated in purely phonological terms are phonological in nature.

The principle which impacts the remit of phonology most forcefully and with the most important consequences for the synchronic status of crazy rules is the *non-arbitrariness condition* (Kaye et al. 1990; Gussmann 2007; Pöchtrager 2006), which says that there must be a plausible causal relationship between the change observed and the triggering context in an alternation. In other words, there is a direct relation between a phonological process and the phonetic context in which it occurs: what a rule does and where it does it are related. So, for example, an alternation that is characterized by vowels being nasalized before coronal consonants cannot be phonological, since there is no plausible way for coronals to nasalize vowels.

Thus, in GP, while there is no specific emphasis placed on phonetic naturalness in rule statements, we do see naturalness emerge as a formal tool in segmental complexity intended to reflect typology and manifest as a kind symbolic naturalness. In addition, the non-arbitrariness condition is clearly a kind of functional naturalness, making direct reference to phonetic factors. The result is that GP places some of the most severe restrictions on the set of possible phonological alternations. Alternations which reference morphological vocabulary or do not meet the non-arbitrariness condition cannot be phonological. Since crazy rules by nature do not satisfy the non-arbitrariness condition, GP excludes them from phonological computation, relegating them to morphology and thus an effect of the lexicon.

2.3.3.5 *Optimality Theory*

The theory which perhaps most fully weaves naturalness into its formalism is OT (McCarthy & Prince 1994; Prince & Smolensky 1993 [2002]). Since its introduction, OT has arguably constituted the dominant theory in phonology, and as such it is impossible to do justice to the various sub-theories, modifications, and works published that have been discussed in the literature since that time (see van Oostendorp to appear for a thorough overview). The thread that runs through every

theory of OT is the use of a constraint-based computational paradigm instead of a rule-based, SPE-style formalism (see Odden 2011; Scheer 2011b; Uffmann 2011 for discussion of constraints and how they differ from rules).

The change in emphasis from rule-based formalism to a constraint-based one was in part a reaction to the raw power inherent in rules which allowed for the description of unattested languages (see the volume edited by Goldsmith 1993). Constraints, it is argued, provide a way of reducing the gap between the set of formally possible languages and the set of attested languages (Uffmann 2011). In a constraint-based theory, computations are not so much performed as they are motivated by sets of constraints that impose well-formedness conditions on phonological objects; as such, constraints become the explanans of LSGs by barring ill-formed structures from reaching the surface (though without dictating how they are repaired). So, while OT marks a stark break with earlier generative theories it shares with the broader generative program the ambition to explain the range of attested phenomena in possible languages. That is, OT is a typologically-oriented theory which seeks to explain, using a system of universal constraints on possible forms, why attested patterns are as they are.

OT is structured around two computational modules: GEN produces a set of underlying candidate forms which is subject to EVAL, a set of interacting constraints that collectively select the optimal candidate in GEN to produce a single surface form. As a result, in OT, the explanatory burden is placed into the computational wing of the theory—specifically on constraint interaction—with relatively little emphasis placed on the representational side.

EVAL consists of two broad categories of constraints: faithfulness constraints and markedness constraints. The two kinds of constraints subtly interact to assign a ranking to underlying forms. Faithfulness constraints act to preserve underlying forms by penalizing divergent forms. Markedness constraints, in turn, effect changes on underlying forms by penalizing “marked” structures. As the relative constraint rankings are language specific, their interaction gives rise to cross-linguistic variation. For example, the interplay between a constraint against final voiced consonants and faithfulness produce and describe the pattern of final consonant devoicing in languages such as German and Catalan, absent in English and Spanish. In German and Catalan a markedness constraint against final voiced consonants is ranked higher than the faithfulness constraint that says underlying consonants should surface faithfully, while in English and Spanish their order is reversed. In the case of German and Catalan, the output of computation is an optimal candidate with devoiced final consonants, while in English and Spanish the optimal candidate is faithful to the input and no devoicing occurs (see Iosad 2018 for more details).

In most orthodox iterations of OT (de Lacy 2006; Kager 1999; McCarthy 2002), markedness is a reflection of typological facts; what is natural is what is robustly attested in natural language. However, in order to limit the proliferation of constraints in OT, they are typically

phonetically grounded (Kager 1999; Myers 1997). The substance of phonetic grounding is generally articulatory, but it has also been argued to be perceptual (as argued for example by Steriade 2001 [2009], who formalizes perceptual similarity in mappings between input and output in what is known as the P-map).

The phonetic substance of markedness constraints is made most explicit in the program of Phonetically Based Phonology (Hayes & Steriade 2004). In this view, phonetic factors—both articulatory and perceptual—serve as an explanation for what markedness is: markedness is the grammaticalization of phonetic constraints on production and perception, and plays an essential role in determining what kinds of surface patterns a grammar produces. As such, languages are as they are because they are shaped by the articulatory and perceptual biology of human beings as reflected in markedness constraints.

In classic OT, then, naturalness is both typological and functional, being motivated by typology, but grounded in functional concerns. The fundamental role played by naturalness in computation means that there is essentially no place for crazy rules in OT-based phonology. The interaction between faithfulness and markedness constraints prevent arbitrary or phonetically-unnatural alternations from being generated (see Green 2006 for an extensive argument to this end). By their very nature, alternations which cannot be generated by restrictive faithfulness constraints or phonetically-grounded markedness constraints must lie outside of phonology: either in morphology or the lexicon.

However, the phonetic grounding of constraints is not a necessary property of OT. In the view of Bermúdez-Otero & Börjars (2006), markedness is not an innate property of UG but rather is environment-driven and emerges over the course of acquisition as a function of the ambient linguistic data and performance effects. As a consequence, markedness is not a reflection of typology and does not entail phonetic grounding. In part, the reasoning of Bermúdez-Otero & Börjars is motivated by crazy rules, requiring a more formal view of the substance of constraints. For example, a constraint CODA COND-Place restricts the class of grammatical coda segments in coda positions. Such a constraint, however, does not reference any phonetic or perceptual facts and only evaluates phonological representations since codas are not phonetic objects. This more formal view of markedness constraints which allows for unnatural alternations is shared by, for example Boersma (1998); Hyman (2001) and Iosad (2017).

2.3.4 Summary

In sum, the ontological status of crazy rules as phonological in nature is a function of the role of naturalness in formal theory. In theories where computation is natural, crazy rules are not phonological. Instead, they are morphophonological (NP, NGP) or morphological and thus lexical phenomena (GrP, GP, OT). Only in OT is this not a direct consequence of the formalism itself; in versions of OT with emergent constraints

(Bermúdez-Otero & Börjars 2006; Boersma 1998; Hyman 2001; Iosad 2017), crazy rules can be accommodated by phonological computation.

Table 2.1: A summary of formal naturalness in phonological theories.

	SPE	NP	NGP	GrP	GP	OT
Formal Naturalness	✓		✓	✓	✓	✓
Typological Naturalness	✓	✓	✓	✓		✓
Phonetic Naturalness		✓	✓	✓	✓	✓

These theories all have in common the hypothesis that phonological theory is characterized by phonetic plausibility; either through the kinds of operations and representations it manipulates, or through constraints which impose phonetic naturalness through specific machinery that rules out unnatural processes or structures. Table 2.1 demonstrates the general condition of crazy rules in phonological theory: they are banished from phonology for multiple reasons, born out of an effort to restrict the set of possible phonological processes.

Generally, this banishment is not explicit, in part because crazy rules are not directly addressed outside of rare exceptions (such as Bermúdez-Otero & Börjars 2006). For example, while Archangeli & Pullyblank (1994: 169) argue that patterns which are not grounded are impossible, they do not mention crazy rules. Kaye (1995: 312) is another notable case, where it is argued that GP cannot express processes such as velar softening or trisyllabic laxing; as a result, “GP predicts that the so-called rules cited above could not occur in phonology.” In most iterations of OT, universal markedness constraints mean that crazy rules are impossible computationally because no configuration of markedness constraints could generate crazy patterns.

Another interesting consequence of the emphasis placed on segmental or phonetic naturalness (with (26b) from Schane 1972 being the exception that proves the rule) is that there is virtually no discussion of structure above the skeleton. Since the naturalness literature focuses principally on segmental properties and phonetic naturalness, it is taken for granted that syllabic structure will be natural: there are no cases of onsets attached to rhymes, or distributional restrictions in onsets but not in codas. Furthermore, it is unknown what unnatural processes above the skeleton might look like: short syllables that attract stress at the expense of long ones, a processes of epenthesis that inserts a vowel into hiatus, metathesis that moves a word-initial consonant to the end of a closed syllable, or the case of length harmony discussed in §2.1.4. Thus in the phonetic view of naturalness, syllables and processes dependent on syllabic structure have virtually no status, as either natural or unnatural.

The result is a class of processes which may be arbitrary, but which can be argued to be motivated by natural structural properties, such as metathesis (Blevins & Garrett 1998, 2004). Metathesis, thus, may be phonetically arbitrary in that it is not motivated by any articulatory

properties in the structural description (though see Hume 2001, 2004b), but the structural change itself is unsurprising. There is in fact precedent for the exclusion of metathesis from the set of possible phonological processes: the Neogrammarians excluded it from their theory of sound change, since Neogrammarian sound change was gradual and metathesis is drastic and sudden.

Similarly, the status of epenthesis is unclear: while epenthesis *qua* hiatus resolution may be given a phonetic explanation in terms of an articulatory link between the epenthetic segment and the vowel context into which it is inserted, as in French *vous liez* [vu lije] ‘you tie 2PL’ where a palatal glide is inserted following a high front vowel (see Lyche 1979), epenthesis also frequently manifests as an arbitrary or unnatural process (Blevins 2008a; Vaux 2001, 2002) with no articulatory motivation behind the selection of the epenthetic segment. An example is found in Uyghur (Turkic), where /j/ or /r/ is inserted between a stem vowel and a vowel initial morpheme (Hahn 1992). Epenthesis, in this case, may be phonetically arbitrary, but phonologically motivated by structural conditions internal to Uyghur.

2.4 CONCLUSION

In this chapter I discussed the function of a theory of phonology as a means of making meaningful generalizations about the structure of phonological grammars. Following Hale & Reiss (2008), I suggest that the proper remit of phonological theory is *possible languages*, but that not all unattested languages are possible. One function of theory is to provide an explanation for why attested languages are as they are, rather than being some other way. Phonological theory, then, allows for a distinction to be made between possible but unattested, and impossible and unattested.

One of the principle ways of distinguishing between the former and the latter has been through restricting the set of possible phonological processes. Since the publication of SPE, formal naturalness has been perhaps the most widely employed means of limiting the generative capacity of grammars. I reviewed its role in the construction of theories, especially in light of its use as an explanatory device and a remedy against overgeneration. In theories which build naturalness into the grammar, there is no place for crazy rules in phonology.

The next chapter provides a census of crazy rules. Its ambition is provide a reasoned empirical review of crazy rule candidates so that phonologists who are interested in the nature of phonological computation, in possible and impossible rules, have a basis on which to make arguments. The rules are contextualized as much as possible given their descriptions in the literature.

The theories of naturalness in this chapter are thus confronted with strong empirical arguments which suggest the predictions they make regarding the set of possible phonological rules is not correct. It thus provides an additional argument that phonological theory must ac-

count for crazy rules (Bermúdez-Otero & Börjars 2006; Hale & Reiss 2000a, 2008; Iosad 2017; Odden to appear; Samuels 2011; Scheer 2015a; Vaux 2008). This is because there is no naturalness within phonological computation, and thus any observed naturalness effects are outside the scope of phonological theory.

Even what is most unnatural is
nature.

GOETHE

Each of the theories surveyed in §2.3.3 limits the scope of phonological computation based on how naturalness restricts the set of possible languages. The ambition of this chapter is to provide an empirical census of crazy rules reported in the literature, such that naturalness and phonological computation can be considered in their light.

This census provided here cannot hope to be exhaustive, but rather aims to be representative of the kinds of crazy rules found in natural human language. As such it is composed of a wide variety of phenomena present in the literature but never treated in a unified manner. The work that has engaged with crazy rules or other phonetically unnatural processes is on the balance impressionistic, with discussion based on sparse data. This census thus constitutes the first effort of its kind to collect in one place the disparate account of crazy rules in the literature.

In selecting the crazy rules presented here, I use a more precise set of criteria than Bach & Harms (1972), for whom crazy rules are simply those which escape plausibility conditions imposed by an evaluation metric, and as such are phonetically unnatural. This is a broad characterization of crazy rules, but it is dependent on the structure of the evaluation metric.

Recalling the discussion in §2.3.2, what constitutes a crazy rule depends to a great extent on what kinds of alternations are within the scope of phonological computation in a given theory. As seen, there is something of a spectrum between more permissive and more restrictive theories; there is no objective, pretheoretical measure of what is phonetically unnatural and what is non-phonological in one theory may be so in another. In an effort to avoid the ambiguities inherent in that spectrum, in the present discussion craziness is embodied in the lack of phonetic motivation at any place in the structural description of a phonological rule¹.

This results in four ways of being crazy:

The four manifestations of rule craziness:

I Through a crazy class of input segments (/p n ʌ/)

II Through a crazy class of triggering environments (/p n ʌ/)

¹ Here rules are presented as descriptive devices, but make no claims about how computation is carried out.

III Through a crazy structural change (/j/ → [k])

IV Through a crazy relationship between the change effected and structural description (p → b / _æ)

The criteria for craziness thus reflect a heterogeneous class of targeted or triggering segments—(I), (II)—or through a phonetically arbitrary relationship between the input and output of a structural change (III). Craziness may also be exhibited through an arbitrary relationship between a structural change and a structural description (IV), when the conditioning environment seems to have no plausible relationship to the change effected.

Just one of these conditions is enough for a rule to be considered crazy. However, craziness is frequently manifest in more than one place without being entirely crazy. For example, a particular context may be a well-known trigger for phonological alternations but produce an unexpected structural change that is both phonetically implausible and seemingly unrelated to its context: l → ʁ / V_V.

The emphasis here is on crazy rules in which the structural change has no phonetic motivation, either in that the input and the output are unrelated, or the output and the triggering context are unrelated. In the first case, an input segment X is realized as Y, where X and Y diverge unexpectedly in manner, voicing, place of articulation, or some combination thereof. In the second case, a change X → Y is conditioned by an environment Z such that Y and Z diverge unexpectedly along the same axes. There may also, in principle, be craziness that is syllabic, stress-related, or concern other properties beyond segmental representations—an expected alternation between long and short vowels in closed and open syllables respectively, for example. In all cases, the emphasis is on rules in which craziness is exhibited in the relationship inherent in the structural change or description itself.

3.1 ON PHONOLOGICALLY ACTIVE CLASSES

The craziness in type (I) and type (II) is inherent in the phonetic heterogeneity of each class. Whereas the term *natural class* suggests that classes of segments which function together phonologically will be *naturally* coherent, a crazy class exhibits no phonetic unity. This notion of unnatural classes which constitute coherent classes of targets or triggers is embodied in the term *phonologically active class* (Mielke 2008), which dispenses with the naturalness criterion. Mielke gives a detailed account of many such phonologically active classes, many of which could have been², in principle, included in the present census. Rather than reproducing his survey here, I present an illustrative case not discussed by Mielke.

² Some of the case studies presented in Mielke (2008) have been shown to be errors of analysis, (see §3.2), a danger in any large-scale survey of lesser-known languages. However, not all of Mielke's examples can be easily dismissed.

In Lakota, a Siouan language also called Teton Dakota, there is a rule targeting only /p/ and /l/, resulting in nasal consonants when preceding a nasal vowel (27):

$$(27) \quad p, l \rightarrow m, n / _ \tilde{V}$$

This is an unusual class, since no clear substantive feature both unites /p l/ into a class while excluding the other consonants in the Lakota phoneme inventory. In the following analysis, I have regularized the use of Americanist phonetic notation to IPA. The consonant inventory is as in Table 3.1³, grouped by articulatory cues and not by phonological features.

Table 3.1: The Lakota consonant inventory (after the analysis of Ingham 2003).

	Labial	Coronal	Alveo-palatal	Velar
Stops	p b	t	tʃ	k g
Ejectives	p'	t'	tʃ'	k'
Aspirated	p ^h	t ^h	tʃ ^h	k ^h
Fricatives		s z	ʃ ʒ	h
Ejectives		s'	ʃ'	h'
Nasals	m	n		
Approximants	w	l	j	

In Lakota, the voiceless consonants /p/ and /k/ voice to [b] and [g] respectively, when preceding /l/ in consonant clusters. Lakota has nasal vowels, and two consonants are realized as nasal consonants [m] and [n] when preceding nasal vowels: /l/ as in (28b), and /p/ if and only if it precedes /l/ in a cluster, as in (28c). The allophone of /k/, [g], does not nasalize (28d)⁴:

- (28) a. ja 'he goes'
 jĩ-kta 'he will go'
 b. la 'you go'
 nĩ-kta 'you will go'
 c. bla 'I go'
 mnĩ-kta 'I will go'
 d. gla 'he goes home'
 gnĩ-kta 'he will go home'

In (28), the vowel /a/ in the prefix undergoes a process of ablaut which also nasalizes it, and that nasalization spreads backwards, nasalizing consonants which are targeted by that process.

³ Matthews (1955) and Ingham (2003) give /b/ and /g/ as phonemes in Lakota, though Carter (1974); Shaw (1980) and even Matthews analyze them as contextual allophones of /p/ and /k/ respectively.

⁴ Data adapted from Shaw (1980).

Shaw (1980: 99) specifically states that only /l/ and /p/⁵ undergo this nasalization, to the exclusion of the other stops and approximants. Carter (1974) notes that /l/ never appears before a nasal vowel, although it is clear that a bare /p/ may do so (as in the form [juspíkta] ‘he will hold it’ given by Shaw). I remain agnostic here as to the use of rule ordering, but it is clear that there is an asymmetry between underlying /p/ which may nasalize in some contexts, and the other stops, which never do. This suggests that it is /l/ and /p/ which undergo nasalization in Lakota—an unusual class.

Since [l] and [t] can vary, as for example in reduplicated forms such as /kʰáta/ ‘hot’ → [kʰálkʰáta] in Lakota (Matthews 1955; Carter 1974), it might be possible to analyze nasalizing /l/ as underlying /t/. However, it can be seen in the forms given by Carter (1974: 36) that near-minimal pairs exist for /pl/ and /pt/ (29a), as well as /kt/ and /kl/ (29b):

- (29) a. [pte] ‘bison’
 [ble] ‘lake’
 b. [kte] ‘to kill’
 [gleza] ‘striped’

This constitutes an additional argument for considering the class of consonants which undergo nasalization preceding a nasal vowel in Lakota as being /p l/, while other stops and approximants /k t w j/, in addition to the sets of glottalized and aspirated stops, do not. Thus, Lakota exhibits a phonologically active class that is difficult to frame as a natural class using phonetically substantive features, as indicated in Table 3.2.

Table 3.2: A ‘crazy class’ in Lakota.

	Labial	Coronal	Palatal	Velar
Stops	p b	t	tʃ	k g
Ejectives	pʼ	tʼ	tʃʼ	kʼ
Aspirated	p ^h	t ^h	tʃ ^h	k ^h
Fricatives		s z	ʃ ʒ	h
Ejectives		sʼ	ʃʼ	hʼ
Nasals	m	n		
Approximants	w	l	j	

Rather than attempting to make an exhaustive account of phonologically active classes, the census that follows is limited to rules in which craziness is manifest as in type (III) and where there is an arbitrary relation between the structural change and triggering context, as in type (IV), as for example in Campidanese Sardinian discussed

⁵ Shaw (1980: 97) uses the exact words “b is neutralized to m and l to n before nasal segments”, but analyzes ‘b’ as underlying /p/.

in the Introduction. Such cases are taken to demonstrate the power of phonological computation to manipulate features in arbitrary ways, unconstrained by articulatory naturalness.

3.2 OVERVIEW OF THE CENSUS

3.2.1 *A word of caution*

The data below are gleaned from a wide variety of sources in the literature, both descriptive and analytic. Individual cases are not meant to constitute unambiguous counterexamples to naturalness theories. In part, the danger of suggesting such a thing is that in each rule there exists the possibility of error of analysis. In fact, this danger is inherent in any large survey of languages which are not well-known to the analyst.

An illustrative case comes from the discussion of Evenki (Tungusic) in [Mielke \(2008: 120f.\)](#). [Mielke](#) identifies a crazy class, /v s g/, a phonologically active class targeted by a process of nasalization triggered by an underlying preceding nasal consonant (30):

- (30) a. /oron-vi/ → oron-mi 'one's own reindeer'
 /ɲanakin-si/ → ɲanakin-ni 'your dog'
 /oron-gaʃin/ → oron-ɲaʃin 'like a/the reindeer'
- b. /giriki-vi/ → giriki-vi 'one's own friend'
 /lamu-gaʃin/ → lamu-gaʃin 'like a/the sea'

Within the context of the Evenki inventory as analyzed by [Mielke](#), /v s g/ constitute a phonetically unnatural class.

[Uffmann \(2018\)](#) argues that the process of consonant nasalization in Evenki cannot be understood as an isolated process; in other processes what is realized as [g] post-nasally is realized as a continuant, [ɣ], intervocally and word-finally. [Uffmann](#) argues that the underlying consonant is /ɣ/, which surfaces allophonically as [g]. Further, both /v/ and /ɣ/ harden in onsets, are exempt from a ban on voiced codas, and together with /s/ do not behave like obstruents phonotactically. In this light, the phonologically natural class in Evenki identified by [Mielke \(2008\)](#) is phonetically natural after all.

Despite the error of analysis exposed by [Uffmann \(2018\)](#), there remain dozens of cases of phonetically unnatural classes identified by [Mielke \(2008\)](#), and his conclusions cannot be disregarded without argument. [Mielke's](#) survey is susceptible to reanalysis because it is based on language descriptions drawn from grammars, where phonetic and phonological levels may be mixed or otherwise not clearly defined. Phonological systems are abstract and require analysis. [Uffmann's](#) point is well taken: conclusions about the naturalness of processes are questionable when made on the basis of isolated phenomena. The best analyses take a holistic approach and view rules as part of a larger phonological system.

3.2.2 *On crazy diachronic changes*

Craziness is also potentially found in diachrony, where phonological change has been argued to be minimal (Beguš 2018b; Picard 1990, 1999), never operating simultaneously over more than one of voicing, manner, or place of articulation. In this view, diachronic change is mediated by phonetic naturalness in that it is bound by articulatory constraints. Thus, in reconstructing the historical change *dw > erk in Armenian, where steps intermediate to the historical segment and its reflex cannot be recovered from the historical record, best practice is to reconstruct intermediate forms that are not attested, but which allow for a natural, step-by-step historical progression to be reconstructed (Scheer 2004a, 2015a).

However, not every researcher may come to the same conclusions about what the correct intermediate forms might be (Picard 1990). Furthermore, Scheer (2004a) cautions against taking a rigid view of minimally possible phonological changes, noting that this can lead to the positing of implausible diachronic derivations. Historical change, rather than being constrained by phonetics, may be a product of phonological structure, reflecting changes in underlying representations (Kiparsky 2008a).

In fact, Blust (2005) argues that there is evidence for historical changes which are surprising in that they do not seem to be phonetically motivated (see also Blevins 2008b). Blust (2005: 221) explicitly argues for changes that happen as “single-step reflexes, not the cumulative product of multiple innovations.” A summary of such changes is provided in Table 3.3.

Table 3.3: Some crazy diachronic changes (Blust 2005: 221).

LANGUAGE	CHANGE	TYPE OF CRAZY RULE
Western Manus	*w/y > p	III
Sundanese	*w/b > c-,nc-	III
Kiput, Berawam	Intervocalic devoicing	IV
Drehet	*dr > k ^h	III
Karo Batak, Berawan	*b/d/g > -m/n/ŋ	IV
Berawan	C > C:/_V#	IV
Berawan	*b > -k-	III
Saʼban	*g > p-, -j-, -p	III
Iban	*an/aŋ > -ay	III
Iban	*em/en/eŋ > -aw	III
Murik, Buginese	Postnasal devoicing	IV

Phonetically unmotivated changes which occur as single changes meet the criteria for craziness given above. Phonological change also may reflect a previous state in which the change was produced by an active process of phonological computation, which was later obscured.

However, in changes where there is a lack of synchronic alternations, they cannot be considered here to be the product of synchronic computation, whatever their genesis.

In this census, each case is included because it exhibits a pattern of alternation which cannot plausibly be conditioned by its phonetic environment—it is agnostic concerning the synchronic status of each alternation presented, which must be determined on a case-by-case basis (see §1.3.2.3 for relevant discussion). Included in the discussion of each case are relevant arguments and literature concerning the phonological status of the alternations concerned. Thus, no individual potential crazy rule is presented as an indisputable argument against naturalness in phonology; rather any theory of phonology that formalizes a notion of phonetic naturalness must either apply that tool to every process here, or exclude them from the remit of phonology.

3.2.3 *On phonetically opaque phonological processes*

Included in this census are a number of alternation patterns which are examples of *opacity*, where the original trigger for a synchronic process has changed so that the phonetic motivation for the alternation has been rendered opaque, without the alternation pattern becoming outright unnatural. The patterns detailed for Limburg Dutch (§3.10.2.4), Icelandic (§3.10.2.3), and Norwegian (§3.10.2.5), for example, are all clear cases of opaque alternations. In many of these cases an abstract analysis, where for instance a triggering segment retains some phonological trace of a now-lost phonetic property, could be given to account for the pattern. That is, a process that on the surface is phonetically unmotivated may be triggered by a segment that is assumed to have an abstract identity, which when taken into consideration provides some measure of phonetic plausibility.

In such cases, it might be argued that although the pattern is abstract, it is natural since the segments concerned are still sensitive to the original phonetic motivation. The ambition of this chapter is not to evaluate such abstract analyses—it is merely to present data relevant to alternations which synchronically are phonetically arbitrary, without necessarily being unnatural as such. This chapter, then, aims to show that, whatever the mechanism, phonology can handle phonetically arbitrary synchronic patterns, and thus is not bounded by naturalness.

3.3 AFRO-ASIATIC

3.3.1 *Chadic*

3.3.1.1 *Zina Kotoko*

Odden (2007) describes a pattern of alternation in Zina Kotoko where mid-tones become low after voiced consonants, glottal stops, and implosives. Typologically, the interaction between tones and consonants

is a robust relationship between voiced consonants and high tones. Voiced consonants lower F_0 , while voiceless consonants produce an opposite effect, causing F_0 to rise, resulting in higher tones (Kingston 2011).

In (31), it can be seen that mid tones occur following [h] and voiceless obstruents:

- (31) a. her-óm 'bite'
 hwat-óm 'inflate'
 hǎrc-óm 'slice'
 hǎl-óm 'steal'
- b. skal-óm 'pay back'
 pay-óm 'bury'
 tam-óm 'touch'
 kah-óm 'take a handful'

There are three tones in Zina Kotoko: L, H, and M, marked with a grave accent, an acute accent, and unmarked respectively. Tones contrast in nouns but not in verbs, where tones are predictable based on the interaction between suffixal tones or floating tones that mark tense-aspect and phonological rules that condition tone lowering triggered by consonants. Underlying L tones are invariant across all consonantal contexts, while underlying H tones surface as H after voiceless consonants. Odden (2007) identifies the tone associated with the recent past tense as underlyingly M, which surfaces as such when preceded by a voiceless consonant.

However, when the initial consonant is an obstruent (32a), sonorant (32b), glottal stop (32c), or implosive (32d) the underlying lexical M is lowered:

- (32) a. ghàg-óm 'close'
 zègl-òm 'carry'
 gùlm-óm 'twist'
 vît-óm 'blow a fire'
 bghwàr-óm 'jump PL'
 zàk-óm 'beat'
- b. yèy-óm 'call'
 màr-óm 'die'
 wèh-óm 'be tired'
 làlf-óm 'bring'
- c. ʔàkf-óm 'approach'
 ʔàk-óm 'snatch'
- d. ðv-óm 'put'
 bál-óm 'dance'
 ðh-óm 'write'
 ðàm-óm 'eat'

The change from M to L is a conventional structural change suprasegmentally, but the triggering context is phonetically arbitrary. The pattern of mid-tone lowering in Zina Kotoko can be described by (33):

- (33) $M \rightarrow L / D_$
Where D includes voiced consonants, sonorants, glottal stops, and implosives.

It is notable that voiced consonants, sonorants, glottal stops, and implosives are not an obvious natural class, but constitute a phonologically active class in the sense of Mielke (2008). However, what makes the rule in (33) crazy is the interaction between the suprasegmental tier and the melodic tier. In this case, the triggering context has an unexpected effect on tones, making it a crazy rule of type (IV).

3.3.2 Cushtic

3.3.2.1 Somali

Somali is a Cushtic language which exhibits an unusual restriction against voiceless stops at the end of syllables (Orwin 1993, 1994; Saeed 1999). Saeed (1999: 25) reports that the voiceless stops /t/ and /k/ never occur in syllable final position. In contexts where lexically specified /t/ or /k/ occur, they are voiced (34):

- (34) a. ark-ay 'I saw'
árag 'See!'
b. gunt-ay 'I knotted it'
gúnud 'Knot it!'

Orwin (1993) gives the following surface alternations for the underlying form of the imperative /duruk/ 'to move oneself' (35):

- (35) wuu durkay 'he moved himself'
way durugtay 'she moved herself'

The alternation is also seen in forms given by Orwin (1994: 224), reproduced in (36):

- (36) [bug] 'to be ill'
[bugtay] 'she was ill'
[bukay] 'he was ill'

These alternations have been suggested to be the product of a rule that voices final stops (37):

- (37) $T \rightarrow D / _ \#$

Final voicing is exceedingly rare typologically (Iverson & Salmons 2006), because voicing in obstruents requires neutral or slack vocal chords to vibrate, but in final position the glottis tends to either spread or constrict, resulting in stiffening of the vocal chords (Halle & Stevens 1971; Avery & Idsardi 2001; Iverson & Salmons 2011). Thus, any process which results in voicing of underlyingly voiceless final obstruents

is typologically rare and a crazy rule of type (IV), since the relationship between the structural change and the structural description is arbitrary.

The rule in (37) has been the subject of some discussion in the phonological literature, since its status as a rule of phonological voicing is contested (see Kiparsky 2006: 224ff. and Lysvik 2020: 33ff.). Orwin (1994: 119ff.) discusses the phonetic implementation of the voice contrast in Somali, determining that “voiceless” consonants are realized with a wide glottis (see Edmondson et al. 2003 for extensive phonetic discussion). Thus Kiparsky (2006) argues that “voiceless” stops in Somali are cued by aspiration, while “voiced” stops are phonologically voiceless and unaspirated, their realization with phonetic voicing being a result of passive voicing. The contrast, Kiparsky argues, is better represented as being one of fortis and lenis rather than voice and voiceless, and the distributional restriction is one on syllable-final wide glottis consonants, which must be realized with a closed glottis. In this view, there is no rule of final voicing, and thus no crazy rule in phonology.

3.3.3 *Omoti*

3.3.3.1 *Hamar*

The data on Hamar (also called Hamer), reported by Lydell (1976) and Petrollino (2016) are conflicting. In both reports, a subset of the stop consonants are targeted for an apparent process of lenition that is triggered by an unusual class of vowels.

The Hamar vowel inventory consists of 10 vowels, a set of tense /i u e o a/ ([+ATR]) and lax /ʊɛɔʌ/ ([-ATR]) vowels. There is a process of vowel harmony in Hamar that spreads [+ATR] to lax vowels. This harmony process works from suffixes, where suffixes containing tense vowels cause lax vowels in stems be realized as tense, so that for example, an underlying /ʌ/ is realized as [a] when followed by a suffix containing a tense vowel. Suffixes containing lax vowels harmonize with stem-final tense vowels. The Hamar stop consonant inventory consists of a set of voiced plosives /b d j g/ and corresponding voiceless plosives /p t c k/.

Lydell (1976: 403) reports that /p/ and /k/ are “usually” fricativized to [f] and [x] in the context of tense vowels; lax vowels do not produce the alternation (38):

(38)	/k'ultakʌ/	[k'ultax]	'with a male goat'
	/bʌka/	[baxa]	'cook n.'
	/api/	[afi]	'eye'
	/epa/	[efa]	'cry v.'
	/bipa/	[bifa]	'spray v.'

That of all the voiceless stops only /p k/ should be targeted by lenition is unusual, but is not crazy by itself. The effect of the triggering

class of lax vowels on consonants is also entirely surprising (see [Local & Lodge 2004](#)).

On the other hand, [Petrollino \(2016: 11ff.\)](#) reports a similar alternation, but which is characterized by a more unusual target class and more restricted triggering class. In [Petrollino's](#) account, /p/ varies with [ɸ], but there is no specific triggering position, as the variation can occur word initially, intervocalically, and word finally. However, /b/ is spirantized to [β] when intervocalic only if the second vowel is the low vowel /a/. In (39a), it can be seen that [b] can be realized in initial position as a singleton, and in intervocalic position as a geminate or as a singleton. However, when the vowel following an intervocalic singleton /b/ is [a], then that /b/ may be realized as [β], as in (39b):

- (39) a. [bíri] 'three pronged stir-stick'
 [dabí] 'wild animal'
 [qálbe] 'leaf'
 [jibbá] 'dislike'
- b. [kubá] or [kuβá] 'wall'
 [gibáz] or [giβáz] 'malaria'
 [labalé] or [laβalé] 'ostrich'

[Petrollino](#) also reports the same conditioning environment for the spirantization of /k/, which is realized surface-true when word-initial or adjacent to another consonant (40a), but realized as [x] when between two vowels, the second of which is /a/ (40b):

- (40) a. [k]erí 'door'
 [b]ankár 'arrow'
 [b]áski 'lover'
 [líkka] 'small'
- b. [saká] or [saxá] 'tomorrow'
 [ʔuká] or [ʔuxá] 'pierce'
 /ʔaafó-xa/ → [ʔaaφóxa] 'with the mouth (M)'
 /ʔaafón-ka/ → [ʔaaφónka] 'with the mouth (F)'

The rule described by [Petrollino \(2016\)](#) can be formalized as (41):

- (41) b k → β x / V_a

In (41) the structural change is not crazy, though the targeted class of segments is unusual. However, that lenition should be a property of a single vowel, /a/, and no other, means that the context of lenition is arbitrary, and thus a crazy rule of type (IV).

3.4 ALGIC

3.4.1 *Algonquian*3.4.1.1 *Eastern Ojibwe (Ojibway)*

In Eastern Ojibwe (Buckley 2000a,b), there is a pattern of alternations whereby /n/ is realized as [ʃ] when followed by [i] (42):

- (42) a. ki-na:n-a: 'you fetch him'
 ki-mi:n-a: 'you give him'
 b. ki-na:ʃ-i-mi 'you fetch us'
 ki-mi:ʃ-i-mi 'you give us'

This alternation, however, is subject to exceptions (43):

- (43) a. ki-we:pin-a: 'you leave him behind'
 ki-we:pin-i-mi 'you leave us behind'
 b. ki-mi:n-in 'I give you'

The exceptions to the alternation suggest that they are not entirely the product of phonology, but Buckley (2000a) notes that they are still productive in inflectional paradigms, and that /n/ is realized as [ʃ] before the set of palatal vocoids: /i i: j/. The alternations, then, can be described by phonological rule (44):

$$(44) \quad n \rightarrow ʃ / _ \left\{ \begin{array}{l} i \\ i: \\ j \end{array} \right.$$

The rule in (44) is crazy because there is no plausible link between the input segment, /n/ and its output [ʃ]. It is thus a crazy rule of type (III).

The exceptions to the rule, however, demand some explanation. Buckley (2000a,b) outlines a series of diachronic events in the development of modern Ojibwe which gave rise to the synchronic situation. In the proto-language, a rule of palatalization targeting /t θ/ was active. In the 17th century, *θ and *l merged as [l], with palatalization extending to [l]. Subsequently, in the 19th century the [l] reflex of *l and *θ merged with [n], but palatalization was not extended to reflexes of *n, resulting in the rule becoming opaque. Additionally, *e merged with [i], but the [i] reflexes of *e do not trigger the palatalization. The result is a rule with exceptions to both targets (43a) as well as triggers (43b), but that remains productive in inflectional paradigms (see also discussion in Kaye 1978 and Piggot 1980).

This diachronic history is the classic origin of crazy rules for Bach & Harms (1972): individual sound changes are phonetically motivated, but as they accrue diachronically the phonetic motivation between the input and output segments is obscured in synchrony (see §4.3.4).

3.5 ARAWAKAN

3.5.1 *Paresi-Xingu*3.5.1.1 *Yawalapiti*

Yawalapiti is an Arawak language of Brazil, spoken by around 200 people living in a single village. The chief reference for the data described here is [de Carvalho \(2017\)](#). In Yawalapiti, there is an alternation at the left-edge of nouns and verbs, targeting /p t k m/ (but not affricates, or nasals at other places of articulation), triggered by preceding morphemes which contain the high vowel /i/.

The pattern of alternations is triggered by all second-person nominal markers, but importantly, not by the third-person nominal marker, which is also [i] (45):

(45)	kuşu ‘head’	tapaka ‘cheek’	munujati ‘forehead’	puti ‘thigh’
	1SG nu-kuşu	nu-tapaka	nu-munujati	nu-puti
	2SG hi-tʃuşu	hi-tapaka	hi-ɲunujati	hi-ruti
	1PL a-kuşu	a-tapaka	a-munujati	a-puti
	2PL i-tʃuşu	i-tapaka	i-ɲunujati	i-ruti
	3PL i-kuşu-pa	i-tapaka-pa	i-munujati-pa	i-puti-pa

The target segments and their surface forms are as in (46):

(46)	p → r
	t → ts
	k → tʃ
	m → ɲ

(46) represents an unremarkable pattern of palatalization in some respects, though the palatalization of the labial is unusual. The first alternation, however, /p/ → [r], where [r] is an apical trill, is crazy, representing a good example of a crazy rule of type (III) since the output segment is not plausibly linked to the input segment. This relation between input and output is one that [de Carvalho](#) considers to be unnatural (47):

(47)	p, t, k, m → r, ts, tʃ, ɲ / i_
------	--------------------------------

The alternation pattern occurs across different lexical and morphological classes, though exceptions such as [piti] ‘village’, where no palatalization occurs, exist. [de Carvalho](#) suggests that the morphophonological nature of the alternation pattern, *along with its phonetic unnaturalness*, suggests that the process has been morphologized, i.e. the pattern in (45) is allomorphic and a product of the lexicon, not of phonological computation. In a phonological theory which requires phonological rules to be natural, the morphological account is the only one available. However, this requires enriching the lexicon

with two forms of every noun and verb which is potentially subject to the alternation.

However, as discussed in §1.3.2.3, a morpheme-specific triggering context does not necessarily mean that a pattern of alternation is non-phonological. As in the case of Ojibwe (§3.4.1.1), a potential representational, phonological analysis exists. Synchronically, there are four vowels in Yawalapiti: /i i a u/. Diachronically, all non-palatalizing /i/s are reflexes of *i which merged with *i in the person/number prefixes. *de Carvalho* suggests that *i, the third-person marker, did not trigger the palatalization rule. In a representational account, when non-palatalizing *i merged with *i, it only merged phonetically, though its underlying phonological representation remained distinct. In this account, there are two kinds of [i]: one which palatalizes, and another which does not (cf. *Compton & Drescher 2011* and *Gussmann (2007)*). The triggering context of rule (47) is restricted to the palatalizing vowel, and all instances of non-palatalizing [i] are representationally distinct from the triggering vowel.

3.6 AUSTRONESIAN

3.6.1 *Malayo-Polynesian*

3.6.1.1 *Sula*

In all dialects of Sula, voicing is contrastive in obstruents. There is a pattern of alternations that causes intervocalic /b d g/ to be optionally realized as voiceless when in the intervocalic position (*Bloyd 2020: 202ff.*), as in (48):

- (48) basel 'to plant' [i-pasel] '3SG plant'
 bis 'full' [a-pis] 'I'm full'
 det 'to cut' [a-tet] 'I cut'
 duf 'hole' [bau-tuf] 'to make a hole'

Morphological contexts giving rise to the triggering context include compound words, prenominal prefixes, verbal prefixes, auxiliary constructions, and reduplication (49a); when the context is created by numeral prefixes devoicing is not an optional rule but occurs without exception (49b):

- (49) a. dona 'burn' [ba-tona] 'CAUS-burn'
 gahu 'to scratch' [ak a-kahu mon] 'I scratch you'
 geka 'ill, hurt' [kalea-keka] 'kidney disease'
 gem 'to hold' [mana-kem] 'to hold (another's arm firmly)
 gaya 'to eat' [a-kaya] 'I eat'
- b. ga- 'cardinal prefix' [pa-ka-] 'ordinal prefix'
 ga-tel 'three' [pa-ka-tel] 'third'

Bloyd (2020: 210) describes this alternation pattern as being productive, suggesting that intervocalic devoicing is a possible synchronic rule (50):

(50) C[+voice] → C[-voice] / V_V

Intervocalic devoicing is not only typologically rare, but runs counter to a natural articulatory tendency to continue passive voicing throughout the articulation of intervocalic consonant sequences (Westbury & Keating 1986; Kingston & Diehl 1994). Intervocalic devoicing, then, is phonetically unnatural because it disrupts this continuous period of voicing. Rule (50) is a good example of a crazy rule of type (IV) since it cannot be reduced to phonetic cues inherent in its structural description.

3.6.2 Northern Formosan

3.6.2.1 Sediq

In the Paran dialect of Sediq, there is an unusual pattern of vowel reduction which causes /e/ to be realized as [u] when it is realized in pre-stress positions (Li 1991: 164; Holmer 1996: 23 ff.). The vowel system of Sediq consists of /i e a o u/ in open syllables. In closed syllables, only /i a u/ occur. Sediq is rich in derivational morphology, in the form of numerous prefixes, infixes, and suffixes (Holmer 1996: 29ff.). As stress always falls on the penultimate—whether it is lexical or derived (Holmer 1996: 23)—any suffix shifts stress rightwards; when this occurs, /e o/ are reduced and neutralized to [u] (or [ə] in the other dialects).

The realization of consonants changes depending on their position in the word (Holmer 1996; Li 1991), with word-final consonants neutralizing as follows (51):

- (51) a. p k b → k
 b. d t c → c
 c. g w → w
 d. m ŋ → ŋ

The processes of affixation, consonant and vowel reduction means that surface forms can diverge significantly from underlying forms.

The alternation between underlying stressed vowels with their lexically specified quality and reduced pre-stress vowels can be seen in the following data from Li (1991: 164) (52)⁶:

6 The symbol ‘V’ stands in for an indeterminable underlying vowel (Li 1991: 163).

- (52) a. BASE GLOSS IMPERATIVE
 /tVdoroj/ 'to roll down' tudu'roj-i
- b. BASE GLOSS IMPERATIVE
 /deheq/ 'to arrive' de'heq-i
 /sebet/ 'to hit, to thresh' su'bet-i

In (52), the neutralization of /o/ (52a) and /e/ (52b) can be seen when the imperative affix /-i/ shifts stress to the right. While the reduction of /o/ to [u] is not unusual, the reduction of /e/ to [u] is; the former is a singular change in vowel height, while the latter is a change in height, frontness, and rounding—a crazy rule (53):

- (53) $e\ o \rightarrow u / _ '(C)V$

The rule in (53) thus demonstrates a crazy structural change, or a crazy rule of type (III).

3.7 BANTU

3.7.1 *Northeast Bantu*

3.7.1.1 *Nyole*

Morris (1963) reports that in Nyole or Lynyole, a Bantu language spoken in Uganda, there is an unusual alternation between /ŋ/ and [p] when the velar nasal is preceded by a nasal prefix (see also Schadeberg 1989). This process is part of a larger pattern of alternations targeting prenasalized consonants, the outcome of which is typically an obstruent homorganic with the underlying segment's place of articulation.

One context of prenasalization in Nyole results from the affixation of the 1PS.SG subject concord to a verb stem (54)⁷:

- (54) a. oxu-ŋuliira 'to hear' pulira 'I hear'
 oxu-ŋumula 'to rest' pumula 'I rest'
- b. oxu-lya 'to eat' n-dya 'I eat'

In (54a), it can be seen that an underlying /ŋ/ in infinitive forms surfaces as [p] in the 1PS.SG; in (54b), in turn, it can be seen that the /n-/ prefix triggers a much more phonetically transparent alternation in other consonants.

Schadeberg (1989: 172) draws attention to the “unnatural” and “crazy” nature of this alternation, since there is no phonetic plausibility that could explain the changes.

The arbitrary pattern of alternation in Nyole is a crazy rule (55):

- (55) $\eta \rightarrow p / _ n$

⁷ Data adapted from Schadeberg (1989: 171f.).

Schadeberg (1989: 172ff.) suggests that this rule may have come about in diachrony, when Proto-Bantu *p became *h in Proto-Nyole. At a later stage, *h was spontaneously nasalized and became /ɲ/. This is a natural process, since, in acoustic terms nasality and glottal sounds both produce similar antiformants—a connection noted by Matisoff (1975) and termed *rhinoglottophilia*. From a structural perspective, since *ɲ had a low functional load in Proto-Bantu, the velar-nasal reflex of *h did not result in very many cases of neutralization or semantic ambiguity.

Synchronically, the arbitrary change from /ɲ/ to [p], in a context which has no plausible phonetic connection to the outcome, is a crazy rule of type (III) and (IV).

3.7.2 Sotho-Tswana

The Sotho-Tswana group of Southern Bantu stands out for a pattern of post-nasal devoicing in several languages (Hyman 2001: 157). In Tswana, for example⁸, when an underlying voiced stop (56a) follows a nasal consonant, it is realized voiceless (56b):

- (56) a. bón-á ‘see’
 dís-á ‘watch’
 áráb-á ‘answer’
 b. m-pón-á ‘see me!’
 n-tís-á ‘watch me!’
 ɲ-káráb-á ‘answer me!’ (< -gáráb-)

In Tswana, post-nasal devoicing is a distributional regularity: within morphemes, voiceless consonants follow nasal segments. In the description of Tswana given by Cole (1955), of the voiced stops, only /b/ is fully phonemic—/d/ has a marginal status and there are no palatal or velar voiced stop. Voiceless stops are articulated as ejectives, though the ejective gesture seems to be optional in unemphatic speech. In contrast, in the closely related Shekgalagari, there is a voicing contrast at four places of articulation: labial, dental, palatal, and velar (Solé et al. 2010). The surface pattern of nasal and stop sequences in Shekgalagari exhibits a surface contrast between [NT] and [ND], the latter being the product of a process of vowel deletion that does not feed the devoicing process. That is, any case of surface [ND] is derived from /NVD/; in all cases of /ND/ where there is no intervening vowel, the surface realization is [NT].

In Sebirwa, another closely related language, as reported by Zsiga & Tlale Boyer (2017) voicing is fully contrastive across /b d g/ but, surprisingly, only /b/ devoices post-nasally (57):

⁸ Data from Hyman (2001: 157).

- (57) a. pala ‘fail’ mpala ‘fail me’
 taça ‘fill’ ntaça ‘fill me’
 kala ‘weigh’ ŋkala ‘weigh me’
- b. bala ‘count’ mpala ‘count me’
 dada ‘bind’ mdada ‘bind me’
 gada ‘stitch’ ŋgada ‘stitch me’
 luma ‘bite’ nduma ‘bite me’

In (57a), it can be seen that there is no alternation in underlyingly voiceless stops. In (57b), on the other hand, underlying /b/ is realized as [p] while other voiced stops remain unaffected. Interestingly, there is also an alternation between /l/ and [d] in this context. In fact, post-nasal devoicing is part of a larger pattern of “strengthening” (see [Cole](#) and [Schaefer](#) for a similar analysis of Tswana). In the larger context post-nasal alternations in Sotho-Tswana, fricatives harden to stops or affricates, and the liquids /r/ and /l/ harden to dental stops (58)⁹:

- (58) xòbʒà ‘to see’ xòm̩pʒà ‘to see me’
 xòféŋà ‘to conquer’ xòm̩pʰéŋà ‘to conquer me’
 xòséà ‘to cut’ xòntsʰéxà ‘to cut me’
 xòʒápà ‘to thrash’ xòj̩tʰápà ‘to thrash me’
 xòxátà ‘to tread on’ xòj̩kʰátà ‘to tread on me’
 xòhúmísà ‘to enrich’ xòj̩kúmísà ‘to enrich me’
 xòárábà ‘to answer’ xòj̩kʰárábà ‘to answer me’
 xòlómà ‘to bite’ xòntʰónà ‘to bite me’
 xòrátà ‘to love’ xòntʰátà ‘to love me’

Further, high-toned high front vowels also trigger the same pattern of alternation in obstruents as in (58) ([Schaefer 1982: 151](#)). This apparent pattern of strengthening lead [Gouskova et al. \(2011\)](#) to argue that the pattern in (56b) is not the result of a phonological process of devoicing, but of a kind of strengthening in which voiced stops are realized as voiceless ejectives to ensure that sonority falls across syllable boundaries between two consonants.

[Hyman \(2001\)](#) argues that the pattern of alternation and the dearth of surface forms exhibiting [ND] sequences¹⁰ make it difficult to argue that the pattern of devoicing in Tswana is morphological. [Coetzee et al. \(2007\)](#); [Coetzee & Pretorius \(2010\)](#) report instrumental results from field-work in Tswana that show clear and consistent post-nasal devoicing, even in the case of non-words. Field work in the Sotho-Tswana language Shekgalagari done by [Solé et al. \(2010\)](#) confirms the categorical nature of post-nasal devoicing alternations which result in complete neutralization of devoiced and underlying voiced stops. These results are taken to confirm the phonological status of the post-nasal devoicing process in Sotho-Tswana. Post-nasal devoicing can be described by the rule in (59):

⁹ Tswana data adapted from [Schaefer \(1982: 150\)](#).

¹⁰ Exceptions to this generalization are vanishingly rare: [Hyman \(2001\)](#) notes two exceptional forms, one of which is a recent borrowing.

(59) C[+voice] → C[-voice] / N_

The rule in (59) says that any voiced consonant will be realized as voiceless when following a nasal consonant. Naturally, this rule glosses over some important distinctions—in Sebirwa for example, only the labial stop is implicated in the process, which would entail a more precise formal rule in this language. Regardless of the exact set of targets, a process of post-nasal devoicing is unexpected from a typological and phonetic point of view. Far more common is it for nasal consonants to trigger voicing in following stops (Herbert 1986: 236) (see also Pater 1996 and Pater 1999).

The reason for this typological situation may lie in facts about articulation: airflow through the nasal cavity should facilitate post-nasal voicing (Hayes & Stivers 1996), resulting in partially voiced stops being perceived as voiced (Solé et al. 2010). Indeed, post-nasal devoicing is an unnatural process in the sense that it is confronted with an unfavorable articulatory configuration (see Beguš 2018a). During the articulation of nasal consonants followed by voiceless obstruents, the velum must be raised and vocal cords must be stilled before the articulation of the voiceless stop following the nasal. When these movements are not precisely coordinated, coarticulation of one or both articulatory gestures may result in patterns of allophony.

Thus, post-nasal devoicing is phonetically unnatural in the sense that it requires greater articulatory dexterity than post-nasal voicing, and runs counter to the more frequent tendency. The pattern in Sebirwa is especially unexpected, since, as Zsiga & Tlale Boyer (2017) note, only /b/ devoices while /d/ and /g/ do not; the smaller supralaryngeal cavity during the production of /g/ results in less space for airflow from the glottis to accumulate, meaning that voicing can not be maintained for as long a time as for /b/ or /d/ (Westbury 1983). It might be expected then that /g/ would devoice before /b/ or /d/, but this is not the case.

It may be, as suggested by Coetzee et al. (2007); Coetzee & Pretorius (2010) and Hamann & Downing (2017), that the motivation for post-nasal devoicing is perceptual rather than articulatory. Post-nasal voiced consonants are relatively short compared to voiceless consonants, impacting their perceptual salience. The devoicing of consonants in the post-nasal context may serve to increase the period of stop closure, ensuring it is less likely to be perceptually confused.

The arbitrary link between the articulatory context of nasal consonants and the devoicing process means that (59) is a crazy rule of type (IV).

3.7.3 Southern Bantu

Southern Bantu is a group of Bantu languages spoken in South Africa, Botswana, Lesotho, Swaziland, Mozambique, Zambia, Namibia, Tanzania, and Malawi (Doke 1954). This group includes the Nguni languages Xhosa, Ndebele, and Zulu, as well as the Sotho-Tswana language, called

Tswana or Setswana. One of the principle phonological characteristics of Southern Bantu is the pattern of labial palatalization triggered by labial consonants. There is a voluminous literature on the subject, of which only a portion is discussed here (e.g. Bateman 2007; Bennett & Braver 2015; Herbert 1977; Hyman 2001; Khumalo 1987; Kotzé & Zerbian 2008; Ohala 1978; Stahlke 1976; van der Spuy 2014).

There are three principle contexts for labial palatalization in Southern Bantu: in the diminutive forms of nouns, in the locative forms of nouns, and in the passive forms of verbs. Palatalization in the diminutive is exemplified in a pattern of alternation from Zulu between roots which end in labial consonants and their corresponding diminutive forms, in which that labial consonant is realized as a palatal (60)¹¹:

(60)	ROOT	DIMINUTIVE	GLOSS
	intab-a	intatʃ-ana	'mountain'
	up ^h ap ^h -e	up ^h aʃ-ana	'feather'
	umkhumb ^h -i	umjhuɲɕ-ana	'ship'
	intam-o	intaj-ana	'neck'
	isigub ^h -u	insiguɕ-ana	'calabash'

The targets of labial palatalization and their surfaces realizations in Zulu can be summarized as in (61):

(61)	/p ^h /	→	[ʃ]
	/p/	→	[tʃ]
	/b ^h /	→	[ɕ]
	/b/	→	[tʃ]
	/m/	→	[ɲ]
	/mp/	→	[ɲtʃ]
	/mb ^h /	→	[ɲɕ]

As noted by Ohala (1978: 377), there is no phonetic motivation for a palatalization process triggered by /a/ or any part of the /-ana/ suffix. While the palatalization triggered by the locative suffix, /-ini/ is somewhat less surprising from a phonetic standpoint, the change from, for example, [mb^h] to [ɲɕ] is unusual in that there is no apparent connection between a labial nasal input and a palatal affricate output.

Labial palatalization is also triggered by the passive suffix /-w-/, as exemplified in data from Ndebele (62)¹²:

(62)	a.	ACTIVE GLOSS	PASSIVE GLOSS
		boph-a 'tie'	botʃ-w-a 'be tied'
		vuβ-a 'mix together'	vufʃ'-w-a 'be mixed together'
		dob-a 'pick up'	doɕ-w-a 'be picked up'
		bumb-a 'mould'	bujɕ-w-a 'be moulded'
		thum-a 'send'	thuɲ-a 'be sent'
	b.	ACTIVE GLOSS	PASSIVE GLOSS
		dal-a 'create'	dal-w-a 'be created'
		thuk-a 'curse'	thuk-w-a 'be cursed'

11 Data adapted from van der Spuy (2014: 76).

12 Data adapted from Hyman (2001: 147f.)

Interestingly, palatalization does not target coronal or velar segments (62b), a class of segments which is cross-linguistically more likely to be the target of palatalization processes than are labials (Bateman 2007; Kochetov 2011). In (62a) the passive affix triggers palatalization of underlying labial consonants; the pattern of alternation in (62) can be summarized as follows:

- (63) /ph/ → [tʃ]
 /β/ → [tʃʰ]
 /b/ → [ɕ]
 /mb/ → [mɕ]
 /m/ → [ɹ]

This palatalization context is especially surprising, since /-w-/ itself is labial, and might be expected to reinforce the labiality of underlying labial segments (Ohala 1978).

The patterns of alternation in (61) and (62) are typical of Southern Bantu languages, even if the exact details vary from language to language. The phonetically arbitrary nature of the alternation and its explicitly morphologically-defined context mean that its status as a phonological alternation has been questioned (see van der Spuy 2014 for a review). The position that Southern Bantu labial palatalization is morphological has been argued for example by Herbert (1977), since the pattern is phonetically unnatural, applies only in certain morphologically-defined contexts, and has exceptions. Here, the unnatural phonetic character of the alternation is used as a criterion for demarcating the division of labor in a pattern of alternation.

The phonological status of Southern Bantu labial palatalization has been argued for, for example, by Stahlke (1976) and Kotzé & Zerbian (2008) for Sotho and Khumalo (1987) for Zulu. Bennett & Braver (2015: 43) report experimental results that suggest at least some speakers extend the pattern to novel nonce words, which they interpret as being an argument for labial palatalization being a productive phonological rule, and more generally as a demonstration of the learnability of unnatural patterns (see Chapter 6 for more on experimental results in phonology).

In the view that sees Southern Bantu labial palatalization as phonological, a broad description of the pattern can be formalized as in (64):

- (64) C[+labial] → C[+palatal] / $\left\{ \begin{array}{l} \text{-w-} \\ \text{-ini} \\ \text{-ana} \end{array} \right.$

The arbitrary connection between /-w-/ and /-ana/—triggers which lack palatal constriction—and labial palatalization means (64) is a crazy rule of type (IV).

3.8 CADDOAN

3.8.1 Northern Branch

3.8.1.1 Pawnee

In the South Band dialect of Pawnee described in Parks (1976: 40), /t/ is realized as [h] before the alveolar sonorant /r/. Though Parks does not provide any alternations of surface forms, the realization of underlying /t/ as [h] in internal sandhi can be seen in (65):

- (65) /ta+t+rauk+:hus/ tahru:ku 'I'm making it'
 /ta+t+rahkasi:+∅/ tahrahkasi 'I'm wearing it'
 /paha:t+rauk+∅/ pahahru 'to redden'
 /i+tat+ri/ itahri 'my sister (male spkg.)'
 /pahit+rauk+∅/ pahihru 'to quiet, make still'

This alternation is systematic in Pawnee wherever /t/ is realized before /r/, and is what Parks (1976: 40) refers to as a rule of "laryngealization", a kind of debuccalization (66):

- (66) $t \rightarrow h / _r$

Because of the segmental context of this rule, there does not seem to be any phonetic relationship between the trigger and the output. It is a crazy rule of type (IV).

3.8.1.2 Wichita

Like Pawnee, Wichita (described by Rood 1971, 1975) is a polysynthetic language with a number of active rules of internal sandhi, one of which in particular defies phonetic explanation. When a lexical /k/ precedes /r/ or /j/, it is realized as [h], as in (67). If the conditioning segment is /r/ (67a), it metathesizes to the position preceding [h], such that any underlying sequence /kr/ will be realized [rh].

- (67) a. ti+a+ʔak+raʔa+s → taʔarhaʔas 'he brought them'
 b. ra+t+a+a+ra:k+ja:i+iki+h → ratára:hé:kih 'you, my children'

The triggering segments, /r/ and /j/, do not appear to form a natural class: while /j/ is a palatal glide, /r/ is a coronal flap, which may be realized with nasalization, and is realized as [n] when word-initial preceding a vowel (Rood 1971). This rule can be formalized as in (68):

- (68) $k \rightarrow h / _ \left\{ \begin{array}{l} r \\ j \end{array} \right.$

As in the case for Pawnee, while there is nothing particularly unusual in /k/ delaryngealization itself, it is surprising to find it conditioned

by two sonorants, which do not pose any particular articulatory difficulties. Other consonants in Wichita do not trigger the alternation. The rule in (68) is thus crazy in two ways: a heterogeneous conditioning environment (type (II)), and a structural change that is phonetically arbitrary in the light of the conditioning environment (type (III)).

3.9 HOKAN?

3.9.0.1 Pomoan

Kashaya Pomoan (Buckley 2000b,a, 2004) is a member of the hypothetical Hokan language family¹³.

This rule is active in three varieties of Pomoan: Southern Pomo, Central Pomo, and Kashaya, as described in Buckley (2000a, 2004). In these closely related languages, /i/ is realized as [u] when it follows /d/, as for example when the Singular Imperative *-i* occurs after /d/ in Kashaya (69b):

- (69) a. $\text{ʃuq}^2\text{a:t-i}$ 'groan IMP'
 $\text{q}^2\text{o-ts-i}$ 'drink!'
 $\text{du-s}^2\text{e:k}^2\text{-i}$ 'pleat it!'
- b. ʃad-ú 'look!'
 wa:d-u 'come here!'
 $\text{duk}^2\text{il-f:t}^2\text{-ed-u}$ 'keep pointing at yourself!'

The Simultaneous *-in* also exhibits the same pattern of alternation (70b):

- (70) a. mo-mú:l-in 'while running around'
 $\text{du-t}^2\text{e:t-ín}$ 'while fastening'
 $\text{du-k}^2\text{il-ín}$ 'while scratching'
 ʔ-inf-e 'I suppose'
- b. mahsad-ún 'while taking away'
 mo-q-a:d-ún 'while running out from here'
 ʔo-lo:q-od-ún 'while poking (head) up'
 cad-únʃ 'I wonder if he saw it'

The rule also applies to the conditional /-i²ba/. Buckley (2004) argues that since the alternation has been generalized to other suffixes, it is encoded in the grammar as a phonological rule. However, there is no clear phonetic motivation for the change /i/ → [u] following /d/, and the triggering context is quite arbitrary—Buckley points out that two other coronal segments, /n/ and /t/, do not trigger the rule. There is no feature inherent in /d/ that can spread to /i/ to yield [u]; as in rule (71):

13 Hokan was proposed by Dixon & Kroeber (1913) based on sound correspondences in lexical sets, but has never been definitively established.

(71) $i \rightarrow u / d_$

Buckley (2004) suggests that this rule came about by reanalysis of a morpheme *-adu* as *-ad* following a rule of syncope. The vowel came to be interpreted as epenthetic and inserted by rule instead of being part of the lexical object. As this epenthetic [u] came to be associated with /d/, all cases of epenthetic [i] came to be realized as [u], a rule which was then generalized to lexical cases of /i/ as well as epenthetic [i]. It is thus a classic case of the situation described by Bach & Harms (1972), where an initially phonetically motivated rule is modified (here by analogy) in a phonetically arbitrary way, but continues to operate, as a crazy rule of type (IV).

3.10 INDO-EUROPEAN

3.10.1 Celtic

3.10.1.1 *Léon Breton*

In modern Breton, there is a tight relationship between the quality of mid vowels and length. Length is a mostly predictable property of vowels, unstressed vowels are always short, stressed vowels are long when preceding lenis consonants¹⁴ (all consonants are neutralized to voiceless lenis in final position), otherwise they are short (Jackson 1961; Press 1986), as in (72)¹⁵.

(72) bra[:z] 'big'
bra[ss]oc'h 'bigger'

In (72), stress falls on the first syllable, and the length of the vowel is a function of the consonant which follows: long preceding lenis [Z] and short preceding the fortis geminate.

Importantly, length also has an effect on the quality of mid vowels, which are "closer when long, on the whole" (Press 1986: 20). This can be seen in (73)¹⁶:

(73) sko:l 'school'
skoʎu 'schools'

This alternation based on length and vowel quality is a rather natural phonetic relationship. Anderson (1981: 521f.) reports data which show that this does not hold for Léon Breton, though, since vowels are lengthened without changing quality when preceding final consonants (74):

14 Press (1986: 14) distinguished between long, tense, "fortis" consonants on the one hand and short, lax, "lenis" consonants on the other—in the description of Breton, fortis and lenis distinctions are not based on laryngeal properties.

15 Data adapted from Press (1986: 17), where [z] represents a consonant neutralized to voiceless lenis.

16 Data from Press (1986: 30).

- (74) [tɔ:g] 'hat'
 [tɔku] 'hats'

The relationship between length and vowel quality has been broken in Léon Breton, following the diachronic developments discussed by [Anderson](#), which resulted in mid vowels that do not alternate as expected. The first is the diphthong /ae/ which was reduced to [ɛ]. The second was the vocalization of /w/ to [o] in some positions. The third was the simplification of consonant clusters which resulted in lengthening of preceding mid vowels, without the concomitant vowel quality alternations.

These diachronic developments resulted in quality becoming distinctive in some environments, for some lexical items. As a consequence, a number of items with lexical mid vowels do not exhibit alternations between mid-vowel quality and length, being mid-open even when long (75):

- (75) [bɛ:leg] 'priest'
 [ɛ:ro] 'oaks'
 [bɛ:red] 'cemetery'

However, in other items, there is evidence of a mid-vowel alternation, where mid close vowels are realized as mid open when short (76):

- (76) a. [bro:] 'country'
 [brɔju] 'countries'
 b. [re:d] 'necessary'
 [rɛtɔx] 'more necessary'

[Anderson](#) suggests that the non-alternating vowels are underlying mid open in quality, while the alternating ones are mid-close; this constitutes an example of a representational difference in the lexicon that is not surface true (see the discussion of Inuit in §1.3.2.3). What is interesting is the nature of the rule which conditions alternating mid vowels, since the conditioning environment—stressed preceding a fortis consonant—has no plausible phonetic relationship to the structural change exhibited; (77) is thus a crazy rule.

- (77) \acute{V} [mid close] \rightarrow V[mid open] / $_C$ [fortis]

Alternations between long vowels preceding voiced consonants and short vowels preceding voiceless consonants is cross-linguistically recurrent and phonetically motivated ([Kluender et al. 1988](#)). Further, length is a well-known correlate of vowel quality ([Schane 1990](#)). However, the conditioning of vowel quality by voicing instead of of length is phonetically unmotivated.

As the diachronic changes outlined by [Anderson \(1981\)](#) produced mid vowels that ruptured the relationship between quantity and quality, it became opaque. The trigger for mid vowel alternations shifted

from quantity to the underlying properties of the following consonant. Thus, (77) represents a collapse of two phonetically motivated processes into a single phonetically arbitrary process of type (IV).

3.10.2 *Germanic*

3.10.2.1 *Buchan Scots*

Paster (2004) describes a pattern of vowel-lowering harmony in Buchan Scots, where an unaccented front vowel in a suffix surfaces as non-high when a non-high vowel precedes it in a stem. High vowels in a suffix following high vowels in stems, as well as those following a class of consonants detailed in (78), are not lowered.

(78)	ROOT	MEDIAL CONSONANT	SUFFIX
	VOWEL		VOWEL
	High	Any consonant	High
	Non-high	Voiced obstruent [b d g v ð z ʒ] or [l m n ŋ] followed by [p t k f θ s ʃ]	High
	Non-high	Any other consonant or sequence	Non-high

The vowel-harmony pattern of Buchan Scots is interesting for several reasons: it is an example of a typologically rare process of a lowering harmony, and unlike most attested patterns of blocking (van der Hulst & van de Weijer 1995), it is blocked by a heterogeneous class of consonants with no secondary articulation that does not share the harmonizing feature.

The forms from Paster (2004: 365) in (79) all contain stems with underlying non-high vowels followed by an /-i/ suffix (generally forming a kind of diminutive). In (79a), the unstressed second vowel of the suffix surfaces as [i] following an underlying high vowel in the stem, while in (79b) the suffix surfaces as [e], following a low vowel in the stem.

(79)	a.	mil-i	'mealie'
		bik-i	'beakie'
		bin-i	'beanie'
		mil-i	'wheelie'
		snut-i	'snooty'
	b.	her-e	'hairy'
		mæs-e	'messy'
		hɛl-e	'hilly'
		las-e	'lassie'
		got-e	'goatie'
		sɔs-e	'saucy'

The forms in (80) show the blocking behavior of the set of blocking consonants, both simplex blockers and clusters, where the /-i/ suffix surfaces as [i] despite the non-high vowels in the stem:

- (80) a. hez-i 'hazy'
 bæd-i 'beddie'
 lad-i 'laddie'
 roz-i 'Rosie'
 dog-i 'doggie'
 dɔŋ-i 'dodgy'
 bænd-i 'bendy'
 lʌmp-i 'lumpy'
 kɛlt-i 'kiltie'

The class of harmony blockers is unusual in that its members do not have a secondary articulation, whereas [van der Hulst & van de Weijer \(1995: 526ff.\)](#) suggest that it is precisely consonants with a vowel-like articulation (/j/ and /w/) and those with secondary articulations which are most likely to block harmony processes (see also [Krämer 2003](#)). [Paster \(2004\)](#) provides the following rule description to account for the harmony pattern of Buchan Scots (81):

$$(81) \left[\begin{array}{c} \check{V} \\ \text{-back} \end{array} \right] \rightarrow \left[\text{-high} \right] / \left[\begin{array}{c} \acute{V} \\ \text{-high} \end{array} \right] X_ \\ \text{Where } X \neq [\text{-son, +voice}], [+lat][\text{-son,-cont}] \text{ or } [+nas][\text{-son}]$$

The heterogeneity of the class of vowel blockers, and the fact that they are not doubly articulated nor do they share any vowel-like features means that there is no phonetic motivation for their blocking behavior. It is thus a crazy rule of types (II) and (IV).

3.10.2.2 Faroese

In standard Faroese (described by [Hellberg 1980](#)), there is a pattern of velar softening, in which underlying /k g/ are realized as [tʃ ɕ] before non-low front vowels (82):

- (82) a. [koma] 'come-INF'
 [tʃemur] 'come-SG.PRES'
 [bøkʊr] 'book-NOM/ACC.PL.INDEF'
 [boutʃin] 'book-NOM.SG.INDEF'
- b. [gav] 'give-PRET'
 [tʃeva] 'give-INF'
 [ɛg:] 'egg-NOM/ACC.SG.INDEF'
 [ɛɕ:ið] 'egg-NOM/ACC.SG.DEF'

The alternation between /k g/ and [tʃ ɕ] in (82) is natural, but is also to an extent idealized, since the actual distribution of the palatalizing vowel [i] is mostly preserved in orthography; in present-day dialects both [i] and [u] have been touched by diachronic sound-change. Notably, [Hellberg \(1980\)](#) describes two dialectal areas—one in the north of the island and one in the south—where /i/ and /u/ have merged. In these dialects the only vowels occurring in endings are /a/ and a

non-low vowel that is variably realized as front in the northern area and as front when in open syllables or back when in closed syllables in the southern area, with an added variation in height and backness between villages (Hellberg 1980: 7). The sound changes can result in cases where the palatalization of velar stops does not occur even before front vowels (83):

- (83) *røkur* [rø:kir] 'rock-ledges'
vikur [vi:ki:r] 'weeks'
lungur [luŋgir] 'lungs'

Interestingly, in these dialects, the palatalization *does* occur preceding the non-front vowel [ø], as in (84) where the underlying velar stop surfaces when directly followed by another consonant as in the preterite form (84a), but as an affricate in (84b) when followed by the vowel [ø]:

- (84) a. *va*[k]-*ti* 'wake-PRET.'
vakir [ve:tʃ-ør] 'is awake'
 b. *ta*[k]-*ti* 'cover-PRET.'
tekir [te:tʃ-ør] 'covers'

In (84) the palatalization of velar stops before non-front vowels is not a phonetically motivated alternation, since the phonetically motivated affrication induced by [i] has been obscured by diachrony and there is no particular reason for the central vowel [ø] to produce the same effect. Thus, the alternation in (84) is the effect of a crazy rule (85):

- (85) $k\ g \rightarrow tʃ\ ɕ / _ø$

Since (85) is in which the triggering context has no clear relationship to the structural change, it is a crazy rule of type (IV).

3.10.2.3 Icelandic

Anderson (1981: 510ff.) discusses a further example of a phonological pattern of "unnatural" palatalization which cannot be reduced to simple phonetic explanations. In Icelandic /k/ and /g/ (realized as [k^h] for voiceless, aspirated /k/ and [k] for voiceless, lenis /g/) are realized as velars when followed by consonants or most of the vowels that are phonetically back (86):

- (86) *kaka* 'cake (n. sg.)' [k^ha:k^ha]
kría 'arctic tern' [k^hri:ja]
gómur 'palate' [kou:myr]
glíma 'wrestle' [kli:ma]

In contrast, when followed by most front vowels, the velar stops are realized as palatals ([c^h] and [c] for the voiceless aspirated and lenis voiceless segments, respectively) as in (87):

- (87) *kílo* 'kilogram' [c^hi:lou]
keila 'cone' [c^hei:la]
gifta 'marry' [cɪfta]
Geysir 'name of famous hot spring' [cei:sɪr]

So far this is an utterly unsurprising pattern seen in a typologically diverse range of languages. However, to stop the description of Icelandic here and suggest that there is a natural rule motivated by phonetics is a misrepresentation of the empirical situation: the phonetically front vowels [y] and [ø] do not trigger palatalization (88a), while the diphthong [ai]—which contains a back nucleus—does (88b):

- (88) a. *kunna* 'know (how to)' [k^hyn:a]
gufta 'steam' [ky:va]
köku 'cake (obl.sg.)' [k^hø:k^hy]
götu 'street (obl.sg.)' [ko:t^hy]
- b. *kær* 'dear, beloved' [c^hai:r]
gæfta 'good luck' [cai:va]

In light of the distributional regularity in (88), a phonetically-motivated synchronic explanation is not tenable. If the pattern is indeed synchronic (see *Árnason 1978* for discussion), then a natural rule of palatalization cannot account for the fact that the front vowels [y] and [ø] do not trigger the assimilation while the back nucleus in the diphthong [ai] does. This pattern of alternation is phonetically arbitrary, and thus a crazy rule (89):

$$(89) \quad k \rightarrow c / \begin{cases} i \\ e \\ ai \end{cases}$$

As *Anderson (1981)* points out, the explanation for the strange palatalization in (88b) can be fruitfully considered in the light of diachrony. While velarization has been a part of Icelandic phonology for centuries, the front round vowels have had their front quality for a much shorter time period, and are the diachronic reflex of the back vowels /u/ and /o/ respectively. As for /ai/, it is the reflex of the front vowel /æ:/.

Anderson (1981) further notes that an abstract analysis which posits underlying /u/ and /o/ for a pair of phonetically round vowels is also possible. Following this analysis, the rule of palatalization would be triggered by the underlying front vowels before another rule of fronting applies. While such an abstract analysis is the sort of thing that motivated the constraints against abstractness discussed above, there is a further problem: if a rule can act on abstract representations, it is not clear what the actual role of articulatory phonetics would be in synchronically motivating that rule since it does not actually act on any phonetic substance. That is, although the abstract analysis allows analysts to understand the original phonetic motivation for the alternation, that motivation is not a factor in its continued existence.

An argument could be made that the data in (87) and (88) can be accounted for by two different phonological rules, one for (87) and one for (88b). However, since these processes are in every way alike except for the relatedness in terms of features between the target and trigger, and indeed are present in individual verb paradigms, this would seem to miss a generalization. Since there is no phonetically plausible reason for [ai] to trigger palatalization, the rule in (89) is a crazy rule of type (IV).

3.10.2.4 *Limburg Dutch*

In Limburg Dutch (Gussenhoven 1996; Hermans & van Oostendorp 2008), there is an unusual pattern of umlaut triggered by the diminutive affix, the adjunction of which causes final, stressed, underlying stem-vowels to front, and to raise if they are low (90)¹⁷:

- (90) /du:m/ + /kə/ 'thumb' → [dy:mkə] 'little thumb'
 /vɔ:t/ + /kə/ 'foot' → [vø:cə] 'little foot'
 /kra:x/ + /kə/ 'collar' → [kre:çske] 'little collar'
 /snɔ:r/ + /kə/ 'mustache' → [snɪrkə] 'little mustache'
 /bəl/ + /kə/ 'ball' → [bɛlkə] 'little ball'

The Limburg Dutch umlaut triggering context seems to be conditioned by this specific morpheme, meaning its status as a phonological process is unsure. However, Hermans & van Oostendorp (2008) bring to light a number of facts that suggest the alternation is in fact phonological, and targets only final, stressed vowels (91):

- (91) kant[uə]r 'office' → kant[yə]r-ke
 CD-r[ɔ]m 'CD rom' → CD-r[œ]m-ke
 kan[ɑ:]l 'channel' → kan[ɛ:]l-ke
 matr[ɑ]s 'mattress' → matr[æ]s-ke

If stress is non-final in the stem, then umlaut is blocked and there is no possible way to derive a diminutive form, as in (92) where the first set of brackets shows the quality of the stressed vowel in each item:

- (92) t[y]m[ɔ]r 'tumor'
 p[u]m[a] 'puma'
 [o:]m[a] 'grandma'
 k[ɑ]s[a] 'check-out point'
 c[ɑ:]mer[a] 'camera'
 z[ɛ:]br[a] 'zebra'
 t[y]b[a] 'tuba'

That stems with a stressed front vowel followed by an unstressed back vowel cannot take a diminutive suffix is difficult to account for in a morphological analysis, since there is no clear reason why such stems

¹⁷ Data from Gussenhoven (1996).

should block diminutive forms. Further, [Hermans & van Oostendorp \(2008\)](#) argue that the forms in (92) show that umlaut can spread to an antepenult, stressed syllable if the stem-final syllable vowel is schwa, as in (93):

- (93) kl[ue]ster ‘cloister’ → kl[yə]ster-ke
 compj[u:]ter ‘computer’ → compj[y:]ter-ke
 m[o:]der ‘mother’ → m[ø:]der-ke
 [ɑ]nker ‘anchor’ → [æ]nker-ke

In a morphological account there is no source from which features could spread, but (93) shows that umlaut spreads to stressed syllables, passing over schwa.

As a phonological process, then, Limburg Dutch umlaut is interesting because the connection between the fronting and raising of low vowels before the diminutive suffix is not phonetically motivated: there is no particular reason schwa should have such an effect on front vowels. It thus constitutes a crazy rule of type (IV).

3.10.2.5 Norwegian

In spoken Norwegian, there exists a process of retroflexion which targets the coronal obstruents /t d s l n/ when they follow the tap /r/, resulting in the two-segment sequences being realized as a single retroflex [t̠ d̠ s̠ l̠ n̠] ([Kristoffersen 2000: 87ff.](#)). Distributionally, this means that, across morpheme boundaries, there are no cases of /r/ followed by a coronal consonant (94):

- (94) /vor-tejn/ → [vo:t̠œjn] *vårtegn* ‘spring sign’
 /vor-dag/ → [vo:d̠ɑ:g] *vårdag* ‘spring day’
 /vor-sul/ → [vo:s̠u:l] *vårsol* ‘spring sun’
 /vor-luft/ → [vo:l̠uft] *vårluft* ‘spring air’
 /vor-nat/ → [vo:n̠ɑt] *vårnatt* ‘spring night’

This alternation is phonetically plausible, since the retroflexion induced by /r/ is describable in terms of the spreading of an apical articulation from /r/ to the following coronal segment.

The phonetic plausibility of this alternation, then, is inherent in the articulatory properties of the triggering segment /r/ which are transmitted to the targeted coronal consonants. In this light, [Stausland Johnsen \(2012\)](#) provides an instructive description of the Frogner, Tvedstrand, and Arendal dialects of Norwegian, in which the tap of standard Norwegian is replaced by dorsal uvular [ɣ]. Despite the uvular realization in which the apical articulation is irrelevant, the coronal retroflexion rule is synchronically active in all of these dialects (95):

- (95) /hø:ɣ/ ‘hear’ + /-tə/ PRET → [hø:t̠ə]
 /tɑ:ɣ/ ‘(nonce)’ + /-tə/ PRET → [tɑ:t̠ə]
 /stu:ɣ/ ‘big’ + /-t/ NEUT → [stu:t̠]
 /fa:ɣ/ ‘father’ + /-s/ POSS → [fa:s̠]

The data in (95) show that the exact phonetic instantiation of the rhotic is totally irrelevant as regards the synchronically active coronal retroflex rule, and retroflexion still happens preceding a velar realization (96):

(96) C[coronal] → C[retroflex] / ʁ_

Since retroflexion of coronal consonants is not phonetically conditioned by the velar rhotic, (96) is a crazy rule of type (IV).

3.10.3 *Hellenic*

3.10.3.1 *Attic Greek*

Sommerstein (1973: 15f.) reports an alternation in Attic Greek between underlying dental stops and fricatives, conditioned by /m/, where dental stops—/d/, /t/ and /t^h/—are realized as dental fricatives when preceding /m/ across morpheme boundaries (97)¹⁸:

(97) klud-ɔ:n ‘wave’
klus-ma ‘drench’

According to Sommerstein, in words of this kind the cluster is part of the stem or the noun-forming suffix, /-t^hmo/, such that it applies only across a morpheme boundary, meaning that heteromorphemic clusters of a dental stop followed by [m] do occur on the surface, as in [arit^hmos] ‘number’. One exception to this generalization is [e:t^h-mos], ‘strain’, which may have been reanalyzed as being monomorphemic. However, in the class of deverbal nouns ending in /-ma/ and /-mos/, there are no other exceptions to this process.

Steriade (1982: 256) suggests that this pattern of alternation is most productive before the derivational suffix /-mat-/ (98):

(98) /peut^h/ → pe-pus-menos ‘having found out’
/pe:t^h/ → pe-pe:s-mai ‘I have persuaded’
/anut/ → a:nus-mai ‘I have accomplished’

Other morphemes do not seem to trigger the alternation, as shown in (99), where the adjunction of /m/-initial morphemes has no effect on underlying dental stops:

(99) keut^h-ɔ: ‘to hide’ keut^h-mɔ:n ‘hiding place’
erett-ɔ: ‘to row’ eret-mon ‘oar’
pi-pt-ɔ: ‘to fall’ pot-mos ‘fate, that which befalls one’

The numerous exceptions to this pattern of alternation, as well as its specific morphological triggering conditions, suggest that it may not be phonological in nature.

¹⁸ Data from Steriade (1982: 255ff.).

Interestingly, Steriade (1982: 255ff.) describes a possibly related alternation from Attic in which *only* /d/ is realized as [s] when followed by *any* /m/, as in (100):

(100)	a.	id-e:n	‘to know’	is-men	‘we know’
		od-ɔd-a	‘I have smelled’	os-mɛ:	‘scent’
		ere:d-ɔ:	‘to prop up’	ere:s-mai	‘propped up’
		damazdɔ:	‘to tame’	Asmestos	‘untamed’
		p ^h razdɔ:	‘to show’	pe-p ^h ras-mai	‘shown’

This pattern of alternation has resulted in a dearth of [dm] clusters in Attic—both hetero- and tauto-morphemic—which suggests that it is a true post-lexical phonological rule, applying in derived as well as non-derived environments. Despite their particular differences, Steriade (1982: 257ff.) draws a link between the two patterns of alternation that suggests they may be related: while there are dialects which exhibit neither pattern, no attested dialect seems to exhibit one without the other. Steriade in fact suggests that both patterns may be the result of a single phonological process, exceptions to the rule, notable cases of /t/ and /t^h/ which do not alternate with [s] in any environment, are onset clusters: /tm/ and /t^hm/, whereas /dm/ is never an onset cluster, but always heterosyllabic. In this analysis, the rule which targets coronals and produces [s] targets only codas; any coronal consonant in onset position is protected.

Considering only the general pattern of alternation in (100), the following crazy rule accounts for the data (101):

(101) $d \rightarrow s / _m$

In this rule, a voiced stop is realized as a voiceless fricative before a labial nasal. While the change from a stop to a fricative preceding another continuant is not remarkable, the absence of any nasalization and devoicing before a sonorant is phonetically arbitrary. The rule in (101) thus constitutes a crazy rule of type (IV).

3.10.4 Romance

3.10.4.1 Campidanese Sardinian

Certain dialects of Campidanese Sardinian exhibit an interesting alternation between /l/ and an uvular [ʁ] or pharyngeal [ʕ] in between vowels in external sandhi¹⁹, described by Bolognesi (1998); Molinu (2009); Scheer (2015a) and Wagner (1941 [1984]). The data in (102) demonstrates the alternation.

¹⁹ A part of a more general pattern of lenition, see Chapter 5.

- (102) [l]imõĩ → de [ʁ]imõĩ 'lemon, of lemons'
 [l]ori → su [ʁ]ori 'cereals, the cereals'
 [l]atti → su [ʁ]at:i 'milk, the milk'
 [l]ebiu → lebieu [ʁ]ebiu 'very light, very mild'
 [l]ũã → sa [ʁ]ũã 'moon, the moon'

This alternation is interesting because it takes place in external sandhi contexts and whenever the adjunction of a vowel-final morpheme results in an intervocalic context²⁰, including definite articles, prepositions, adjectives, and reduplication. Data reported by Scheer (2015a: 324f.) demonstrate the generalized context of the external sandhi environment in which the alternation takes place (103):

- (103) [lɔŋga] → ['braβa 'ʁɔŋga] 'long, long beard'
 [li'mõĩ] → ['binti βi'mõĩzi] 'lemon, twenty lemons'
 [lampaðaza] → [ɛk:omin'tsau 'ʁampaðaza] 'June, June just started'

That this alternation takes place across word boundaries and does not depend on any particular morpho-syntactic context means that it is not a lexicalized alternation—its status as a phonological alternation is secure. The alternation in (102) and (103) is phonetically arbitrary since there is no obvious motivation in the change from a lateral [l] to an uvular or pharyngeal fricative, and there is no apparent link between the input and output and the intervocalic context. The alternation in (102) can be described by the rule in (104):

- (104) l → ʁ / V_V

The arbitrary relationship between the triggering context in (104) and the structural change effected means it is a crazy rule of type (IV).

3.10.4.2 Catalan

Bonet et al. (2005) report data from Catalan, which exhibits a pattern of word-final consonant deletion after stressed vowels. In (105a), lexical items are realized with a surface [n] when morphological contexts result in that [n] being intervocalic. In contrast, [n] cannot be realized word-finally (105b).

- (105) a. taliba[n]s 'taliban-PL.' taliba[n]et 'taliban-DIM'
 ple[n]a 'full-FEM' ple[n]itud 'fullness'
 comu[n]es 'common-FEM PL' comu[n]al 'communal'
 b. talibà 'taliban'
 ple 'full'
 comú 'common'

The same generalization holds for /r/, which surfaces when intervocalic (106a), but is elided in word-final position (106b):

²⁰ Though see discussion in §5.4, for further precision.

- (106) a. *cla[r]a* 'clear-FEM'
pape[r]às 'big paper'
monesti[r]et 'monastery-DIM'
- b. *clar* [klá] 'clear'
paper [pəpé] 'paper'
monestir [munəstí] 'monastery'

That stress plays a critical role in this alternation is clear, since after unstressed vowels both /n/ and /r/ are permitted word-finally (107):

- (107) a. *plàta[n]* 'banana'
exame[n] 'exam'
misoge[n] 'misogynist'
àto[n] 'atonal'
- b. *bárba[r]* 'barbarian'
semàfo[r] 'traffic-light'
caràcte[r] 'character'
màrti[r] 'martyr'

This pattern of /n/ and /r/ deletion is unexpected in that no other consonants—glides or other liquids or nasals—are targeted. It can be formalized as the rule in (108):

$$(108) \quad \begin{cases} n \\ r \end{cases} \rightarrow \emptyset / \acute{V}_ \#$$

Although it is common for languages to exhibit segmental alternations that are conditioned by stress, the usual effect of stress is to strengthen sounds while unstressed syllables tend to undergo weakening (see [Gordon 2011](#) for discussion). The deletion of segments in stressed syllables, then, makes this pattern both typologically unusual and phonetically unnatural. Given the unexpected, phonetically-arbitrary role of stress in the conditioning context, the rule in (108) is the inverse of the expected typologically recurrent pattern, a crazy rule of type (IV).

3.10.4.3 *Romansh*

[Kamprath \(1987: 62, 216ff.\)](#) describes a process of “glide hardening” in the Berguener dialect of Ràto-Romansh which causes the glides /j/ and /w/ to be realized as a velar stop [g] or [k] respectively—subject to contextual devoicing—when preceding any consonant. In (109), underlying glides preceding a consonant are realized as stops:

- (109) /dejt/ → [dekt] 'finger'
 /dijra/ → [digra] 'hard FEM'
 /mjowt/ → [mjokt] 'ground PP'

A number of morphonemic alternations motivate the synchronic status of this alternation. In (110), there is an alternation between [j] and [k], with [k] surfacing when followed by a consonant.

- (110) a. /krɛj+a/ → [krɛjə] ‘believe-2ps.’
 /krɛj+r/ → [krɛkr̥] ‘to believe’
 b. /ʒdrej+a/ → [ʒdrejə] ‘destroy-2ps.’
 /ʒdrej+r/ → [ʒdrekr̥] ‘to destroy’

Kamprath (1987) analyzes glide hardening as a process which spreads a [+consonantal] feature from a consonant back to a preceding glide (see discussion in Hume & Odden 1996 and Kaisse 1992). While the hardening of /w/ → [g] is unsurprising, the velar articulation inherent in the /j/ → [g] alternation is arbitrary, and Kamprath posits an arbitrary default velar feature insertion rule to account for it. The arbitrariness of this rule stems from the fact that the velar stop’s place of articulation is not that of the underlying palatal, /j/, and is unrelated to its context (111):

$$(111) \quad \left\{ \begin{array}{l} j \\ w \end{array} \right. \rightarrow g / _C[+voice]$$

Since the alternation is triggered by *any* consonant, velar or not, the velar feature cannot be derived from the rule’s context. Thus, the velar input from a palatal input is a structural change unrelated to the triggering context, making (111) a crazy rule of type (IV).

3.10.5 Indo-Iranian

3.10.5.1 Sanskrit

Sanskrit exhibits a well-known pattern of alternation conditioned by an unusual class, known as the “ruki” rule (for background see Renou 1996 and Whitney 1896). The ruki rule describes a sound change in Balto-Slavic (Andersen 1968; Pedersen 1895) and Indo-Iranian (see Dishington 1974: 490f. for a description) where PIE */s/ shifted from a dental articulation to palatal and retroflex reflexes. Synchronically, the ruki rule describes a phonological process in Sanskrit (Zwicky 1965, 1970), by which /s/ is realized as [ʃ] when preceding /r u k i/.

The synchronic status of the alternation in Sanskrit is supported by the morphonological data in (112)²¹, adapted from Zwicky (1965: 57f.) and Zwicky (1970: 549), in which the realization of the locative plural morpheme [-su] depends on the preceding context.

21 Note that, except for the case of long *o* which I have changed to *oː*, the data from Sanskrit is not in IPA, but conserves the International Alphabet of Sanskrit Transliteration system from the sources cited. Length is indicated by a macron above the vowel: ē is equivalent to [eː]. Retroflexion is indicated by a nuqta under the letter: ṛ is equivalent to [ɻ], except for in the case of ḥ which marks length of the preceding vowel.

- (112) a. STEM LOC.PL. GLOSS
 jā jā-su 'progeny'
 marut marut-su 'wind'
 ap ap-su 'water'
- b. STEM LOC.PL. GLOSS
 agni agni-ṣu 'fire'
 śatru śatru-ṣu 'enemy'
 vāc vākṣu 'voice'
 swasr swasr-ṣu 'sister'
 kāma kāmai-ṣu 'love'

In (112a), the morpheme is realized with an alveolar [s] when it follows a non-ruki segment. In (112b), any member of the ruki class causes that same sibilant to be realized as [ʃ].

The effect of the ruki class is also seen in a strong distributional regularity²² in the citation form of verbal roots (113), where sibilants following a non-ruki consonant are realized as [s], as in (113a), but the sibilant following a member of the ruki class is realized as [ʃ], as in (113b):

- (113) a. tsar- 'creep up on'
 psā- 'devour'
 b^harts- 'revile'
 vas 'clothe'
 b^hās- 'shine'
 tras- 'be terrified'
 kas- 'open'
 hras- 'shorten'
- b. kṣud^h 'crush'
 kṣam 'endure'
 akṣ 'attain'
 dwiṣ 'hate'
 d^hrṣ 'dare'
 kuṣ 'tear'
 hraiṣ 'neigh'
 b^hūṣ 'adorn'

The conditioning class shares no obvious articulatory properties, making it phonetically arbitrary²³. In the notational system of Chomsky & Halle (1968), Zwicky (1970: 554) suggests that the ruki class can be specified by the features [-anterior -low]. Zwicky (1965: 58), using the feature system of Jakobson et al. (1952), formalizes the ruki alternation as in the rule in (114):

22 Zwicky (1970: 553) notes that the ruki rule has no exceptions when the conditioning segment is *k*, but has "numerous" exceptions when the conditioning segment is *r*, *u*, or *i*, though this may be a historical accident. He suggests that perhaps the ruki rule is in fact two rules.

23 Though Vennemann (1974: 95) suggests that the members of the ruki class share an acoustic property that lowers the frequency of energy in a following [s]. In this view, the phonological class is one based on an acoustic, rather than an articulatory effect.

$$(114) \begin{bmatrix} +\text{obstruent} \\ +\text{continuant} \\ -\text{compact} \end{bmatrix} \rightarrow \begin{bmatrix} +\text{compact} \\ +\text{flat} \end{bmatrix} / \begin{bmatrix} \alpha\text{consonantal} \\ \alpha\text{compact} \end{bmatrix} (\#)_$$

The use of only a few features seems to indicate that the ruki class is a natural class (Vennemann 1974; Zwicky 1970), but this apparent simplicity is an effect of the notational use of Greek letter variables which belies the heterogeneous nature of the conditioning class. The use of Greek letter variables in (114) is in fact an extension of their use by Chomsky & Halle (1968), where they indicate feature value relations *across* segments, for example in rules of assimilation. Here, the rule formalism says that *either* [+consonantal +compact] segments ([k] and [r], though not [l]) *or* [-consonantal -compact] segments ([u], [i], and their allophones) will trigger retroflexion. In other words, the Greek letter variables, by uniting a class of segments in a conditioning environment, rather than indicating a relation between an input- and an output-segment in a structural change, indicate a natural class.

Without the formal tools that allow for this unusual use of feature variables, a more descriptive rule formalism reveals that the conditioning class is not easily united in terms of articulatory features. The alternation can be described by the rule in (115):

$$(115) \quad s \rightarrow \xi / \left\{ \begin{array}{l} r \\ u \\ k \\ i \end{array} \right. _$$

The heterogeneous class of triggering segments makes (115) a crazy rule of type (II). It is, however, mostly phonetically well motivated: in surveys of retroflexion processes, both Bhat (1973: 43ff) and Hamann (2003: 83ff.) provide a number of examples representative of recurrent processes which result in retroflexion in the context of rhotics, back vowels, and velar consonants. Each is attested in a number of languages in a variety of language families, and each has both articulatory and perceptual motivation.

For example, alveolar approximant rhotics are susceptible to spontaneous retroflexion since the tongue tip is not inhibited during the production of the alveolar articulation, leaving it free to retract or curl backwards into a retroflex articulation (Hall 1997: 215). Hamann (2003: 87f.), in turn, notes that the resultant lower F3 enhances the perceptual cues inherent in rhotic segments. Back vowels, in turn, are articulated with a retracted tongue body, just as retroflexes are (Hamann 2003: 92f.). Thus, processes which cause segments to be realized as retroflex in back vowel contexts can be viewed as coarticulation effects as the tongue body shape in consonantal gestures adapts to those of back vowels. In turn, the relatively lower F3 inherent in acoustic cues associated with backness can be reassociated from vowels to consonants. Simi-

larly, gestures of retraction inherent in velar consonants may result in coarticulation with adjacent segments and concomitant retroflexion.

However, the front vowel context seems to be neither typologically well-attested nor phonetically motivated. The typological record shows many cases of retroflexion following back vowels, and a paucity of retroflexion before front vowels (Bhat 1973). In fact, Bhat (1974: 234) and Hamann (2003: 94f.) note a typologically robust dispreference for retroflex segments in high vowel contexts, as well as a number of “avoidance strategies” in the form of phonological processes that result in a cross-linguistic distributional gap of retroflexes in high front vowel contexts. These include deretroflexion of consonants to anterior coronals and changes in front vowels resulting in retraction, lowering, diphthongization, or rounding. In the former, the high vowel gesture impedes the realization of the retroflex gesture, while in the latter the opposite is true, and the retroflex gesture effaces the front high vowel gesture.

The reason for this distributional paucity lies in phonetics. Production of retroflex consonants requires a flat tongue middle and retracted tongue back, while a front vowel requires a nearly opposite articulatory configuration with a high tongue middle and fronted tongue back; back vowels, in turn, are produced with a lowered fore-tongue gesture which is quite compatible with retroflexion (Bhat 1974: 234; Hamann 2003: 103). The articulatory incompatibility of retroflexes and high front vowels means that the movement of the tongue from one extreme position to the other during sequential articulation of high vowel/retroflex sequences is phonetically unmotivated. The upshot of this discussion is that in addition to being a crazy rule of type (II), (115) is also a crazy rule of type (IV) since the retroflexion conditioned by /i/ is phonetically arbitrary.

In the context of the unnatural articulatory movements needed for retroflexion in high front vowel contexts, Hamann (2003: 109f.) discusses the exceptional nature of the ruki rule. She suggests that the current pattern of alternation is the result of a series of diachronic changes, each of which has a phonetically natural and well-motivated motivation. Hamann discusses several possible scenarios which differ in the details of each change—in each case, however, the Proto-Indo-Aryan sibilant had different allophonic realizations depending on its context. These include a retroflex fricative in a rhotic context, a velarized fricative in the context of /k/ and /u/, and an alveo-palatal fricative in the context of /i/. In the final step of each diachronic scenario all of the disparate sibilant allophones are merged into the retroflex [ʂ].

Another unusual pattern in Sanskrit is the alternation in external sandhi between word final sequences of [as] and [o:] preceding voiced consonants; further, in [a:s] sequences, the [s] is simply deleted, resulting in [a:]. This pattern has received relatively less attention than the ruki alternations (though see Bloomfield 1882; Allen 1962; Zwicky 1965).

Sanskrit is characterized in part by regressive voicing assimilation which targets obstruents, in both internal and external sandhi (Allen

1962). In external sandhi, word-final voiceless obstruents are voiced preceding voiced obstruents, nasals, liquids, glides, and vowels. Where the sibilant is concerned, there are some further complications.

When word-final /s/ follows /i u/, it is realized as [ʃ], as per the ruki rule. If the the following word begins with a voiced consonant, then that same /s/ is realized instead as [r], rather than [z], the outcome that might be predicted from retroflexing and voicing /s/. Selkirk (1980: 121) provides some relevant examples (116)²⁴:

- (116) avis mama → avir mama
 d^henus iva → d^henur iva
 guṇais yuktaḥ → guṇair yuktaḥ
 manuṛ gacc^hati → manuṛ gacc^hati

If, instead, /s/ follows /a/ and precedes a voiced consonant, the result is [o:] as in (117)²⁵:

- (117) nalas nāma → nalo: nāma
 tapas-nid^hi → tapo:-nid^hi
 devas gacc^hati → devo: gacc^hati

This is an unexpected alternation, since, although there is a well-known relationship between voicing and length, as well as length and elided consonants, there no is phonetic quality inherent in a voiced consonant that could conceivably trigger the raising and backing of /a/ to [o]. The phonological status of this alternation seems quite secure, since it takes place in external sandhi and the status of [-as] as the nominative plural case ending means it occurs quite frequently. This process can be described by the rule (118):

- (118) as → o: / _C[+voice]

The rule in (118) has no plausible phonetic link between the structural description and change effected, and is thus a crazy rule of type (IV). In order to account for this alternation, Zwicky (1965: 144ff.) develops an abstract analysis by which /s/ is first voiced by the regressive-voicing process characteristic of final obstruents in external sandhi. The resultant [z] never surfaces, and instead is replaced by a [u] when preceded by short [a] and followed by a non-vowel or a vowel other than [a].

This solution does provide a sort of phonetic plausibility, since [au] vowel sequences are good candidates for sound changes resulting in [o], but it also engenders a number of difficulties. Putting aside the problematic nature of overly abstract analyses, the process that would change [z] to [u] is still itself quite unusual from a phonetic and typological standpoint. Ultimately, the solution proposed by Zwicky (1965) merely pushes the unnatural process into an abstract domain with no echo on the surface.

24 See also Emeneau & van Nooten (1968), Macdonell (1910: 70), and Whitney (1896: 59).

25 Data from Selkirk (1980: 122).

However, the synchronic account in Zwicky (1965) does, to a certain extent, correspond to the diachronic account provided by Bloomfield (1882: 31), who suggests that this alternation is the result of a diachronic sound change which voiced the sibilant in external sandhi. This voiced sibilant then fell in a subsequent development, leaving a “trace” of voicing on the preceding vowel, manifest as length. Allen (1962: 101ff.), however, rejects this account, suggesting that it is not voicing that is responsible for the [o:] reflex, but rather aspiration following the loss of [s], and then diphthongization to [au]. Finally, [au] would have coalesced into [o:], conserving the length of the diphthong.

3.10.6 *Slavic*

3.10.6.1 *Polish*

In Polish, there is an unusual pattern of vowel alternation where /o/ is raised to [u] before voiced word-final obstruents and sonorants (Buckley 2000b, 2001; Gussmann 1980, 2007). This pattern of alternation is known as /o/-raising and is shown in (119)²⁶, where [ɔ] alternates with [u] when case morphology changes the syllabic position of a voiced stop²⁷:

(119)	a.	lod-y	[lɔdi]	‘ice-NOM.PL.’
		noż-e	[nɔʒɛ]	‘knife-NOM.PL.’
		gwoździ-e	[gvoʒdzɛ]	‘nail-NOM.PL.’
		bobr-a	[bɔbra]	‘beaver-GEN.SG.’
		row-y	[rɔvi]	‘ditch-NOM.PL.’
		lodz-i	[wodzi]	‘boat-GEN.SG.’
	b.	lód	[lut]	‘ice-NOM.SG.’
		nóż	[nuʃ]	‘knife-NOM.SG.’
		gwoźdź	[gvoʒtʃ]	‘nail-NOM.SG.’
		bóbr	[bupr]	‘beaver-NOM.SG.’
		rów	[ruf]	‘ditch-NOM.SG.’
		łódź	[wutɕ]	‘boat-NOM.SG.’

Though the alternation in (119) is between genitive and nominative singular nouns, it is generalized within inflectional morphology (Gussmann 2007), extending to the nominative singular of masculine adjectives and pronouns (e.g. *zdrow-a* [zdrɔva] ‘healthy-FEM.’ ~ *zdrów* [zdruf] ‘healthy-MASC.’), the genitive plural of feminine and neuter nouns (e.g. *sow-a* [sɔva] ‘owl-GEN.SG.’ ~ *sów* [suf] ‘owl-GENPL.’), and in the second person singular imperative (e.g. *rob-i-sz* [rɔbiʃ] ‘make-2ps’ ~ *rób* [rup] ‘make-IMPER.SG.’).

This alternation seems phonological in most respects, given its purely phonological structural description. There are however reasons to doubt the synchronic status of Polish /o/-raising. The first is that

26 Data from Gussmann (2007: 262).

27 Final devoicing obscures the relationship between voice and the alternation, but underlying voicing plays a direct role in the pattern.

there are exceptional cases of /o/-raising failing to be triggered by voiced consonants in nouns (120):

- (120) a. drozd-a [drɔzda] 'thrush-GEN.SG.'
 węgorz-a [vɛŋgɔza] 'eel-GEN.SG.'
 perkoz-a [pɛrkɔza] 'grebe-GEN.SG.'
 mimoz-a [mʲimɔza] 'mimosa-GEN.SG.'
- b. drozd [drɔst] 'thrush-NOM.SG.'
 węgorz [vɛŋgɔʃ] 'eel-NOM.SG.'
 perkoz [pɛrkɔs] 'grebe-NOM.SG.'
 mimoz [mʲimɔs] 'mimosanom.sg.'

There are also exceptions in verbal paradigms (121):

- (121) a. chodz-i [xɔdʑi] 'go-3PS'
 za-orz-ę [zaɔʒɛ] 'plough-1PS.FUTURE'
 szkodz-i [[kɔdʑi] 'harm-3PS'
 skrobi-e [skrɔbʲɛ] 'scratch-3PS'
- b. chodź [xɔtɕ] 'go-IMPER.SG.'
 za-orz [zaɔʃ] 'plough-IMPER.SG.'
 szkodź [[kɔtɕ] 'harm-IMPER.SG.'
 skrob [skrɔp] 'scratch-IMPER.SG.'

Curiously, there are also seven cases (Gussmann 1980) of *voiceless* consonants which seem to trigger the alternation (122)²⁸:

- (122) a. stop-a [stɔpa] 'foot-GEN.SG.'
 robot-a [rɔbɔta] 'work-GEN.SG.'
 sobot-a [sɔbɔta] 'Saturday-GEN.SG.'
 powrot-u [pɔvrɔtu] 'return-GEN.SG.'
- b. stop [stup] 'foot-GEN.PL.'
 robót [rɔbut] 'work-GEN.PL.'
 sobót [sɔbut] 'Saturday-GEN.PL.'
 powrót [pɔvrut] 'return-NOM.SG.'

The alternation pattern in words ending in voiceless consonants extends to specific morphological contexts, such as the masculine third-person singular past tense of verbs, where voicing plays no role in describing the pattern of raising.

Gussmann (2007: 261f.), arguing from within the framework of GP and the non-arbitrariness condition (§1.3.2.3 and §2.3.3.4), sees /o/ raising as a morphophonological process, since it always occurs as a result of inflectional morphology and it is arbitrary in that there is no obvious connection between the change and context in which it occurs. That is, since there is no obvious reason for voiced consonants to trigger vowel raising, it cannot be a phonological process.

28 Data from Gussmann (2007: 264).

However, Gussmann (1980: 120f.) takes a perspective that is agnostic to the methodological principle of non-arbitrariness. Although Gussmann notes the morphophonological character of /o/-raising, he argues that the fact that it is fully generalized within inflectional morphology and is conditioned by the segmental structure of the string makes it phonological. Those exceptional cases of /o/-raising which are not conditioned by segmental structure are lexically marked and the product of allomorphy.

Buckley (2001) also sees /o/-raising as being synchronically active, in that its structural description relies only on phonological information: the target is a vowel in a final syllable, the trigger is a voiced, non-nasal, word-final consonant. Buckley's solution to exceptional forms is representational and a property of specific vowels: non-alternating /o/ is [-high] underlyingly, while alternating /o/ is unspecified for [high]. In this view, /o/-raising targets those vowels unspecified for [high] and causes them to be realized as [+high] in the appropriate context.

In the phonological account of /o/ raising, since voiceless consonants do not trigger the alternation in (119), /o/ raising cannot be a kind of well-attested alternation where syllable structure affects vowel quality; rather the melodic properties inherent in voiced consonants are the determining factor in triggering the alternation. The pattern of alternation can thus be formalized as in (123):

$$(123) \quad o \rightarrow u / _C[+\text{voice}, -\text{nasal}]\#$$

However, there is no apparent phonetic connection between voiced consonants and vowel raising. Thus, (123) is a crazy rule of type (IV).

Buckley (2001) provides a plausible diachronic account of the alternation process, suggesting that it began as a relationship between vowel length and voicing in a following consonant, a well-known association. In the early 16th century, vowel length lost its contrastive function in Polish—in most cases resulting in a vowel merger between long and short versions of related vowels. Long /o/, however, merged with /u/ resulting thus in a reanalysis of the length alternation as one of raising.

3.10.6.2 *Oboyan Russian*

Bach & Harms (1972) discuss a rule in the Oboyan dialect which dissimilates pretonic non-high vowels when following a palatalized consonant. Descriptively, the vowels in question are realized as [i] when preceding a low stressed vowel, and [a] if the following stressed vowel is not low. The exact change can thus be described as in (124):

$$(124) \quad e \varepsilon o \circ a \rightarrow \begin{cases} i / _ \varepsilon \circ a \\ a / _ e \circ \end{cases}$$

While it is natural for an unstressed vowel to raise when it follows a palatalized consonant, it is strange that this should happen only when following a low vowel. The exact rule is formalized by Bach & Harms (1972) as in (125):

(125)

$$V[-\text{high}] \rightarrow \begin{bmatrix} \alpha \text{ high} \\ -\alpha \text{ low} \\ -\alpha \text{ back} \end{bmatrix} / C^i_C_0 \begin{bmatrix} V \\ +\text{stress} \\ \alpha \text{ low} \end{bmatrix}$$

Bach & Harms (1972) do not provide any data to illustrate this alternation, however, and I can find virtually no mention of it in the literature. If the situation is as they describe, (125) is a crazy rule of type (IV), since there is no plausible phonetic explanation for the effect of the triggering environment.

3.10.6.3 *Ukrainian*

In Ukrainian there is a pattern of alternation between the two mid vowels /e/ and /o/ and the high vowel [i] known as *ikavism* Bethin (1975, 1981); Kenstowicz & Kisseberth (1977). Descriptively, both /e/ and /o/ are realized as [i] before word-final consonants (126)²⁹:

(126)	N.SG.	G.SG.	GLOSS
	hrim	hromu	'thunder'
	viz	voza	'cart'
	mist	mostu	'bridge'
	rih	roha	'horn'
	dim	domu	'house'
	pitʃ	petʃi	'stove'
	osin'	oseny	'fall'
	noha	nih	'leg'
	hora	hir	'mountain'
	zorja	zir	'star'
	ʃkola	ʃkil	'school'
	pole	pil'	'field'

As can be seen, regardless of the specific morphological context, if a vowel /e/ or /o/ is realized in a closed syllable, it is realized as [i]. Kenstowicz & Kisseberth (1977: 64f.) suggest that this alternation is synchronically active, but they do so without discussion. Indeed, despite the purely phonological structural description of this alternation, there are reasons to doubt its synchronic status as phonological.

The first is that there are lexical exceptions to the generalization—pairs where the alternation does not take place in native vocabulary (127a) as well as borrowings (127b)³⁰:

(127)	a.	xod	xodu	'type of cart'
		holova	holovka	'head of cabbage'
		klen	klena	'maple'
	b.	aktor	aktora	'actor'
		moda	mod	'fashion'

²⁹ Data from Bethin (1981).

³⁰ Data from Bethin (1981).

The second is that ikavism seems to perform a morphological function, marking the genitive plural in pleophonic words—those having more than one vowel—in particular (128)³¹:

- (128) N.SG G.PL GLOSS
 boroda borid 'bear'
 doloto dolit 'chisel'
 doroha dorih 'road'
 bereza beriz 'birch'

Bethin (1981) suggests that, though this alternation does not seem to be the product of a synchronic rule, it was at one time phonologically conditioned. The diachronic loss of yers in Ukrainian resulted in compensatory lengthening and diphthongs in closed vowels. Subsequently, when length disappeared in Ukrainian, the vowel reflex was [i], resulting in the synchronic situation (Bethin 1975).

In a view that considers the alternation in (126) to be the product of synchronic phonology, it may be formalized as in (129):

$$(129) \quad \begin{cases} e \\ o \end{cases} \rightarrow i / - \begin{cases} C\# \\ C.C \end{cases}$$

The rule in (129) is unnatural in that there is no phonetic motivation for a closed syllable to raise vowels, and the change from the back vowel /o/ to the front vowel [i] is especially unexpected. It is thus a crazy rule of type (IV).

3.11 ISOLATES

3.11.0.1 Zuni (*Shiwí'ma*)

Zuni, spoken in New Mexico and Arizona, is described by Newman (1965: 13) and Michaels (1971: 189ff.) as having a process of palatalization that targets the velar stops /k/ and /k^ʔ/ when they are realized before [i e a] as in (130)³²:

- (130) a. kiwihcinne → k^jwihcinne 'kiva'
 la:k^ʔi → la:k^ji 'today'
 b. kemme → k^jemme 'leather'
 ʔak^ʔe → ʔak^je 'large metate'
 c. wehka → wehk^jæ 'Eastern Keres'
 k^ʔaweʔ → k^jæweʔ 'water'

The data in (130) do not show alternations, rather it is a distributional fact of Zuni phonology that /k/ and /k^ʔ/ are systematically realized with palatalization when preceding [i e a]. The vowel system of Zuni is described as consisting of five vowels, /i e a o u/, each of which has

31 Data from Bethin (1981: 30f.)

32 Data from Buckley (2000a: 4).

a long counterpart Newman (1965); Walker (1972); only the first three trigger palatalization.

The pattern of alternation in (130) is unusual in that there is no plausible reason for /a/ (a low, central vowel) to cause fronting of /k/. It is further unusual in that the pattern exhibited in (130c) shows that when /a/ follows a target of palatalization, it is fronted to [æ]. Thus, while back round vowels do not trigger the alternation, front unround vowels do. An additional distributional fact regarding velars is that the plain velar does not contrast with the labiovelar [k^w] before round vowels. This is accounted for by the fact that the rounding of [k^w] is an effect of coarticulation with the following vowel, thus spreading round from round vowels to the velar stop (Buckley 2000a).

Buckley (2000a) suggests then that the palatalization of the velar before [æ] arose with a fronting of velars before non-back vowels as co-articulation with [i, e], but was then generalized to /a/, which itself shows a co-articulation effect by fronting. Buckley argues that this exaggeration of velar fronting, extending the pattern from a phonetically natural context to a phonetically arbitrary context, is unnatural—so much so that when the triggering vowel is elided, the fronting of /k/ still takes place (131):

- (131) $\text{susk}^j\text{i}^?ok^w\text{ik}^j\text{æ} \rightarrow \text{susk}^jok^w\text{ik}^j\text{æ}$ ‘coyote woke up’
 $\text{ʔanak}^?o^?elak^j\text{æ} \rightarrow \text{ʔanakela}^?ok^j\text{æ}$ ‘the fox stood up’

The pattern of /k/ fronting can be described by the rule in (132):

$$(132) \quad k, k^? \rightarrow k^j, k^{?j} / _ \begin{cases} i \\ e \\ a \end{cases}$$

Since there is no plausible phonetic motivation for /a/ to front /k/, (132) is a crazy rule of type (IV).

3.12 NORTHEAST CAUCASIAN

3.12.1 *Lezgi*

3.12.1.1 *Lezgian*

Lezgian (described by Haspelmath 1993) exhibits an interesting pattern of alternations that shows final voicing of underlying non-voiced stops in monosyllabic nouns. In (133)³³, it can be seen that when a voiceless obstruent in intervocalic position is realized word-final, it will be voiced:

³³ Data from Haspelmath (1993: 53f.).

- (133) a. p → b
 SINGULAR PLURAL GLOSS
 pab pap-a 'wife'
 rab rap-uni 'needle'
 seb seb-erar 'curse'
- b. t → d
 SINGULAR PLURAL GLOSS
 ɕed ɕet-er 'star'
 gad gat-u 'summer'
 kard kart-ar 'falcon'
- c. k → g
 SINGULAR PLURAL GLOSS
 mug muk-ar 'nest'
 rug ruk^w-adi 'dust'
 pag^w pak^w-ar 'rib'
- d. q → ɸ
 SINGULAR PLURAL GLOSS
 juɸ juq-ar 'day'
 myɸ myq-y 'bridge'
 naɸ^w naq^w-adi 'tear'
- e. ts → z
 SINGULAR PLURAL GLOSS
 warz warts-ar 'moon, month'
 murz murts-ar 'edge'
 tsaz ts-ats-uni 'thorn'

Word final ejectives also surface as voiced in words with ejective initial consonants (134)³⁴:

- (134) ABSOLUTE SINGULAR PLURAL GLOSS
 t'ub t^{hw}p'-u 'finger'
 t'ib t^{hj}p'-er 'owl'
 tʃ'ib tʃ^hp'-er 'span'
 ts'ib ts^{hj}p'-er 'pot'
 ts'ig ts^{hj}k'-er 'middle'
 q'yɗ q^{hu}t'er 'winter'

Yu (2004) reports results from an acoustic study that confirms that the pattern of alternations in (133) and (134) is one of word-final voicing. The origin of this alternation, suggests Yu: 83ff., is in a diachronic process of intervocalic gemination and subsequent devoicing of final geminates. Yu argues further that intervocalic stops were later degeminated, resulting in the synchronic pattern.

Indeed, in some monosyllabic nouns, the alternation pattern is between intervocalic ejectives and final aspirated consonants (135)³⁵

34 Data from Haspelmath (1993: 61).

35 Data from Haspelmath (1993: 60).

(135)	ABSOLUTE PLURAL	ABSOLUTE SINGULAR	GLOSS
	met'-er	met ^h	'knee'
	net'-er	net ^h	'louse'
	jak'-ar	jak ^h	'meat'
	haq'-ar	haq ^h	'truth'
	req'-er	req ^h	'way'

The alternation in (135) is not like the one in (134), being instead between ejectives and final aspirates. This suggests that the pattern of alternation in (134) and (135) is related to underlying length, where length is manifest as either aspiration or an ejective gesture. Kiparsky (2006) extends this length-dependent analysis, arguing that plain stops are in fact phonologically-voiced geminates which are degeminated and devoiced in syllabic onsets. In this view, there is no synchronic process of final voicing, but rather one of degemination and devoicing in non-final position.

In the view that takes the pattern of stop alternation in Lezgian as being one of final stop voicing, the alternations in (133) and (134) can be described by the following rule (136):

(136) C[-voice] → C[+voice] / _#

The rule in (136) is typologically rare, and as in the discussion of Somali in §3.3.2.1, not motivated phonetically. As such, it constitutes a crazy rule of type (IV).

3.13 PLATEAU PENUTIAN

3.13.1 *Sahaptian*

3.13.1.1 *Nez Perce (Nimipuutímt)*

Aoki (1970: 39) describes a process in Nez Perce by which a voiceless affricate with a lamino-alveolar articulation /ts/ is realized as [s] when followed by [n] or [w] (137):

(137) $ts \rightarrow s / _ \begin{cases} n \\ w \end{cases}$

The change from /ts/ to [s] is a kind of assibiliary spirantization, usually analyzed as lenition (Kirchner 1998). However, the change in (137) is not conditioned by the target's syllabic position, as is usually the case with lenition (see Szigetvári 2008: 204), but rather by its melodic content (138)³⁶:

³⁶ Data adapted from Aoki (1970: 39).

- (138) a. /yúʔts/ 'poor, pitiful'
 /yúʔs-ne/ 'poor-OBJ.'
 b. /ʔoylá-qts/ 'six'
 /ʔoylá-swa/ 'six (of men)'

In (138a), when /ts/ is followed by the nasal consonant /n/, it is realized as [s]. This alternation is triggered by /n/ in other morphological contexts, including both the ergative and direct object cases (139)³⁷:

- (139) χáχaats 'grizzly bear-NOM.'
 χáχaas-nim 'grizzly bear-ERG.'
 χ'aχaas-na 'grizzly bear-OBJ.'

Further examples can be found in Crook (1999: 29, 81) and Rude (1985: 468), adapted in (140):

- (140) a. miyáʔts 'child'
 miyaʔás-nim 'child-ERG.'
 miyaʔás-na 'child-OBJ.'
 b. tùpéʔts 'rib'
 tùpeʔés-ne' 'rib-OBJ.'
 c. táʔts 'good-NOM.'
 tàʔás-na' 'good-OBJ.'
 d. pálx̄ts'snowshoe rabbit-NOM.'
 pàlx̄ís-na 'snowshoe rabbit-OBJ'
 e. kuckuts 'small'
 kùckús-nim 'small-ERG.'

The alternation is not limited to these morphological contexts, as the data from Crook (1999: 88) shows (141):

- (141) a. sàyaq'its 'beautiful'
 sàyaq's-níχ 'beautiful-ADJ.VERY'
 b. àyts 'wild parsnip'
 àys-níme 'wild parsnip-PLACE (Mission Creek, Idaho)'

However, the alternation does not take place after other nasal consonants (142)³⁸:

- (142) yúʔts-me 'pitiful one-PL.'
 yúʔts-me-nm 'pitiful one-PL.ERG'

I was unable to find examples of the rule conditioned by /w/. Amy Rose Deal (p.c.) says the only reference to /w/ as a triggering environment is in Aoki (1970), and doubts its existence, pointing to several cases where /w/ does not trigger an alternation between /ts/ and [s] (143):

37 Data adapted from Mithun (1999: 329) and Rude (1982: 466).

38 Data adapted from Crook (1999: 75).

- (143) mats-wa 'how many-HUMAN'
miil'ats-wa 'a few-HUMAN'

Thus, it seems the correct rule is as in (144):

- (144) $ts \rightarrow s / _n$

There is no obvious reason why a dental nasal should trigger spirantization of a dental affricate. This does not seem to be a case of assimilation, since in nasal articulation there is no continuous airflow through the oral tract, and there is no phonetic reason why /ts/ should be realized as a fricative; in any case, neither nasality nor voicing spreads to the target. This is also not a clear case of dissimilation, since although the change from /ts/ to [s] results in a fricative rather than a stop, the place of articulation of [s] and /n/ is the same, meaning any processes of dissimilation is incomplete, and its value as an articulatory or perceptual enhancement is reduced to practically nil. Further, for both a hypothesis of assimilation or dissimilation, it is unclear why only /n/ triggers the alternation, while /m/, or other obstruents do not. The rule in (144) is thus crazy in the sense that there is no plausible connection between the outcome produced and the conditioning environment, a crazy rule of type (IV).

3.14 SIOUAN

3.14.1 *Dakotan*

3.14.1.1 *Lakota*

Miner (1979) reports a pattern of alternation in Lakota where word-final (and finally in the first syllables of reduplicated forms) voiceless stops are realized as voiced (145a), and voiced fricatives are realized as voiceless (145b)³⁹:

- (145) a. sápa 'black' → sábsapa 'to be black'
 ʃóka 'thick' → ʃogʃóka 'to be thick'
 b. yúza yús 'hold'
 ʃníʒa ʃníʃ 'faded'

Blevins et al. (2020) also report the pattern of coda voicing (146)⁴⁰:

³⁹ The final /a/ in these forms is an ablaut vowel inserted via epenthesis (Rood 2016).

⁴⁰ The vowel indicated as <A> is a convention used to represent a stem-final vowel that alternates between [a], [e], and [iŋ] and is subject to deletion in morphologically complex forms. Contracted Forms (CF) are indicated in the gloss.

- (146) a. *tópa* 'four'
tób 'four' (contracted form)
tóbtopa 'by fours'
- b. *napótA* 'to wear sth. out with the feet' (of footwear)
napól 'to wear sth. out with the feet' (of footwear) (CF)
napólpotA 'wearing sth. out with the feet'
- c. *ǰókA* 'to be thick'
ǰóg 'to be thick' (CF)
ǰogǰókA 'to be thick'

Blevins et al. (2020) argue that this is a true pattern of synchronic syllable-final obstruent voicing, and present acoustic data in support of that claim; to wit, syllable-final voiced obstruents do not show significant differences with their syllable-initial homologues in terms of duration, and are measured as being fully voiced.

Lakota then is another potential case of final obstruent voicing, a pattern argued to be impossible (Kiparsky 2006, 2008b; Lysvik 2020). The alternation can be formalized as in (147):

(147) C[-voice] → C+voice] / _#

The pattern of obstruent voicing is the historical residue of an earlier pattern of intervocalic voicing before final unstressed vowels. The second conditioning vowel was then lost in diachrony, but the distribution of voiced stops was maintained. As in Lezgian (§3.12.1.1) and Somali (§3.3.2.1), final voicing of voiceless stops is phonetically unmotivated, making (147) a crazy rule of type (IV).

3.15 URALIC

3.15.1 *Mordvinic*

3.15.1.1 *Mokša*

Mokša (Vaysman 2009: 134ff.) exhibits a pattern of free variation between lenited and nonlenited segments, which is sensitive to stress. In stressed syllables, the following changes can take place:

1. voiceless stops spirantize and voice
2. voiced stops spirantize
3. fricatives voice
4. /m/ is realized as [w]
5. /n/ is reduced to zero

Representative examples are provided in (148). Stress in Mokša is sensitive to the quality of the vowel: if a word contains only low-sonority vowels [i u ə] or only high-sonority vowels [e o a ɑ], then

stress falls on the initial syllable of the word. If a word contains vowels from both classes, then stress falls on the leftmost high-sonority vowel. In (148a), stress is always on the word-initial syllable, and underlying consonants are unaffected by lenition. However, the addition of the possessive suffix causes stress to shift to the final syllable, with concomitant lenition of the last root-final consonant when it becomes the onset of the stressed syllable (148b).

- (148) a. 'sʲibəsʲ 'collar'
 'kum '(close) friend'
 'bʲənʲəʃ 'boat'
 'kud 'house'
 'inʲzʲəʦ 'raspberry'
 'bʲinʲ 'stump'
 'rug 'horn'
 'sʲəlʲbʲedʲ 'tear'
 'pəʲəʃʲ 'knife'
 'sʲirək 'elm'
- b. sʲibəsʲ-'oze ~ sʲibə'zʲ-'oze 'my collar'
 kum-'oze ~ ku'w-'oze 'my (close) friend'
 bʲənʲəʃ-'oze ~ bʲənʲə'ʃ-'oze 'my boat'
 kud-'oze ~ ku'ð-'oze 'my house'
 inʲzʲəʦ-'oze ~ inʲzʲə'dz-'oze 'my raspberry'
 bʲinʲ-'eze ~ bʲi-'ēze 'my stump'
 rug-'oze ~ ru'ɣ-'oze 'my horn'
 sʲəlʲbʲedʲ-'eze ~ sʲəlʲbʲe'ðʲ-'eze 'my tear'
 pəʲəʃʲ-'oze ~ pəʲə'lʲ-'oze 'my knife'
 sʲirək-'oze ~ sʲirə'g-'oze 'my elm'

The pattern of variation in (148) depends on two things: the target syllable being intervocalic (lenition never targets word-initial consonants or post-coda consonants), and the target syllable being stressed. In fact, stress is a critical condition for lenition, the more general context of intervocalic position is not sufficient to trigger lenition. The lenition rule in Mokša can thus be formalized as in (149):

$$(149) \quad C \begin{bmatrix} \text{-voice} \\ \text{-cont} \end{bmatrix}, C \begin{bmatrix} \text{+voice} \\ \text{-cont} \end{bmatrix}, m, n \rightarrow C \begin{bmatrix} \text{+voice} \\ \text{-cont} \end{bmatrix}, C \begin{bmatrix} \text{+voice} \\ \text{+cont} \end{bmatrix},$$

$w, \emptyset / V_V$

(149) says that voiceless stops are realized as voiced, voiced stops are realized as voiced fricatives, /m/ is realized as [w], and /n/ is entirely elided. The rule in (149) is interesting in the effect it exerts on each of its targets: voiceless stops undergo a change of mode, voiced stops undergo a change of manner, /m/ is de-nasalized, and /n/ is lenited to nothing. This makes (149) a crazy rule of type (III), since the structural change is not uniform across the class of targets. The essential role played by stress is also unusual, and all the more so since lenition in stressed syllables is unexpected (Gordon 2011). The pattern of lenition in Mokša is thus also a crazy rule of type (IV).

3.15.2 *Saami*3.15.2.1 *Northern Saami*

Bals Baal et al. (2007) report data from the Guovdajohtolat dialect of North Saami, spoken in Guovdageaidnu (Kautokeino) county, Norway. In Saami, case and number are marked by suffixation and by *gradation*—stem-internal consonantal modifications. Gradation is also a property of verbal paradigms, though here I focus just on nominal morphology, in particular the nominative and accusative singular forms, which can be categorized in terms of *strong* and *weak* grades, respectively. The facts are exhaustively laid out in **Bals Baal et al. (2007)**; I reproduce relevant data here.

Taken together, gradation describes a phonetically heterogeneous series of alternations in some North Saami nominal and verbal inflections. Gradation is a characteristic property of Saami morphology, but as shown by **Bals Baal et al. (2012)**, is predictable when reduced to phonological principles. That is, there is a regular correspondence between strong-grade forms and weak-grade forms; a partial schematic representation of the some of the major examples of gradation is provided by **Bals Baal et al. (2007: 19)**:

(150)	strong grade	weak grade
	a. ...hp...	...b...
	b. ...ʔm...	...m...
	c. ...ss...	...s...
	d. ...bb...	...pp...

The alternations in (150) illustrate aspiration (150a), glottalization (150b), gemination (150c), and voicing (150d). On the surface, no clear underlying principle serves to unite the series of alternations in (150). According to the analysis developed in **Bals Baal et al. (2007)** and **Bals Baal et al. (2012)**, however, it is revealed that each of the alternations in (150) can be reduced to length, or an alternation between short consonants in the weak-grade forms, and long consonants in the strong-grade forms. This conclusion is a surprising result in the light of (150d), since there is no phonetically plausible circumstance in which strengthening of a geminate should result in that geminate being voiced.

In short, the strong-grade forms are the product of strengthening, most clearly demonstrated by the gemination in (150c), exemplified in (151)⁴¹:

41 Data from **Bals Baal et al. (2007: 20)**

(151)	NOM.SG	ACC.SG	GLOSS
	guolli	guoli	'fish'
	staallu	staalu	'troll'
	healla	heala	'heel of shoe'
	viessu	viesu	'house'
	siessaa	siesaa	'paternal aunt'
	maannaa	maanaa	'child'
	nuorra	nuora	'young'
	nierra	niera	'cheekbone'
	mearra	meara	'sea'
	gaaffe	gaafe	'coffee'
	fuođđu	fuođu	'wild animal'
	roađđi	roađi	'redness'
	blaađđi	blaađi	'sheet, leaf, newspaper'
	dievvaa	dievaa	'mound'

Bals Baal et al. (2007) and Bals Baal et al. (2012) argue that apparent exceptions to this generalization, for example the preaspirate and glottalized strong-grade forms, are the result of lengthening what are underlying aspirated stops and glottalized nasals respectively. Thus, gradation can be generally characterized as a process that results in strong-grade forms which are longer in the strong grade and shorter in the weak grade (Bals Baal et al. 2012: 173).

One consequence of this position is that the alternation in (150d) is also the product of phonological lengthening, where voiceless geminate stops /pp tt kk/ are voiced in exactly the context that produces length in other strong-grade forms (152)⁴²:

(152)	NOM.SG	ACC.SG	GLOSS
	reabbaa	reappaa	'crab'
	daabbaa	daappaa	'upper forearm marrow bone'
	gabba	gappa	'all-white reindeer'
	faaddaa	faattaa	'fire-starter (tinder)'
	loddi	lotti	'bird'
	bididi	bitti	'sappy wood'
	jeaggi	jeakki	'marsh'
	roggi	rokki	'depression, hollow'
	mugga	mukka	'jug'

Although the fact that this alternation takes place in specific morphological contexts makes it possible to analyze as a non-phonological alternation in the domain of morphology, the fact that gradation is a property of a great many nominal and verbal paradigms in Saami weakens any strictly morphological approach. Indeed, for Bals Baal et al. (2012), there is a unity in gradation, which they argue falls out from a prosodic affix represented solely by a mora. This affix is inserted in some morphosyntactic contexts, in particular the nominative singular, associating with post-tonic consonants. The syllabic consequences

⁴² Data from Bals Baal et al. (2007: 29)

entailed by this mora result in the length alternations of that consonant, which are characteristic of gradation.

Concerning the data in (152), the voicing of underlyingly geminate plain stops is the result of this additional mora (Bals Baal et al. 2012: 171). In this view, the difference between strong and weak grades is in how moras are associated to prosodic structure: consonants in weak forms are associated with the mora projected by the immediately preceding vowel, while consonants in strong forms receive an additional mora from the NOM.SG suffix, which remains unsyllabified and is realized as voicing on stops with no laryngeal specification (Bals Baal et al. 2012: 178). As a result of the way the mora is mapped to segmental content, the alternations associated with gradation can be shown to be rule governed, and phonological.

The mora's effect on post-tonic consonants constitutes a form of strengthening, whereby a mora is essentially a timing position (see §4.4.2.6), and entails the lengthening of consonants. When unsyllabified moras are linked to underlying voiceless geminates, the result is a voiced geminate (Bals Baal et al. 2012). This analysis reveals the systematic relationship between length and segmental alternations in North Saami, and shows the unexpected consequence of strengthening underlying geminates which results in strong, voiced geminates, one of the most marked contexts for voicing. The rule in (153) is thus a crazy rule.

(153)

$$TT \rightarrow DD / \acute{V} \overset{\mu}{_}$$

Furthermore, there is no phonetic explanation for how phonological lengthening could produce voicing of voiceless geminates. Indeed, phonetic principles make this result unlikely. Since phonetic voicing entails an increase in oral pressure, but the production of stops reduces air flow through the buccal cavity, the longer a stop is held, the less likely it is to be voiced (Ohala 1983). Since there is no plausible phonetic link between the structural description and change effected, the rule in (153) is a crazy rule of type (IV).

3.16 CONCLUSION

This chapter provides an empirical census of phonological patterns reported in the literature which contravene principles of naturalness as embodied in the theories discussed in §2.3.3. The patterns surveyed in this chapter cannot be explained in terms of phonetic plausibility, as they run counter to expectations about what kinds of possible phonological patterns can be generated by UG if grammars are circumscribed by naturalness.

The 34 cases of crazy rules in the present census are summarized in Table 3.4. Taken together, they pose an empirical challenge for natural-

ness theories. Some rules permit a range of analytic solutions, of which some of those may be non-phonological. Other rules seem both phonetically implausible and entirely phonological. Those rules demonstrate that phonology can compute crazy rules, and that there is no naturalness in melodic computation.

Table 3.4: A summary of crazy rules.

LANGUAGE	ALTERNATION	TYPE OF RULE	ANALYTIC POSSIBILITIES	SECTION
Attic Greek	$d \rightarrow s / _m$	IV	phonological	§3.10.3.1
Buchan Scots	$\left[\begin{array}{c} \check{V} \\ \text{-back} \end{array} \right] \rightarrow \left[\begin{array}{c} \check{V} \\ \text{-high} \end{array} \right] / \left[\begin{array}{c} \check{V} \\ \text{-high} \end{array} \right] X_$	II & IV	phonological	§3.10.2.1
Campidanese Sardinian	$l \rightarrow \beta / V_V$	IV	phonological	§3.10.4.1
Catalan	$\left\{ \begin{array}{l} n \\ r \end{array} \right\} \rightarrow \emptyset / \check{V}_ \#$	IV	phonological	§3.10.4.2
Eastern Ojibwe	$n \rightarrow f / _ \left\{ \begin{array}{l} i \\ i: \\ j \end{array} \right.$	III	abstract phonological	§3.4.1.1
Faroese	$k g \rightarrow \text{f} \check{\text{g}} / _ \text{e}$	IV	abstract phonological	§3.10.2.2
Hamar	$b k \rightarrow \beta x / V_a$	IV	phonology	§3.3.3.1
Icelandic	$k \rightarrow c / _ \left\{ \begin{array}{l} i \\ e \\ ai \end{array} \right.$	IV	abstract phonological	§3.10.2.3
Lakota	$T \rightarrow D / _ \#$	IV	phonological	§3.14.1.1
Léon Breton	$\check{V}[\text{mid close}] \rightarrow V[\text{mid open}] / _ C[\text{fortis}]$	IV	phonological	§3.10.1.1
Lezgian	$T \rightarrow D / _ \#$	IV	abstract phonological	§3.12.1.1
Limburg Dutch	$^i V \rightarrow V[+\text{front}] / _ (C)\# \text{e}$	IV	abstract phonological, morphological	§3.10.2.4
Mokša	$C \left[\begin{array}{l} \text{-voice} \\ \text{-cont} \end{array} \right], C \left[\begin{array}{l} \text{+voice} \\ \text{-cont} \end{array} \right], m, n \rightarrow C \left[\begin{array}{l} \text{+voice} \\ \text{-cont} \end{array} \right], C \left[\begin{array}{l} \text{+voice} \\ \text{+cont} \end{array} \right], w, \emptyset / V_V$	III & IV	phonological	§3.15.1.1
Nez Perce	$ts \rightarrow s / _ n$	IV	phonological	§3.13.1.1
Norwegian	$C[\text{coronal}] \rightarrow C[\text{retroflex}] / _ \#$	IV	abstract phonological	§3.10.2.5
Nyole	$\eta \rightarrow p / _ n$	III & IV	phonological	§3.7.1.1
Oboyan Russian	$V[\text{-high}] \rightarrow \left[\begin{array}{l} \alpha \text{ high} \\ \text{-}\alpha \text{ low} \\ \text{-}\alpha \text{ back} \end{array} \right] / C^i C_0 \left[\begin{array}{l} V \\ \text{-stress} \\ \alpha \text{ low} \end{array} \right]$	IV	no data	§3.10.6.2
Pawnee	$t \rightarrow h / _ r$	IV	phonological	§3.8.1.1
Polish	$o \rightarrow u / _ C[\text{+voice}, \text{-nasal}]\#$	IV	phonological, morphological	§3.10.6.1
Pomoan	$i \rightarrow u / d_$	IV	phonological	§3.9.0.1
Romansh	$\left\{ \begin{array}{l} j \\ w \end{array} \right\} \rightarrow g / _ C[\text{+voice}]$	IV	phonological	§3.10.4.3
Saami	$TT \rightarrow DD / \check{V}_ \overset{u}{i}$	IV	phonological, morphological	§3.15.2.1
Sanskrit	$s \rightarrow \check{s} / \left\{ \begin{array}{l} r \\ u \\ k \\ i \end{array} \right. _$	II	phonological	§3.10.5.1
Sanskrit	$as \rightarrow o: / _ C[\text{+voice}]$	IV	phonological	§3.10.5.1
Sediq	$e o \rightarrow u / _ (C)V$	III	phonological	§3.6.2.1
Somali	$C[\text{-voice}] \rightarrow C[\text{+voice}] / _ \#$	IV	abstract phonological	§3.3.2.1
Sotho-Tswana	$D \rightarrow T / N_$	IV	phonological	§3.7.2
Southern Bantu	$C[\text{+labial}] \rightarrow C[\text{+palatal}] / _ \left\{ \begin{array}{l} \text{-w-} \\ \text{-ini} \\ \text{-ana} \end{array} \right.$	IV	phonological, morphological	§3.7.3
Sula	$D \rightarrow T / V_V$	IV	phonology, morphology	§3.6.1.1
Ukranian	$\left\{ \begin{array}{l} e \\ o \end{array} \right\} \rightarrow i / _ \left\{ \begin{array}{l} C\# \\ C.C \end{array} \right.$	IV	phonological, morphological	§3.10.6.3
Wichita	$k \rightarrow h / _ \left\{ \begin{array}{l} r \\ j \end{array} \right.$	II & III	phonological	§3.8.1.2
Yawalapiti	$p, t, k, m \rightarrow \text{r}, \text{ts}, \text{f}, \text{p} / i_$	III	phonological, morphological	§3.5.1.1
Zina Kotoko	$M \rightarrow L / D_$	IV	phonological	§3.3.1.1
Zuni	$k, k^? \rightarrow k^i, k^{\check{e}} / _ \left\{ \begin{array}{l} i \\ e \\ a \end{array} \right.$	IV	phonological	§3.11.0.1

This empirical survey summarized in Table 3.4 allows for the formulation of three generalizations (154):

(154) *Three hypotheses regarding crazy rules:*

- (i) All crazy-rule candidates show melodic craziness. That is, there are no cases on record that involve crazy alternations

regarding syllable structure or stress, which are properties located at and above the skeleton. This generalization is discussed in greater detail in §4.4.5.2.

- (ii) Crazy rules appear to be the result of cumulative diachronic changes to a phonological system. Rules are born phonetically natural, and continue to function as phonological change modifies the objects in the structural description of the rules. This is the insight of [Bach & Harms \(1972\)](#), which will be further developed in §4.3.4.
- (iii) When a rule becomes crazy due to diachronic change, the language does not necessarily change teleologically to reintroduce phonetic naturalness; rather the now crazy rule may continue to function normally (see §4.1.2).

These hypotheses allow for predictions to be made about what kinds of possible and impossible languages there are. For example, (154i) predicts that no language will have a process by which vowels in closed syllables lengthen and shorten in open syllables, since such a rule would be operating at a level above segmental phonology, where alternations are not crazy (see also [Dresher & Kaye \(1990\)](#)). The census in Table 3.4 represents an essentially random sampling of languages, limited to what has been reported in the literature and what I was able to find. It may turn out tomorrow that there is a language with a crazy syllabic rule, though it would be surprising if it were so given the random nature of the empirical sample. There are, after all, at least 34 reasonable candidates for crazy segmental processes, but no clear cases of syllabic craziness.

If the two kinds of craziness were equally distributed, we would expect to find the same proportion of each in the sample. The absence, then, of syllabic crazy-rules is unexpected and suggests that they are absent altogether. The next chapter will discuss some of the consequences of this census—and especially of the predictions in (154)—for phonological theory.

WHAT A THEORY OF PHONOLOGY SHOULD BE AND WHAT IT SHOULD DO

Nothing in biology makes sense
except in the light of evolution.

DOBZHANSKY

Empirically, the typological record shows that a great many phonological patterns hew close to the bone of the physical world and can be explained by or even potentially reduced to functional explanations in articulatory or perceptual phonetics, as discussed in Chapter 2. However, any theory of phonology must also confront crazy rules, a census of which is presented in Chapter 3. This tension is well articulated in an observation made by Anderson (1981: 509):

On the one hand, we find that a great many phonological rules are tantalizingly close to some sort of phonetic explanation; but on the other, we find that when we try to pin them down in such terms, they have evidently been transformed into something which is no longer merely “functional phonetics”. An adequate account of the nature of phonological structure will have to deal with both of these aspects of the phenomena: it must provide some basis for the apparent connection between phonetic and phonological effects, but must also recognize the essential independence of the latter domain from rigid deterministic control by the former.

Let us refer to this as “Anderson’s Paradox”. While much of the empirical record is characterized by alternations with parallel functional descriptions, crazy rules are indisputably attested. Anderson’s Paradox captures the alternating emphasis in theory construction between functional explanations found in phonetics and purely formal tools agnostic to phonetics.

This chapter presents a discussion of naturalness in the light of Anderson’s Paradox, and argues that while phonological patterns are shaped by functional factors, this effect comes strictly from outside of the grammar. I argue that naturalness faces insurmountable empirical and conceptual obstacles, and should not be the foundation of theory construction. Instead, it should be recognized that phonological theory is blind and deaf to phonetics; in this view phonetically natural rules and crazy rules have the same ontological status and are formally comparable. While crazy rules are certainly more limited in distribution than conventional rules, the reasons for this asymmetry also lie outside of grammar—specifically in diachrony.

Finally, if phonological computation is ungirdled by functional concerns and can produce crazy rules, what makes an impossible phonological grammar? A potential response to this question is posed in substance-free phonology. I argue that phonology is an arbitrary computational system entirely devoid of phonetic content, composed of (at least) two computational domains.

The first domain is melodic, composed of symbolic phonological features which interface with the real world; in this domain phonological rules can manipulate melodic material without restriction, giving rise to crazy rules. The other domain is purely mental, with no interface to the real world. It is composed of prosodic structures that organize the melodic symbols; in this domain there is no arbitrariness and thus no craziness. Distinguishing between these two domains provides a way to make predictions about possible and impossible languages (see §2.1.2).

4.1 UNNATURAL PHONOLOGY

4.1.1 *Naturalness and markedness as absolute constraints*

The empirical census of crazy rules in Chapter 3 poses a serious obstacle for theories which yoke explanation to naturalness *qua* phonetic processes. However, formal naturalness also faces a number of conceptual problems which make it of limited epistemological value. In part, this is because the pretheoretical notion of naturalness is not a rigorous term (Ohala 1974), but rather is found in the eye of the beholder; how phonetic naturalness is formalized is a function of its definition.

While phonologists have frequently taken it for granted that phonetic naturalness is a straightforward notion, phoneticians do not have a generally agreed-on framework for the evaluation of the naturalness of phonological rules (Keating 1988). Lass (1984: 196) views naturalness in a loose, general sense: natural rules are phonetically motivated, unnatural rules are unmotivated. Impressionistic notions such as “more simple”, “more common”, “normal” or “optimal” are shaky grounds on which to base operational criteria, limiting the use of naturalness in constraining grammars (De Cuypere & Willems 2008: 12).

In the terms of Kiparsky (1972) (see §2.3.1), naturalness is a kind of relative constraint—the function of which is to reduce the space between formally possible languages generated by a theory of Universal Grammar (UG) and natural languages attested in the typological record. de Lacy & Kingston (2013) point to relative constraints as a source of what they call *synchronic explanation*: there are cognitively imposed restrictions on phonological grammars. However, markedness (§2.2.3.2), the classic formal embodiment of naturalness, is a vaporous term (Haspelmath 2006; Hume 2004a), variable in its meaning and the role it plays in linguistic theory (Samuels 2011). Since it is not clear how markedness represents naturalness or what naturalness means

exactly, as a formal tool for constraining grammar it is inadequate both empirically and conceptually.

4.1.2 *Empirical issues*

One critical flaw inherent in formal naturalness *qua* markedness is that it is too restrictive: the taxonomy of natural types defined by Schane (1972) (§2.3.3) is not, in fact, empirically adequate (Dinnsen 1980: 178) (see also Skousen 1972). Dinnsen points to cases of rules whose structural description and output do not follow from phonetic explanations; rules of maximum differentiation predict that segments will be perceptually as distinguishable from one another as possible, but Dinnsen cites the case of Western Catalan, in which an underlying contrast between /a/ and /e/ is neutralized to [e] in word-final, unstressed closed syllables, instead of the expected, maximally distinct, peripheral vowel [a]. This outcome is surprising if maximum differentiation is a formal property of phonological grammars.

Another of Schane's natural type of rules are those of preferred syllable structure, whereby syllables of the shape CV are "optimal" and grammars favor CV syllables over CVC syllables. This is an example of markedness derived from a cross-linguistic tendency: what is natural is what is attested frequently, what is unnatural is what is rare. For Lass (1980: 34) such claims constitute probabilistic "pseudo-predictions" that cannot be used to explain and are unable to account for languages which exhibit a tendency towards non-optimization. Lass cites the case of Toda, a language which has deleted final vowels in disyllabic words and dropped vowels in affixes and post-positions, such that where cognate languages have CV syllables, Toda has syllables of the shape CVC, or even CVCC, CVCCC, etc.

In OT based theories, avoidance of putative unnatural structures is subsumed by markedness constraints. Since the architecture of OT in particular is built on limited, universal, and functionally-motivated constraints, it is fundamentally constructed to allow for exclusively "natural" grammars (Vaux 2008). As a result, it not only makes the false prediction that phonological processes will always be functionally motivated, but it is also unable to explain diachronic black swans which give rise to unnatural synchronic processes (see discussion in §4.3.3).

4.1.2.1 *Naturalness is inert in diachrony*

In fact it is in diachrony where the absence of naturalness-enforcing trends is most conspicuous. Since formal naturalness exerts pressure on unnatural structures at a systemic level, one prediction is that unnatural processes should over time be less stable and more subject to change relative to natural ones as a function of the influence of naturalness enforcing constraints (Lass 1975). If this were so, we would expect to see languages coalesce around the set of sound patterns which reflect natural processes, as diachronic change should not give rise to structures that contravene naturalness. However, Kaye (1979) argues

that phonological change can result in marked structures being preferred over alternatives, seriously reducing the use of markedness as a predictive tool.

Kaye (1989) observes that languages exhibit an array of diverse phonological systems, with little evidence suggesting that diachronic changes result in a convergence towards simpler or more natural states. Kaye suggests that diachronic change *can* reflect arguably natural patterns, such as the reduction of articulatory complexity in the diachronic evolution of Italian that resulted in C_1C_2 sequences in Latin being realized as C_2C_2 geminates, such as *dottore* ‘doctor’, *fatto* ‘fact’, and *adottare* ‘adopt’; in this case two disparate articulatory gestures are reduced to one. However, such outcomes are by no means universal, as seen in Moroccan Arabic where a process of vowel elision results synchronically in consonant clusters with equivalently disparate articulatory gestures (155):

- (155) ktib ‘he wrote’
 kitbuu ‘they wrote’

The plural form is the result of the concatenation between the input *kitib* and *uu*—the first vowel, /i/, is deleted in a process which causes a vowel to be elided when it precedes another vowel in a given phonological string, resulting in a [kt] surface sequence. From the standpoint of naturalness, this is a surprising result, and it seems that in one language phonological computation is perfectly capable of producing complex articulatory output that is avoided in another. If naturalness plays no role in some languages, its ontological status as an element of formal theory is questionable.

Hyman (1975: 181f.) suggests that formal naturalness could be salvaged by a particular kind of predictive evidence. The argument that naturalness is a part of synchronic phonology would be strengthened by a putative language with a rule of the following form: $A \rightarrow B / C$. If the triggering context C is destroyed or obscured, then two results are possible: either the language may continue to realize A as B in the new context, or, since the conditioning environment is no longer relevant, A stops alternating with B —and the rule becomes unproductive. In other words, if it can be shown that speakers will abandon rules whose phonetic context is lost, then a synchronic role for naturalness will have been adduced. A third possibility not discussed by Hyman is for the rule to remain productive but to change A B or C such that the rule returns to being natural.

There does not seem to be any general tendency for phonetically unnatural rules to change back into natural ones; Hyman (1975: 181f.) argues that the more frequent outcome of change-induced unnaturalness is a kind of phonological inertia where processes continue to operate in changed contexts, rather than losing productiveness (see for example Stausland Johnsen 2012). That is, there is no synchronic pressure to maintain rule naturalness, and instead they tend to lose their phonetic motivation over time.

Potentially, a weak version of naturalness could maintain that grammars do reflect naturalness in that they do not exclude unnatural patterns and merely favor natural patterns. That is, most phonological patterns are natural because phonological grammars are conditioned by phonetic naturalness, but unnatural processes may still arise through unlikely diachronic events (Hyman 2001). However, as pointed out by Stausland Johnsen (2012), the more diachronic accounts are made to explain unnatural processes, the distinction between synchronic phonology and diachronic phonology becomes less clear, until there is virtually no way of distinguishing between the two.

4.1.2.2 *On the typological record and remote islands*

As discussed in §2.3.2, one of the principle ways of adducing naturalness in a pattern is through its reflection in typology: a typologically recurrent pattern is natural. There is, however, a critical conceptual problem with any notion of naturalness which depends on the typological record, and the assumption that attested languages represent the breadth of computationally possible human language is unwarranted. This is because the set of attested languages is arbitrary by nature due to capricious non-linguistic factors such as the research interests of linguists, historical accidents such as population movements, the whims of missionaries, where graduate students are trained and how they are funded, and so forth (Hale & Reiss 2008: 2). Thus, sampling methods and historical accidents conspire to make it difficult to both measure and interpret the relative frequency of any given structure or process (Maddieson 2009: 134).

There is also the insurmountable problem posed by time and space. One estimate for the number of taxonomic languages spoken on Earth at present ranges anywhere from 5,000 to up to 8,000 (Evans 2009). The exact number is difficult to ascertain due to the fuzzy line separating languages and dialects in the literature. Of these standardized E-languages, less than 10 percent have been described in enough detail to have full grammars and dictionaries (Evans 2009); nothing at all is known about the language of the pugnacious inhabitants of North Sentinel Island, among others. Typological generalizations are also limited in perspective when the past is considered: there have likely existed at a minimum 500,000 natural languages (Pagel 2000). This estimate has an important implication for linguistic conclusions based strictly on typological generalizations: the languages on which those generalizations are based constitute a random sample of fewer than two percent of human languages (Evans 2009). If a language featuring a unique structure goes extinct before being recorded, that structure is absent from the typological record, despite constituting a language in the set of possible languages.

This sampling issue extends to large language families such as Niger-Congo and Austronesian, which are much more represented relative to small language families and isolates, skewing the kinds of representative and recurrent phenomena that appear in the typological record.

Social and economic effects also skew the record towards languages that are national languages, increasing the chances of these languages being well-documented by grammars. We also know relatively less about languages spoken in underdeveloped communities, since the chances of native speakers being able to pursue an education in linguistics and participate in the global community of scholars are seriously reduced by socioeconomic conditions.

Furthermore, there is a sampling issue inherent in the distinction between E-languages and I-languages which inflates the number of possible grammars well above the figures cited by [Evans \(2009\)](#). Any E-language—Czech, Mexican Spanish—is an abstraction, what [Jackendoff \(2007: 349\)](#) refers to as a “convenient idealization.” In contrast, the French spoken by a rural resident of the Niçois hinterland and that spoken by an individual born and raised in Paris represent two different I-languages which are characterized by grammars that differ in fundamental ways, such that they both constitute discrete elements of the set of possible languages.

Similarly, we have no access to any data from languages as they will be spoken in the future: the English of the Virginia Piedmont, Réunion creole, Navajo, Kabyle Berber, and all the languages spoken on Earth at the time of this writing are subject to change within the structural limitations imposed by UG. As noted by [Odden \(2003: 164\)](#) the “sampling of language is small, and countless distinct linguistic patterns happen to be unattested today, but will become attested tomorrow or the next day.” Given the paucity of the data set, it is difficult to see how credible conclusions can be drawn concerning the limits of the set of possible human languages: any pattern stipulated to be unnatural or impossible may tomorrow be found in an as yet undocumented language.

The danger is in positing overly restrictive relative constraints targeting accidental gaps, because not only does this lead to false conclusions about the nature of UG, but it serves to end inquiry—if an explanation for a typological gap is found in a relative constraint in grammar, then alternative explanations do not need to be sought. Theoretical tools used to exclude specific unattested patterns reduce the coherence of a theory by introducing *ad hoc* kludges which do not fall out from general principles, based only on an assumption that those patterns are impossible ([Blaho & Rice 2014](#)). Thus the specter of circularity slips into phonological theory: one linguist claims that certain structures are rare because there is an UG-based injunction against them, while the next claims that evidence for the injunction against those structures is derived from the fact that they are rare ([Harris 2008](#)).

In light of sociolinguistic research which shows that smaller, isolated linguistic communities tend to preserve typologically rare structures relative to larger communities in frequent contact with speakers of other language varieties ([Nettle 1999](#); [Trudgill 2011](#); [Wohlgemuth 2010](#)), the sampling issue potential has even more far-reaching consequences for crazy rules. This is because it is precisely smaller, isolated linguistic communities which tend to be less well-represented in linguistic studies and because historically, most human beings lived in smaller,

relatively more isolated communities up until quite recently, about 5,000-6,000 years ago (Trudgill 2012).

This means that human society during the neolithic was characterized by just the kind of small, tight-knit, isolated linguistic communities in which rare structures tend to be found. Trudgill (2012: 93) argues that “exotic languages” with typologically unusual structures are, far from being unusual, rather the norm, being what human languages looked like for most of the tens of thousands of years of human history on Earth. Given the disproportionate representation in the typological record of language families associated with the spread of agriculture, military conquest, and massive, continent-spanning trade networks, it is probable that crazy rules are underrepresented in the typological record relative to the number of languages which have existed in the past.

4.1.2.3 *Admitting unnatural patterns in phonological theory*

It might be argued—to varying degrees of success—that LSGs in the form of crazy rules are not phonological in nature (see discussion in §2.3.3). From this perspective, formal naturalness does constrain grammar, but the task of accounting for unnatural LSGs is simply moved elsewhere, as in the case of NP and NGP. Scheer (2011b) estimates that naturalness theories remove 80 or 90 percent of processes from phonological grammar; they are simply shunted into a resurrected morpho-phonological level where their origin lays somewhere outside of phonology—in the lexicon, in allomorphy, in analogy, or in the interface. However, given the pervasiveness of unnatural patterns (Chapter 3), it is not just crazy rules which pose a challenge to naturalness theories; one of the principal desiderata of a theory of phonology is to account for exceptional and unnatural processes, those which are arbitrary in phonetic terms (Vaux 2008: 27).

Calabrese (2005, 2009) is an example of a middle road, arguing that markedness is active in grammar but provides a natural explanation for only some phonological generalizations—there are also arbitrary, idiosyncratic generalizations that are not subject to the well-formedness conditions imposed by markedness. In this view, there are two phonologies at work. In the first, the Markedness Module imposes constraints that block prohibited structures for articulatory and/or perceptual reasons. Marking statements identify configurations that are suggested to be phonologically complex; as in the processes of NP, these statements can be deactivated by language learners confronted with marked structures. In the other phonology, there are positive instructions which dictate how a marked configuration will be repaired, and this phonology is conventional, being the reflection of language’s social function, where the effects of historical changes are accrued and give rise to exceptions and idiosyncratic rules that obscure the natural aspect of phonology.

In this view, the effect of arbitrary computation is recognized, but is characteristic of only a portion of the grammar. The question then

arises, why, if the computational system is capable of handling some arbitrary patterns, should there be a second phonology only for natural patterns? This position is also confronted with general arguments against markedness raised for example by Bermúdez-Otero & Börjars (2006); Hale & Reiss (2000b, 2008); Haspelmath (2006); Hume (2004a) *inter alia* (see §4.1.3).

Formal naturalness is one tool used to bend theories such that they reflect probabilistic distributions in typology. That is, formal naturalness is a way of building theories about not just what kinds of languages do exist but also what kind of languages are *likely* to exist; as noted by Newmeyer (2005: 104), encoding typology into grammar changes the remit of linguistic theory from *possible* language to *probable* language. However, recall from the discussion of the hierarchy from Hale & Reiss (2008: 3) discussed in §2.1.3: possible, humanly-computable languages are the proper remit of phonological theory.

In fact, there is no reason to assume that UG should include information about why, for example, there are more SVO languages than VSO languages in the world (Newmeyer 2005: 119). Typological frequency may be an *explicanda* of linguistic theory, but it does not follow that the *explicandum* is found in UG and thus should be encoded in formal theory. Newmeyer argues that typology is reflective of facts of E-language—facts independent of UG; since phonological theory is concerned with I-language, typological generalizations are only indirectly relevant to the construction of theory. Put another way, incorporating naturalness *qua* typology into UG is a violation of the Saussurean distinction between *langue* and *parole* (Scheer 2004b: 390). Typology is a reflection of the frequency of a pattern, and as pointed out by Haspelmath (2006: 43), a property of *parole* or performance, rather than of language structure or competence. Haspelmath (2004) argues that cross-linguistic data cannot be used to argue for a model of UG, precisely because cross-linguistic generalizations are the product of extra-grammatical functional constraints on language use. Any cross-linguistic generalization, even apparently exceptionless ones, may be shown to be false given a large enough sample size.

If there are no phonological universals, then all unattested patterns are nothing more than accidental gaps: nothing in grammar prevents an unattested pattern from occurring. An accidental gap in typology could be filled in the future as it is discovered in some as yet undescribed language. While length harmony is unattested now, it should not be assumed to be impossible because it may eventually be found to be a part of the phonology of a language spoken on a remote island. Scheer (2019b) refers to this as the *remote island argument*: since the empirical record is incomplete, absolute statements about impossible linguistic patterns cannot reasonably be made. The remote island argument is valid for the melodic domain as well as syllabic structure. The absence of non-melodic crazy rules is surprising (see Chapter 3), given the randomness of the typological sampling available to linguists. This suggests that there are no remote islands to be found where syllable structure is concerned.

Like Archangeli & Pullyblank (1994: 433), Scheer (2019b) distinguishes between accidental and systematic gaps in the typological record. The former are artifacts of history, sampling issues, or unlikely diachronic processes, while the latter are impossible languages. The remote island argument says that the distinction between accidental and systematic gaps, and thus between possible and impossible languages, is impossible to make. This is because there is no meaningful difference between the two: any putative systematic gap may be argued to be accidental. As a consequence, there is no need to suppose that there is any UG for phonology¹.

The necessity of UG follows from the fact that there are no functional mechanisms that provide a full explanation for the shape of typology (see Morley 2015a: e40f. for discussion). Length harmony is an example of a pattern which is entirely unattested, though given its perceptual salience it is in principle as good a candidate as other kinds of long-distance phenomena that might provide listeners with a more robust cue for identifying dependent feature values (Kaun 1995; Kimper 2017; Gallagher 2010; Suomi 1983). Its absence from the typological record then is not entirely reducible to functional factors. The surprising cross-linguistic absence of length harmony can potentially be explained as a limit inherent in the architecture UG on the set of possible languages: there is no way to compute length harmony.

I argue that impossible patterns are prevented not by relative constraints imposed by UG which target particular unnatural structures, but rather by absolute constraints following from the basic architecture of the representational and computational system underlying phonology *qua* cognition. I will return to the subject of remote islands in §4.3.2, where some operational criteria for distinguishing between accidental and systematic gaps will be discussed.

4.1.3 Conceptual issues

In addition to the empirical issues raised in the preceding section, including formal naturalness in theory construction presents a number of conceptual problems. As discussed in Chapter 2, the impetus for a theory of formal naturalness is in part to provide explanatory adequacy—to explain why possible rules are possible and why impossible rules are impossible. Dinnsen (1980: 172), however, rejects the usefulness of naturalness as an explanatory mechanism, saying that no appeal to phonetic principles can explain every structural aspect of a phonological rule; for example why any given rule has the *particular* structural description or structural change that it has. In the case of American English flapping for instance, the *existence* of a rule targeting coronal stops between sonorous segments may have an explanation in articulatory facts, but those facts cannot explain *the reason* coronal stops should become flaps instead of spirants (see Uffmann 2011). This issue

¹ Thus, the position held by Fitch et al. (2005) and Hauser et al. (2002), that phonology is not a part of FLN proper, would be vindicated. See §1.1.1.

is reproduced in OT and any theory that is output oriented rather than process oriented, and has come to be known as the *too-many-solutions problem* (see discussion in Steriade 2001 [2009]). That is, even when a process can be given a phonetic explanation, such explanations are not of much use in understanding phonological patterns since they make limited predictions and are not falsifiable.

This is an inherent property of the inductive nature of OT constraints, which are based not on general principles, but rather individual observations. In a sense, constraints recapitulate description, and have nothing to say about *why* a given phenomenon is as it is. For example, de Lacy & Kingston (2013) argue that UG contains a constraint against epenthetic consonants with a dorsal articulation, based on a typological observation that no attested language contains such a segment². However, while a UG-endowed constraint would effectively provide an explanation for the typological pattern, it would in turn require explanation itself: *why* should UG provide such a constraint? Why does markedness discriminate against the dorsal feature instead of labial or coronal features?

The general lack of explanatory power provided by constraints is symptomatic of their circular nature; the explanation for typological observations relies on a restatement of the observation itself, not on any fundamental principles (Scheer 2004b: 478). In OT, constraints are *ex post facto* principles introduced on a case-by-case basis to explain observations taken to be LSGs. Because of their inductive nature, there are no underlying principles determining what a markedness constraint is or does. OT is not a theory of constraints, but rather a theory of constraint interaction (Scheer 2004b, 2010b). There are no constraints on constraints, as it were, and as such there is no theoretical limit as to what kind of constraints can be employed in a grammar; any constraint can be introduced on-the-fly to account for data that is not described by the existing set. As a consequence, the set of constraints must be augmented for every idiosyncratic, language-specific accidental gap (Vaux 2008: 47).

In fact, there is no formal property of OT that even says a constraint has to be linguistic in nature; this wide-ranging scope of constraints is the origin of, for example, the constraint *LAZY, which says that representations should be economical in terms of energy expenditure, in accordance with general human tendencies (Kirchner 1998). The power of potential constraints is illustrated in a *reductio ad absurdum* by the constraint NOBANANA in Reiss (2008), which bars bananas from phonological representations. Thus, constraints which restate facts related to extra-grammatical phenomena can be incorporated directly into the grammar; as a consequence, markedness constraints are part and parcel of a theory of everything which ultimately explains nothing.

A further conceptual issue inherent in formal naturalness is that it constitutes a duplication of explanation (Cohn 2007; Sampson 1975). Processes of phonological assimilation, for example, can be explained

2 Whether this is empirically valid or not is another question, see Vaux & Samuels 2019.

by facts about their historical development and the influence of articulatory phonetics on those processes; any explanation required from the formal theory is then superfluous, making *natural rules* and *natural explanation* indistinguishable (Dinnsen 1980: 180ff.). Dinnsen cites an example from English, where a nasal consonant followed by a fricative triggers epenthesis of a consonant homorganic with the nasal and agreeing in voice with the fricative, as in *prince* [prints].

There is a ready explanation for this process of epenthesis in articulation: velic closure precedes oral release in the transition from the nasal to the fricative, resulting in a stop being realized between the two. Dinnsen (1980) argues that the phonetic explanation amounts to nothing more than the articulatory facts—a formal constraint on this process does nothing more than recapitulate the description. As such, there is no hypothesis, only the restatement of facts that are to be explained. Duplication of explanation applies wherever there is a plausible phonetic explanation for phonological patterns, if explanation for the pattern is found in both phonetics and a cognitive bias that mirrors the phonetic explanation, there is no way of determining which explanation is in fact responsible for the question. In such cases phonological theory cannot be said to actually provide explanation, since neither potential explanation can be pointed to with any certainty.

A further conceptual problem is in the distributional facts markedness is meant to explain. One view of markedness sees it as a property of phenomena which diverge from randomness of distribution. Following Lass (1980: 16f.), consider a structure *S* and five possible typological distributions (156):

(156)	Languages with <i>S</i> (%)
	D ₁ 50
	D ₂ 45
	D ₃ 90
	D ₄ 0
	D ₅ 100

D₁-D₂ are essentially random distributions and thus do not represent an LSG. Both D₄ and D₅ are candidates for some property of UG, though D₄ may also correspond to trivial universals such as pharyngeal nasals, sounds which are physiologically impossible. Markedness, however, is typically taken to be a reflection of distributions such as that of D₃. It is thus a probabilistic generalization, not an absolute one. If a structure is a property of 90% of languages, it is absent from 10%, but presumably that 10% of languages functions with no major issues because of that absence.

It is unclear why UG, being a property of individuals, should directly encode information about typology, a macroscopic property of human languages. That is, typological markedness views a structure as marked or unmarked relative to an analogue structure in other languages: typological frequency can only be determined by comparing a single language to the set of attested languages. From a more local point of

view, that of a single language family or in particular from that of an I-language speaker, this is not a useful notion. A given structure or configuration is said to be marked—e.g. [+round] front vowels—when that structure or configuration is rare in a relative sense. But there is nothing unexpected about it from the point of view of an individual speaker or when a language family which contains such a structure is considered. For speakers of a language with front round vowels, [+round] is a perfectly conventional feature of front vowels. For Lass (1975: 485), formal conventions such as markedness applied to such unremarkable structures are empirically vacuous.

Further, learners of a language with a putatively marked structure have no need to encode constraints against that structure (Lass 1975). A constraint against voiced coda obstruents, for example, has to be overcome in the evaluation of descriptively adequate grammars a learner exposed to German could construct. Hale & Reiss (2000b, 2008) in turn argue that the ambient language provides all the positive evidence a child needs to construct a grammar, and that the knowledge encoded in markedness is never brought to bare (see Newmeyer 2005 for a parallel argument in syntax). In the case of a linguistic environment which does have voiced coda obstruents, such as English, the child must in fact *overcome* this innate knowledge in order to construct a grammar that corresponds to the positive evidence. In either case, UG-endowed knowledge/markedness is either unnecessary or insufficient for the grammar that needs to be constructed.

Thus, explanations provided by naturalness is non-empirical: they cannot be used to predict particular states of affairs, nor can they be used to counter-predict their opposites (Lass 1980: 20). Any predictions made hold only over aggregates, not for individual members of aggregate sets. SPE-style markedness is an inherent quality of segments meant to reflect a frequency over the set of attested languages, but Lass argues such notions have no explanatory power, being merely descriptive devices for observed distributions. Returning to front round vowels, for example, Lass (1980: 25) suggests that 15 percent of the world's languages contain front round vowels, while 85 percent do not. This then raises two questions:

1. How is it a property of something that only n percent of the world's languages have it?
2. How can it be a property of languages that only n percent of them have something?

The typologically-based definition of naturalness introduces the specter of circularity into formal theory. As noted by Carvalho (2002), phonology identifies a process $/x/ \rightarrow /y/$ as natural because it is commonly attested, meaning that processes are natural or unmarked because they are frequent, and they are frequent because they are unmarked. Lass (1975: 486f.) argues that this is a logical, but circular, progression:

- a. Some structures are common relative to others.

- b. Thus common structures are marked relative to less common, unmarked structures.
- c. What is most common must be ‘natural’, meaning that unmarked structures are natural, and marked structures are unnatural.
- d. Since what is common and natural is relatively optimal, and the metatheory defines optimality as simple—‘common’, ‘natural’, ‘optimal’, and ‘simple’ are equivalent.
- e. This shows that common, natural structures are simple, because given (d) common, natural things would not exist if they were not also simple.

What began in (a.) as a simple observation of descriptive generalizations becomes a metric of naturalness through an *ad hoc* and circular process of reasoning. There is no basis, then, for imbuing typological generalizations with intrinsic content.

Furthermore, it is not clear that naturalness—as a kind of articulatory or perceptual ease—is the best tool for bending formal theory in the shape of typology. Westbury & Keating (1986) show that typology of stop voicing is not predictable based on articulatory ease. Voicing depends on airflow across the vocal folds, when that airflow is insufficient—as in stops—voicelessness should be favored over voicing. However, at least in regards to the distribution of stop voicing, ease of articulation does not seem to be reflected in the typological record, where voiced stops are abundant. In terms of stop voicing distribution, articulatory ease is not a useful predictor of typology. Similarly, while not all segments are *likely* candidates for epenthesis processes, there seems to be no limit on the range of *possible* candidates (Samuels 2011; Vaux 2001); here typology constitutes nothing more than a heuristic, rather than a true predictive tool.

The empirical and conceptual issues related to formal naturalness seriously undermine its explanatory value. This suggests that understanding of phonology does not come from taxonomic, data-fitting models, but rather from understanding the basic architecture of phonological computation (Reiss 2003: 334). Rather than imposing relative constraints on a case-by-case basis, theory construction which proceeds by induction and derives attested languages by basic, general principles has more explanatory value. That is, following Odden (2020), observations are fitted into simple abstractions, and which in turn are integrated into higher-level abstractions; the alternative is the arbitrary stipulation of higher-order abstractions for which specific instances are deduced.

In a bottom-up approach to explanation, there exist only absolute constraints: impossible patterns are those which cannot be generated by the tools which generate possible patterns. In this view, the set of possible languages is defined purely by the nature of representations and computations. A theory of computation that provides principles for defining possible rules also allows attested patterns of cross-linguistic

variation, including crazy rules—UG’s set of possible computations constrains the set of possible languages (Hale & Reiss 2000a: 173). The task of phonological theory, then, is to define the formal primitives and to explore how they interact to give rise to attested languages. If the formalism also generates unattested patterns, they are *ipso facto* possible rules.

Anderson’s Paradox, however, reminds us that most phonological patterns are describable in phonetic terms, a fact which also demands explanation as part of full account of phonology. That is, while their explanation need not be ascribed to UG, the patterns circumscribed by markedness are real. The rest of this chapter will establish a programmatic approach towards resolving Anderson’s Paradox.

4.2 MINIMALISM: BEYOND EXPLANATORY ADEQUACY

Thus far the discussion has argued that naturalness as a formal device faces a number of empirical and conceptual difficulties, limiting its use as a predictive and explanatory tool. Yet, as Anderson’s Paradox suggests, that so many phonological patterns can be described in terms of phonetic naturalness seems unlikely to be a coincidence. Any theory which dispenses with naturalness, for conceptual or empirical reasons, potentially faces the charge of what Embick (2010: 21) terms the “putative loss of generalization”, a claim that such theories miss an important generalization about the nature of certain patterns, and why they are attested instead of others. Such a theory, it could be suggested, is deficient since the distribution of typological patterns is arbitrary in formal terms.

One solution to the paradox is to loosen the reins of naturalness, meaning that rather than a rigid system which dictates the form of attested languages in an absolute sense, naturalness functions more as a suggestive system that coaxes patterns into recurrent typological patterns, but which can be overcome by other pressures. This is, in fact, essentially the way OT works, since markedness constraints may potentially be out-ranked by faithfulness constraints. However, the greater the number of phonetically arbitrary and unnatural patterns UG is found to be capable of generating, the more difficult it becomes to make a conceptual difference between natural and unnatural patterns; naturalness risks becoming an empirically vacuous notion. Logically, if naturalness cannot be used to explain *some* synchronic patterns, then it may not play a synchronic role in *any* patterns.

As discussed in §2.2.2, the theory of phonology articulated in Chomsky & Halle (1968) allowed for a liberal interpretation of what kinds of information was available to phonological computation, including all kinds of morphological, historical, and phonetic information. One ambition of the work done in the post-SPE period was to restrict the power of the formal theory by, among other things, limiting the ways in which it could reference morphological information (see Scheer to appear(b)). However, the review of naturalness in §2.3 shows that not

only was phonetic information not subject to the same scrutiny, it was specifically given formal status in an effort to provide explanatory adequacy.

One effect of enshrining naturalness as a formal element was to give it status in *UG* itself, since what is in formal theory is by nature in *UG*. The result is a commensurate enlargement of *UG*, resulting in a rich structure and a suite of innate mechanisms used to describe individual languages or linguistic properties, such as the battery of markedness constraints typical of *OT*. From a biolinguistic perspective (see §1.2.1.1), the structure of *UG* itself demands explanation: why does language have the properties it has? Richly detailed structures such as naturalness constraints which are attributed to *UG* must be instantiated in human brains, and have neurobiological correlates. They must be the result of selective pressures resulting in their evolution. There must be some *reason* for them to be included in *UG*, lest they be reduced to mere stipulations.

Chomsky (2005: 8) points out that the more varied and intricate a theory is, the more difficult it is to present a reasonable account of why that theory is the way it is. In a counter-current to the ever-increasing complexity of *UG*, Chomsky (2007) suggests that another way of conceptualizing *UG* is to approach it “from below”, by seeking to account for the variety of linguistic patterns with as little machinery as possible being attributed to *UG* itself. This “bottom-up” approach is known as the minimalist program (see Boeckx 2015b; Chomsky 1995, 2002a; Mobbs 2015). *UG* *qua* natural object—a mental organ—is a biological entity with an evolutionary history (Rizzi 2004). Chomsky (2002a: 92) maintains that minimalism is a program, rather than a theory *per se*. That is, “there are minimalist questions, but no minimalist answers, apart from those found in pursuing the program.” The principle question asked by minimalism is *why language is the way it is*, by discovering the minimal conditions under which it can be described. As such, the minimalist program provides a regulatory framework which constrains the development of a theory, but does not constitute a theory alone (Boeckx 2015a: 493).

The primary ambition of the minimalist program is to “go beyond explanatory adequacy” (Boeckx & Piatteli-Palmarini 2005; Chomsky 2004; Rizzi 2016), that is, to ask *what* the properties of *UG* are, but also to explain *why* *UG* has the properties it has, instead of being built in some other conceivable way. Adopting minimalism means examining formal tools through the lens of explanation: is a given tool or mechanism *ad hoc* or does it have a principled explanation that can be derived from biology? The pursuit of explanatory principles in *UG* design means the minimalist program adheres to a strict Galilean approach to theory construction in that nature is best described according to the most simple principles Boeckx & Piatteli-Palmarini (2005: 456). This is an application of the principle of Occam’s razor: elements of explanation are not multiplied unless necessary (see Odden 2013, 2020). In turn, a theory of *UG* consists of the *minimum* number of primitives needed to describe attested grammars (Hale & Reiss 2000a: 176).

A complete account of phonological patterns involves, then, a theory of the formal grammar that reflects speaker competence, as well as those extra-grammatical factors that impinge on performance and do not need to be accounted for in the formal grammar. In this view, **UG** is an innate biological structure built by the human genome and common to the species; its basic properties are a product of nature. However, nurture has a role in the exact structure and expression of any I-language built out of **UG** endowed primitives. Further, whatever the structure of **UG**, it must be “sufficiently sparse” to plausibly be the result of a sudden, recent event in the evolution of *Homo sapiens* (Chomsky et al. 2019: 230).

Following Chomsky (2005) an application of Occam’s razor to develop a “sparse” architecture of **UG** differentiates between three factors contributing to a full explanation for linguistic patterns:

1. Genetic endowment; that which is specific to the cognitive module which interprets linguistic experience and determines the development of **FL**.
2. Experience; the particular linguistic environment and stimuli experienced by the learner.
3. Principles not specific to **FL**.

This “third factor” consists of a number of disparate subtypes: general cognitive principles of data processing that could be marshaled by **FL** such as categorization, and principles of structural architecture and developmental constraints, including principles of efficient computation (Chomsky 2005: 6).

In turn, Rizzi (2016) points out that explanation “beyond explanatory adequacy” can be found in each factor, only one of which being **UG** itself, given that functional factors are relevant to the form of language (see Golumbia 2010 for discussion). Haspelmath (2004: 565) argues, in fact, that language structure is primarily constrained by functional factors, rather than **UG**. The minimalist program’s emphasis on a bottom-up conception of **UG** means that formal mechanisms meant to confer explanatory adequacy—for example naturalness in the form of constraints or markedness—have a potentially extra-grammatical ontology. The third factor lies both outside of **UG** and outside of individual experience, in facts about human articulatory biology, human perceptual biology, the nature of sound wave propagation in air, and so forth.

Emphasis on the third factor means that explanation for possible patterns can be given in the starkest terms possible. The set of possible languages can be circumscribed without recourse to **UG** itself—there can be no language spoken at too high a pitch for humans to hear, for example. Haspelmath (2004: 565) in turn suggests that possible languages which are unattested may just be very “user unfriendly”, for example a language with eight labial and sixteen dorsal consonants but no coronal consonants could in principle be acquired and used, though it would pose significant useability problems.

As noted by Reiss (2007: 58-59), logically there are a minimum number of things that must be true about a possible language, (157):

- (157) A possible language *must*:
- (i) Be acquirable from the evidence presented to a learner
 - (ii) Not overload the processing capacity of human brains
 - (iii) Be able to be presented to the language faculty via the perceptual and articulatory systems

What is crucial to note is that all three minimum requirements in (157) lay outside of a theory of phonology *qua* computation. Considering **UG** from the bottom-up means conceptualizing phonology as being non-teleological, without ease of articulation, without ease of perception, without markedness and without naturalness. This brings several advantages, notably simplifying acquisition and drastically simplifying the architecture of **UG**. A symbolic formal grammar, with all notions of phonetics excised is in-line with the modular model of cognition discussed in §1.3. In biolinguistic terms, this entails a more plausible evolutionary history (Samuels 2015).

What is left in **UG** after third-factor explanations then are the minimally sufficient tools for generating attested phonological patterns unique to phonological computation. By determining the minimal structure needed for phonological computation, the properties of **UG** related to phonology can be elucidated. In turn, the set of possible phonological grammars can be predicted—if **UG** can generate a language, it is a possible language; if **UG** cannot generate a language, it is an impossible language. The third factor is the key to resolving Anderson's paradox: naturalness does creep into grammar, but it comes from outside of **UG** in third-factor effects.

4.3 TOWARDS A RESOLUTION OF ANDERSON'S PARADOX

4.3.1 *Explanation and the third factor*

As discussed in §4.1, naturalness as a formal tool faces empirical and conceptual issues which undermine its explanatory value; from a minimalist perspective, naturalness and by extension markedness are not valid formal mechanisms. Anderson's Paradox, however, recognizes the preponderance of phonetically natural patterns in the typological record. The putative loss of generalization argument, however, need not be invoked, since not every generalization is a product of grammar (Embick 2010: 119f.).

The explanation for phonetic-naturalness effects in typological distributions then may lie in third factor effects, rather than within **UG**—meaning that naturalness has no role to play in formal theory itself. In contrast to theories which explain naturalness effects through recourse to **UG** imposed constraints, a minimalist-inspired theory derives phonetic naturalness effects from outside the grammar. In this view,

explanation for typological distributions does not come from formal naturalness or other “top-down” deductive constraints. Rather, explanation is derived from the third factor and emerges from the nature of the independently motivated synchronic grammar.

4.3.2 *Channel bias*

Concerning naturalness effects there exists an avenue of third-factor explanation in what [Moreton \(2008\)](#) calls *channel bias*: language transmission and acquisition may be subject to systematic errors which result in differences in representations between what speakers *do* and what learners *hear*. Channel bias is an extragrammatical artifact, the effect of acoustic, articulatory, and perceptual facts that lay outside the domain of phonological cognition. One of the principal kinds of channel bias is in the phonetic precursors that accompany the physical manifestation of linguistic sounds; for example the phonetic nasalization of vowels preceding nasal consonants. Phonetic precursors are automatic effects of articulation that can potentially be exaggerated by speakers and reinterpreted as being phonological, resulting in their grammaticalization (§4.3.3). These automatic artifacts of the mechanical act of speech production constitute a major extra-grammatical explanation for typological patterns: typology reflects the effect of channel bias as phonetic precursors are likely to be reinterpreted as phonological processes. As concerns crazy rules, these common patterns may either be more likely to be innovated, or survive better when transmitted between generations ([Moreton 2008](#): 83). Naturalness thus is brought into phonology through grammaticalization of natural phonetic processes.

Channel bias provides an explanation for phonetic-naturalness effects in synchronic phonology without making appeal to functional biases within grammar. Instead, phonetic naturalness is induced into phonology through diachronic evolution; phonetic precursors common to all human beings usher in recurrent phonological patterns through normal language change ([Anderson 1981](#); [Blevins 2004, 2009](#); [Hellberg 1978](#); [Hyman 1976, 2001](#); [Stausland Johnsen 2012](#); [Vaux 2008](#)). Channel bias explanation has been used to argue for the extreme view that there is no synchronic grammar at all—sound patterns are mostly reduced to phonetics ([Ohala 1974](#)). [Ohala](#) argues, for example, that the recurrent pattern of devoiced coda obstruents does not require encoding in synchronic grammar since its phonetic explanation lies outside of linguistic competence. The Evolutionary Phonology program ([Blevins 2004](#)) argues that all typological patterns are the result of the way normal sound change proceeds: change is steered by phonetics, proceeds along common paths, and results in recurrent typological patterns. In this view, very little in phonology is innate, and there are no phonological universals, only tendencies, some of which are simply more likely than others.

Evolutionary Phonology and any theory for which unattested patterns are just accidental gaps makes no predictions about impossible

languages: nothing in UG prevents a storable phonological pattern from being discovered somewhere in the past, present, or future (recall the remote island argument from §4.1.2.2). In this view, the only predictions about impossible languages are based on the intuitions of linguists. For example, while Hale & Reiss (2008) argue that reference to prime numbers is unavailable to UG (§2.1.3), Scheer (2019b) points out that Hale & Reiss are stipulating what lies outside the scope of UG based on a wish (see also Kiparsky 2008b and Kiparsky 2008a). Moreton (2008: 87) argues that theories which are flexible enough to admit crazy rules also admit many unattested processes, and cannot be used to make predictions about possible and impossible languages.

In contrast, the virtue of a theory with systematic gaps is that it makes predictions about what kinds of languages are possible and what kinds are impossible (this is the ambition of Archangeli & Pulleyblank 1994, for example). This means that a desideratum of a theory of phonology is a way to distinguish between putative accidental and systematic gaps, such that predictions about possible languages can be made. Scheer (2019b) argues that the Popperian solution is to make analyses maximally restrictive by considering all gaps to be systematic until evidence can be brought to bare that falsifies that assumption. Scheer suggests that accidental gaps are chaotic in nature, making no sense according to any descriptive devices or operational criteria. In contrast, systematic gaps will make sense when viewed through the lens of some well-established principle of phonology. In this view, systematic gaps are likely to emerge from independently motivated formal properties, while accidental gaps will receive no coherent description or explanation within the grammar.

An example of an accidental gap can be found in Barnes (2006: 19ff.), who makes a typological observation regarding unstressed vowels. Unstressed vowels are frequently subject to a pattern of alternations known as *vowel reduction* which results in neutralization of contrastive vowels. The overwhelming majority of vowel reduction patterns result in the loss of height contrasts, although nasalization and quantity contrasts may also be targets. Barnes notes, however, that contrasts based on other articulatory configurations, including palatality, roundness, ATR/RTR, or pharyngealization—features operative in patterns of vowel harmony—never seem to occur. Barnes argues that this asymmetry demands an explanation. One possible analytic solution is to suppose that something in UG, perhaps a markedness constraint, prevents vowel reduction from targeting roundness; in this case, the fact that vowel reduction never results in the loss of roundness contrasts would be a systematic gap.

However, the gap in vowel reduction patterns is chaotic in the sense that attested patterns of vowel harmony target an arbitrary subset of articulatory features including height and nasalization. Palatality, roundness, ATR/RTR, and pharyngealization also constitute a subset of articulatory features which in purely formal terms are indistinguishable from the features targeted by vowel reduction. In this sense unattested patterns of vowel harmony are gaps which make no sense on the basis

of any primitive aspect of phonological description. In order for the attested asymmetry to be the result of grammar, some intrinsic quality related to vowel reduction must be assigned to height and nasalization, at the expense of other phonological features. The division of the set of articulatory features into features targeted by vowel reduction and features immune to vowel reduction would thus be stipulative. The same objections to other markedness constraints apply: what evolutionary pressures resulted in grammar distinguishing between different articulatory features in such a specific way?

Channel bias provides an alternative explanation. Barnes (2006) argues that the preponderance of height contrast neutralizations in vowel reduction patterns is a product of phonetic properties inherent to those systems. The first relevant observation is that vowel reduction tends to be concurrent with durational asymmetries between stressed and unstressed syllables; in languages with vowel reduction, stressed syllables are categorically longer in duration than unstressed syllables. This imposes what Barnes calls *durational limitations* on vowels in unstressed syllables—there is less time to articulate vowels in unstressed syllables and thus articulatory movements are abrogated. As a result the articulation of each individual vowel takes place in a less expansive vowel space relative to stressed syllables. This reduced vowel space leads to spectral overlap of unstressed vowels at the same time as listeners have a shorter time to identify any given vowel.

In consequence, vowels which are merged tend to already share vowel space, which become more difficult to discern as that vowel space is reduced. Barnes (2006: 30) argues that vowel height in particular is reduced as the vowel space shrinks, meaning that it is the height contrast which is the most likely to be neutralized. On the other hand, frontness/backness, roundness, ATR/RTR, and other articulation based contrasts are less likely to be affected by reduced duration. The gap in vowel reduction properties can thus be explained as a third-factor property of articulatory constraints imposed on speakers by durational contexts, rather than a systematic gap produced by phonological grammar; as such it need not be imputed to UG.

In contrast, a systematic gap makes sense in that it falls out from independently motivated established principles of phonology. Recall the example of vowel harmony in Halh Mongolian and in Hungarian (§2.1.3). They are natural in the sense that good principles of articulatory and perceptual phonetics can be marshaled to provide explanation for the attested patterns: vowels in a domain are all round, or back, or pharyngealized and so on because this involves less overall movement of the articulators. Most harmony systems operate in terms of well-motivated phonetic principles (Anderson 1980); how a sound is realized is after all a function of articulatory factors. In this light, the absence of any reported pattern of length harmony is surprising, since there is no known articulatory or perceptual reason that length harmony should not occur as frequently as other kinds of harmony; in fact a process of length harmony resulting in a stable length throughout a string would reduce the need for computing length. In short, this gap cannot be explained

through recourse to channel bias effects—particularly since length is itself phonetically salient and makes a robust phonetic precursor.

It is possible, in principle, to simply say that something in the theory bars length harmony—an explicit constraint against length harmony. An alternative is that length harmony is impossible because the formal machinery of phonology simply does not produce such a pattern. Such a system, when faced with potential evidence for length harmony, would be unable to grammaticalize it as a phonological pattern. In this case, the absence of length harmony is a property of how phonology is instantiated in human brains, and constitutes a systematic gap (I will discuss this further in §4.4.3).

This conclusion is based on a principled operational criterion. Attested vowel harmony patterns always involve some articulatory factor: roundness, height, backness, ATR, and so forth. In contrast, length harmony concerns the *temporal* properties of segments, and thus lie in an entirely different realm of description. This distinction is recognized in any theory of phonology with a timing tier (Clements & Keyser 1983; Clements 1986; Goldsmith 1990; McCarthy 1981a; Prince 1984). Unlike attested patterns of vowel reduction, and vowel harmony where the set of concerned features is an arbitrary subset, temporal properties may in principle have an entirely different kind of representation (this will be formally established in §4.4.2). Thus, given the consensus about autosegmental structure where melody and timing units are different in kind, length harmony is a plausible candidate for a systematic gap.

4.3.3 *Diachronic explanation*

The first part of Anderson's Paradox is an echo of the long-standing observation that much of phonology is easily described in phonetic terms. As discussed in Chapter 2, this has led to formal devices that recapitulate natural patterns in the formalism, while barring unnatural patterns from the realm of phonology. These formal devices provide a source of synchronic explanation for the typology of phonological patterns, suggesting that all unnatural patterns are systematic gaps. The second part of Anderson's Paradox is a reminder that, as reflected in the census in Chapter 3, phonological patterns sometimes defy natural expectations, and that phonetic explanations are insufficient.

Even if formal naturalness is dispensed with as an explanatory device and expunged from phonological theory, the fact that so much of phonology seems to be natural still demands an explanation. However, as suggested by the channel bias account (Moreton 2008), this explanation may not come from the synchronic grammar itself, but instead be the result of influences coming from outside the grammar. If this is the case, then there is no need to provide the explanation in the theory of phonology. This does not, however, constitute a full explanation, since it provides no account for the relative scarcity of crazy rules in the typological record.

An explanation in the interplay between diachrony and synchrony is anticipated in the work of [Baudouin de Courtenay \(1870 \[1972\]\)](#) (see [Anderson 1985: 64](#)). In [Baudouin de Courtenay's](#) view, the origin of synchronic patterns lies in phonetic factors—a property of physics and physiology which can be integrated into grammatical systems. Patterns, then, are always related to natural physical and physiological properties, and constrain the kinds of alternations which can be expected to be found in linguistic systems. Variations on this *diachronic account of naturalness* have been argued for by [Bach & Harms \(1972\)](#); [Barnes \(2006\)](#); [Bermúdez-Otero \(2007\)](#); [Blevins \(2004\)](#); [Hyman \(1975\)](#); [Stausland Johnsen \(2012\)](#); [Kenstowicz & Kisseberth \(1977\)](#); [Scheer \(2015a\)](#) (see [Hansson 2008](#) for an informed overview). Here, the typological record is a reflection of tendencies in language change, which themselves tend to reflect phonetic naturalness ([Ohala 1974, 1992](#)), due to facts about human articulation and perception. Universal phonetic factors provide the initial motivation for phonological rules, meaning that descriptions of phonological rules will tend to recapitulate descriptions of their phonetic precursors and appear phonetically plausible, or natural ([Hyman 1975: 173](#)).

Crucial to the diachronic account of naturalness is the notion of *phonologization* ([Hyman 1976, 2008](#)), whereby an intrinsic, contextually conditioned byproduct of human articulation becomes an extrinsic property of human cognition as part of a phonological grammar. In phonologization, phonetic precursors—either articulatory or acoustic—become reanalyzed by language learners as allophonic alternations. For example, if gradient phonetic nasalization of vowels preceding nasal consonants is perceived as exaggerated and an effect of assimilation rather than phonetic co-articulation, learners will be said to have phonologized nasalization of vowels preceding nasal consonants when they realize vowels with categorical allophonic nasalization. Since the intrinsic aspects of speech production are by nature phonetically natural, this results in phonologization preserving their natural aspect, at least in descriptive terms.

Inherent in the change from gradient phonetics to categorical phonology is the commensurate change from physical to symbolic; once a pattern passes beyond the veil and comes under the purview of phonology, it is a purely cognitive object. Since a given pattern has, at the time of its inception, a phonetic motivation, it will mirror that phonetic motivation. However, given the nature of the modular hypothesis (§1.3), phonological computation does not communicate with the phonetic module except for at the interface when transduction occurs—there is, as such, no actual phonetic information in a phonological pattern, no matter how seemingly natural. The result is that phonology is not responsible for any reflection of phonetic naturalness: it produces phonetically unnatural patterns as easily as phonetically natural ones.

This conceptual distinction of a modular system with physical, natural phonetic effects and symbolic, abstract phonological operations is the first part of a solution to Anderson's Paradox: why are so many phonological patterns phonetically natural? The answer is that the func-

tional exigencies of speech production and speech perception influence the nature of sound change as a function of phonetic precursors. Since phonetics never produces anything unnatural, nothing unnatural can ever be grammaticalized. Unattested patterns with no phonetic precursor are not phonologized. This does not mean, however, that they are impossible for the computational system to generate, only that they are unlikely to arise or be learned.

The discussion of vowel reduction in §4.3.2 can be used to illustrate how diachrony can give rise to accidental gaps in synchrony. In vowel reduction, the reduction in vowel space and consequent neutralization of height contrasts is an intrinsic property of the articulatory constraints imposed on speakers by the durational context, not a product of the phonological grammar; the phonetics and the phonology of a reduction pattern are initially distinct. This intrinsic property, however, can be perceived by learners as an intrinsic aspect of the realization of vowels in unstressed syllables and be phonologized.

Once phonologization occurs, the reduction of vowels in unstressed syllables is no longer an unintentional side-effect of the articulatory exigencies inherent in the context of reduced durations, rather it is a product of phonological computation. Since phonetic reduction is most salient along the dimension of vowel height, it is exactly that contrast which is lost when vowel reduction passes beyond the veil into phonology. Neutralization of frontness/backness, rounding, or ATR/RTR, being less affected by durational restriction, have less robust phonetic cues, and are correspondingly less likely to be phonologized. While unattested vowel reduction patterns are less likely to occur, since there is no robust phonetic precursor to be phonologized, they are not made impossible by UG.

4.3.4 *Diachrony can lead to craziness*

The diachronic approach thus provides an explanation for recurrent typological patterns of naturalness, while also allowing for the possibility of unattested, computationally possible languages; in short it overgenerates. In an approach which overgenerates in this way conventional rules and crazy rules have the same ontological status as far as the computational system is concerned. It requires no special formal machinery to provide a ready explanation for the preponderance of phonetically natural rules, while at the same time being perfectly capable of computing crazy rules. Nothing in this approach, however, explains how crazy rules come to be, and there is nothing in the computational system to suggest why crazy rules are rare relative to phonetically plausible rules, something that formal machinery weighted against crazy rules can explain easily.

The solution to this puzzle is to be found in diachrony and the modular bulkhead between phonetics and phonology. Crazy rules are derived from phonetically plausible rules by a sequence of individual diachronic steps, each of which may be phonetically natural but to-

gether can result in unnatural patterns in the grammar (Bach & Harms 1972; Beguš 2018b; Scheer 2015a). Since phonology is isolated from phonetic influence, once phonologized, the structural description of a phonological rule is no longer sensitive to the phonetic context at its origin—rules are no longer yoked to phonetic exigencies. If a further change to the target, trigger, or conditioning environment occurs, the rule may lose its natural description while continuing to operate (see Harris 2008 and Scheer 2015a).

4.3.4.1 *Telescoping*

Bach & Harms (1972: 18) suggested that one path for the development of crazy rules was through a diachronic process that resulted in the accretion of phonological changes in a rule:

[T]he fact that languages have plausible rules is, in our opinion, the result of strong naturalness constraints on the initiation of phonetic rules. These constraints are essentially diachronic and should not be incorporated into the simplicity metric. . . The existence of implausible rules can be shown to result in large part from the transmission and simplification of plausible rules.

Through time rules can become “denaturalized” (Hyman 1975: 173ff.). Hyman and (Kenstowicz & Kisseberth 1977: 64ff.) discuss a number of processes by which rules can lose their phonetic motivation. The first of which is known as *rule telescoping* (Wang 1968): when a sound change affects an already existing phonological rule such that its phonetic motivation is lost. Kenstowicz & Kisseberth (1977: 64) describe this process, when “in a language, A changes to B in the context X, and then later B changes to C, the result is that some A alternates with C. If there is no rule or context which changes A to B, there can only be a rule turning A to C.” While each diachronic stage reflects phonetic naturalness, the synchronic, telescoped rule does not, since the intermediate B has become irrelevant in the structural description of the rule.

As an example, consider the following description of Buriat, a Mongolian language, from Vago (1973). In Buriat, there is a process of vowel harmony whereby affixes agree in frontness and backness with stem vowels. Additionally, non-high vowels in affixes also agree with rounding in stems. The harmony system is exemplified in (158) for the affixes meaning ‘to’ (158a) and ‘on, at, in, to one’s own’ (158b) respectively.

- (158) a. axa-da ‘to the elder brother’
 modon-do ‘to the tree’
 xi:-de ‘to the dung dust’
 b. axa-da: ‘to one’s elder brother’
 modon-do: ‘to one’s tree’
 xi:-de: ‘to one’s dung dust.’

However, the harmony system in Buriat is surprising in that two stem vowels, [æ:] and [œ:], always take back non-round and round suffixes respectively, even though they are phonetically front.

- (159) a. æ:-da 'to the yurts'
 æ:-da: 'to ones' yurts'
 b. xo:lœ:-do 'to the throat'
 xo:lœ:-do: 'to one's throat'

(159a) and (159b) show that [æ:] and [œ:] behave as rounded mid-back vowels, since the suffix vowels are realized as back vowels, instead of the expected front vowels. Historically, Vago (1973) points out that [æ:] and [œ:] were the back diphthongs /aj/ and /oj/ respectively, for which the harmonizing vowels would be expected to be back. Diachronically, the diphthongs coalesced into singleton long vowels, realized phonetically front under the influence of the /j/ off-glide; phonologically however, their identity was unaffected and they continued to trigger back-vowel harmony. The result, if not entirely crazy, is certainly phonetically arbitrary. As such changes accrue diachronically, what begin as phonetically plausible rules can become crazy.

4.3.4.2 Rule inversion

A second process is through what Vennemann (1972) calls *rule inversion* (see also Hyman 1975: 176 and Kenstowicz & Kisseberth 1977: 65). An inverted rule results from learners inverting the structural description of a rule. If a rule changes A to B in context X, B may be reinterpreted as the underlying form, resulting in a rule turning B into A in environments other than X. The resulting rule may obscure the phonetically natural origins of the original rule.

An example is the "intrusive" [r] of Boston English (McCarthy 1991; Vaux 2002). In Boston English, /r/ is deleted in syllable codas, and inserted after low vowels preceding another vowel, which results in neutralization before consonants (160)

- (160) a. *spar* 'beam'
 the spa closed
 the spar is missing
 b. *spa* 'place to buy lottery tickets'
 the spa closed
 the spa[r] is closed

In this case intrusive [r] is the result of rule inversion (McCarthy 1991). Historically, a rule of [r] deletion operated as in (160a). The failure of the process to operate in 'the spar is missing' led to reanalysis of the pattern as a rule of [r] insertion, as in (160b). In other words, the rule $r \rightarrow \emptyset / _C$ led an analysis of 'spar' as /spa/, resulting in a rule $\emptyset \rightarrow r / V_V$. Vaux (2002) argues that the insertion of [r] is unexpected, since a more likely candidate for epenthesis would be a homorganic

glide or glottal stop (though see Broadbent 1991 for an argument that [r] is glide formation triggered by low vowels). In the view of Morley (2018), any consonant epenthesis is a rare process, emerging only from the accumulation of diachronic changes.

Dominican Spanish may represent an ongoing case of restructuring from rule inversion. In Dominican Spanish, an active synchronic process deletes lexical /s/ in codas (161):

- (161) /atraskos/ [atrako] 'delays'
 /moska/ [moka] 'fly'

The deletion of coda /s/ has become so wide-spread that some speakers, especially those with rural backgrounds, seem to have lexicalized at least some words with codas /s/ in standard varieties as being coda-less (Núñez Cedeño 1988; Núñez Cedeño et al. 2020; Terrel 1986). Speakers, knowing that standard varieties contain lexical items with coda /s/, sometimes insert /s/ into codas where none exists underlyingly in a hypercorrective register known as *fisno* (162)³:

- | | | | |
|-------|------------------------|-----------------|-----------|
| (162) | Dominican <i>fisno</i> | STANDARD | GLOSS |
| | <i>estúspido</i> | <i>estúpido</i> | 'stupid' |
| | <i>dipusta</i> | <i>disputa</i> | 'dispute' |
| | <i>dedes</i> | <i>desde</i> | 'since' |

Bullock et al. (2014) report corpus-data results showing that speakers do have knowledge of underlying /s/ codas, suggesting that complete restructuring has not been carried out. Nevertheless, it is clear that a rule inserting /s/ into codas has been innovated, and given that such a rule is an inversion of the rule which removed them in the first place, this represents a case of an ongoing process of rule inversion.

4.3.4.3 Morphologization

A third process through which phonological rules can become unnatural is through what Hyman (1975: 175) refers to as *morphologization*⁴. In morphologization, a rule is reinterpreted as being conditioned by a particular grammatical category. German Umlaut is a classic example (see §1.3.2.3). The plural for the word *Gast* [gast] 'guest' is *Gäste* [gɛstə], whereby [a] becomes [ɛ]. Historically, the plural marker was [i], and triggered allophony in the preceding stem vowel. The plural vowel was eventually reduced to [ə]: *gasti* > *gɛsti* > *gɛstə* 'guests'; the alternation can only be stated synchronically in morphological terms.

While morphologization is a process by which rules become more deeply embedded into the grammar and eventually lose their phonological status, both rule telescoping and rule inversion can result in perfectly active synchronic processes which are phonetically unnatural;

³ Data from Núñez Cedeño (1988: 322).

⁴ Or what Kenstowicz & Kisseberth (1977: 74) call *grammaticalization*.

in short, they can give rise to crazy rules⁵. Though phonological rules are born natural, through a series of cumulative, individual diachronic changes, they can lose their phonetic mooring and become crazy. Crazy rules are not synchronically any different from natural rules, since both can be reliably computed by phonology. Ontologically, crazy rules have the same status as natural rules, but they are comparatively more rare only because they are the fruit of a rare bloom which requires a complex and unlikely—but not impossible—historical evolution.

4.3.5 *The life cycle of phonological rules*

It might be expected, given the multiple possible paths by which a crazy rule can come into existence, that they should be even more prevalent in the typological record. If crazy rules were, for example, less stable than phonetically plausible rules then such an observation could be marshaled as evidence against their equal ontological standing; in this view, diachronic changes can give rise to crazy rules, but biases in synchronic grammar render them unstable and susceptible to reanalysis or leveling. In fact, all rules are unstable in a sense: Janda (1987: 61) argues that phonological alternations have a life cycle (see also Bermúdez-Otero 2007, 2015): they begin as mechanical, non-phonological processes, undergo phonologization, and then pass out of phonology as they become subject to morphological conditions. Finally, they may become isolated lexical correspondences entirely out of grammatical control, recoverable only by etymologists. This stage marks the “death” of phonological rules, as they return “in a sense, to nothingness” (Janda 1987: 70f.). The life cycle is as much a fact of crazy rules as of phonetically plausible rules.

The life cycle of phonological rules predicts that a phonological process is not an immutable operation carried out in isolation, as formal synchronic rules may suggest, but that it is embedded in an evolving grammatical system, undergoing a series of changes as language evolves. Just as a phonologized process becomes isolated from its phonetic precursor, a rule that moves “up” in the grammar (by a process Bermúdez-Otero 2015 calls *rule scattering*) may come under the influence of morphological factors. Rule scattering results in a tendency for older phonological processes to apply in more restricted domains as they move up in the grammar. Crazy rules, being at the “mid-life” stage of the life-cycle, have been exposed longest to the processes which drive rule scattering and are more likely to be moved up in the grammar than freshly-grammaticalized phonetically plausible rules to which no further diachronic changes have applied. These tendencies, however, are not inherent properties of crazy rules which are not shared by phonetically plausible rules, but rather, as argued by Bermúdez-Otero (2015), epiphenomena of the life cycle which do not require synchronic explanation.

⁵ Blevins (2004, 2008a,b) argues that analogy and language contact also produce crazy or arbitrary patterns.

4.3.6 *Language change, craziness, and isolated languages*

Finally, the diachronic account also offers an explanation for the overrepresentation of small, isolated languages with fewer speakers in the census of crazy rules in Chapter 3. [Nettle \(1999\)](#) argues that language change does not proceed at the same rate across space and time. Rather, language change spreads faster in small communities relative to large communities where usage and sheer exposure to unchanged structures impede the spread of innovation. According to the notion of “linguistic equilibrium” in [Dixon \(2007\)](#), diachronic evolution is characterized by long-term stability and isolation during which language transmission proceeds primarily from adult to child with virtually no L2 transmission. Such circumstances “produce long—generally centuries or even millennia—periods of uninterrupted language change”, ideal conditions for the sorts of diachronic developments—i.e. rule telescoping and rule inversion—that lead to “mature phenomena” ([Trudgill 2012: 91](#)).

[Trudgill \(2012\)](#) identifies a number of social factors which he considers to be complexity producing, including small size, dense social networks, large amounts of shared information, high stability, and low contact. In speech communities with these characteristics, complex changes can develop, spread, and be sustained from generation to generation. In contrast, languages which are subject to extensive contact with foreign languages through trade, the movement of people, a centrally imposed standard, and so forth, are acquired by adults with a concurrent simplification of complex structures—conditions which disfavor both innovations which lead to crazy rules and crazy rules themselves (see [Trudgill 2011](#)).

The diachronic explanation of phonetic naturalness provides several advantages over naturalness theories which derive explanation from the grammar itself. First, it does not suffer from the empirical and conceptual pitfalls inherent in theories of synchronic naturalness and markedness—in fact it is entirely agnostic to them. It also respects the modular bulkhead established between the physical realm of gradient, continuous phonetic phenomena and that of the symbolic realm of categorical phonology. Most importantly, not only does it provide a ready explanation for the large distribution of phonetically plausible rules attested in the typological record, but it also accounts for phonetically unnatural patterns, such as arbitrary patterns and crazy rules, without positing any *ad hoc* theoretical machinery. Finally, it is in line with the tenets of minimalism, since it appeals to third-factor explanation and thus demands less of the architecture of [UG](#) in generating attested patterns. In short, it redirects the remit of phonological theory to the computational system of phonology itself by placing the responsibility for typological distributions outside of grammar.

4.3.7 *Analytic bias*

Recalling the discussion in §4.3.2, in which some systematic gaps are argued to be due to third-factor phenomena, a further source of systematic gaps is what Moreton (2008) refers to as *analytic bias*: cognitive biases which inhibit the learning of some patterns while facilitating others. Formal naturalness represents a classic case of a proposed analytic bias, being one of the principal ways of explaining patterns of typological distribution in some phonological theories, and has been the subject of a voluminous literature seeking to show its effects (see Chapter 6). Any relative constraint (§2.3), in the sense of Kiparsky (1972: 191f.)—including the synchronic explanation of de Lacy & Kingston (2013), markedness constraints, and naturalness theories which impose specific constraints on grammars—is a kind of analytic bias. Analytic bias may also include extra-grammatical cognitive biases such as general pattern recognition and analogy.

To illustrate an example of extra-grammatical analytic bias, consider the experimental results presented in Moreton (2008). Typologically, patterns of height harmony (HH) between two vowels are more frequent than patterns of height-voice (HV) harmony where voiced consonants cause vowels to raise. Moreton argues that despite the typological asymmetry, there is no difference in the magnitude of the phonetic precursors associated with each pattern, which are robust. In a series of experiments, Moreton showed that the HH pattern is more easily acquired by learners than the HV pattern, reflecting the typological asymmetry⁶.

Moreton (2008: 117) asks a crucial question regarding this learning bias, to wit: “[w]hat is the specific content of the analytic bias responsible for the HH/ HV asymmetry?” In any theory with formal naturalness biases, the content of analytic bias can be reduced to whatever specific formal tools are tailored to account for learning and typological asymmetries. However, as discussed, from a minimalist perspective such solutions demand a further explanation: why should phonology have a bias for HH harmony over HV harmony?

Another explanation is one that does not have to be specifically encoded in the grammar for specific cases, but that can be applied globally and emerges from the independently motivated nature of phonological features: in terms of features, HH harmony represents a F_1F_1 configuration in that a single feature is implicated in the harmony pattern, while HV harmony represents a F_1F_2 configuration, in that two different features are implicated in the harmony pattern. In other words, the computational system is more likely to recognize a harmony pattern that refers to a single feature than a harmony pattern that refers to two different features. From this point of view, the learning bias is a bias for

6 Kimper (2017: 31) argues, based on experimental evidence, that vowel harmony “confers a perceptual advantage,” meaning that analytic bias may not in fact be at play in this asymmetry. Indeed, Yu (2011: 513) argues that Moreton’s method of evaluating relative phonetic precursor robustness is inadequate, and that ultimately “irrefutable evidence for analytic bias remains elusive.”

less complex phonological rules, not a product of a constraint favoring HH harmony or disfavoring HV harmony.

The bias for HH harmony may be an artifact of a general bias in the cognitive system for formal simplicity—a rule manipulating one feature is easier to learn than a rule manipulating two features (see §6.1.2). In this case, there is no need for a specific formal bias against HV harmony to establish the asymmetry, since it falls out from general properties of cognition. If the bias for HH harmony can be derived from third-factor explanation, this makes it conceivable that other cases of bias do not need an explanation in the grammar. Biases may be derived from general principles of cognition; explanation for impossible languages, in turn, is derived from the absolute constraints (§2.3) inherent in the specifically linguistic system.

That is, there *is* analytic bias (see Lai 2015), but analytic bias within grammar itself does not have to be in form of top-down constraints, rather the bias can fall out from the shape of the formal system itself, inherent in general principles of grammar. For example, the apparent systematic gap in patterns of length harmony may be a reflection of there being no computational process that can harmonize timing slots. In this sense, UG itself is a kind of analytic bias, in that it allows the learning of possible languages and prevents the learning of impossible languages.

If UG does not generate length harmony, it will not do just to stipulate that length is a different kind of feature from, for example, roundness, and then mark length as unharmonizable in the grammar, for example with a markedness constraint. Rather, however length is represented, we should expect it to be different in kind from features, since the latter harmonize freely while the former do not, a fact that should emerge from the grammar. If the process responsible for harmony patterns is sensitive only to features, and does not operate over whatever kind of object length is, then the reason there are no attested length patterns falls out naturally from the formal system.

The next section will outline a program of inquiry that accounts computationally for crazy rules, while demonstrating how the formal primitives provided by UG can give rise to systematic gaps—in this case length harmony—with no markedness, no constraints, and no naturalness.

4.4 THE SUBSTANCE-FREE PROGRAM

4.4.1 *No phonetics in phonology*

Thus far I have argued that phonology is a component of mind, a CR system that operates over symbolic contrastive units known as features. The census of crazy rules in Chapter 3 suggests that phonology is unbounded by naturalness. In turn, §4.3 argues that there are no substantive elements in the computational grammar itself—typological patterns are the result of functional effects operating in diachrony. I

have argued that the absence of patterns of length harmony from the typological record constitutes a true systematic gap; a language with such a pattern is an impossible language.

The task of phonological theory, I argue, is to provide an explanation for the properties of possible languages through investigation of the nature of representations and computations which underlie them, such that the properties of impossible languages fall-out from the nature of those representations and computations with no additional stipulations. The purpose of this section will be to briefly examine the nature of those representations and computations and how they interact with the interface between phonetics and phonology.

As seen in §1.1.3.1 and §2.3.3, much of phonological theorizing since SPE has tightly linked phonology to phonetics, and imbued much of phonology with substantive properties that make direct reference to the physical world of phonetics. In sharp distinction to this substance-laden view of phonology, the principle claim of Substance-Free Phonology (SFP) (Blaho 2008; Hale & Reiss 2000b,a, 2008; Iosad 2017; Odden 2006; Reiss 2003, 2008, 2018; Samuels 2011; Volenec & Reiss 2017, 2020) is that there is no phonetics in phonological computation. In this view, there is nothing labial in the phonological notion of *labiality*—phonological features are symbolic counters that can be freely manipulated by the computational system. SFP is a research program in the sense of Kuhn (1962): rather than being an explicit theory, it lays out a set of hypotheses and principles by which a theory can be constructed.

While there are a number of different approaches to details of the SFP approach (see Blaho 2008: 8ff. for discussion), all share a number of basic assumptions which are in line with the minimalist conception of phonology developed in this thesis. The principal trait is a commitment to a metatheoretical approach to phonology which Odden (2013) calls Formal Phonology (FP); that is, rather than beginning with a body of technical claims about the nature of grammar, FP embodies an epistemology which advances hypotheses regarding phonology based only on what is known. Any claim about the nature of grammar then follows from the methodology of FP and facts about language, but do not constitute axiomatic stipulations of the theory. In the most simple terms, the SFP approach is an investigation of the formal properties of phonology (Hale & Reiss 2000a; Reiss 2003); that is to say, an investigation of the properties of the representations and computations which underlie phonology (Hale & Reiss 2000b).

Pre-theoretically, the SFP program sees phonology as a universal, innate, and modality unspecific system of symbolic computation—an aspect of I-language. Being modular in nature, phonology is distinct from phonetics, and phonetic information does not play a role in phonology; phonological features are “substance free”, containing no articulatory or acoustic information. Since phonology is blind and deaf to outside information, phonological computation is non-teleological and carried out ungirdled by naturalness, which is a nonsensical notion within phonological computation.

In this FP perspective, a phonological theory should not account for every true generalization about phonology (Reiss 2018: 425). Since the emphasis of SFP is insight into the computational system of phonology, facts about physical entities such as sound waves, the physiology of articulation, and so forth are extraneous to the symbolic properties of computation (Hale & Reiss 2008; Reiss 2008). As in the diachronic view of naturalness, facts about typological probabilities are epiphenomena whose explanation lies outside of phonological grammar. Thus, probabilistic typological distributions and other markedness phenomena are outside the remit of phonological theory; they are the products of performance rather than competence.

Any explanation for patterns of naturalness, derived from diachronic trends as well as the putative substantive properties of phonological representations and the way those properties interact with the computational system, is a duplication of explanation and violation of Occam's razor. Reliance on the substantive properties of phonological representations and how they limit or restrict the computational system is an example of what Hale & Reiss (2000b, 2008) call "substance abuse". When an extra-grammatical account provides explanation for a given pattern, using phonetic properties to duplicate an explanation not only needlessly bloats the theory of synchronic grammar, it also obscures the nature of the object of phonological inquiry: the formal core of phonology. Reiss (2008: 301) argues that, in this view, *a priori* notions of what rules "should" be like prevents empirical investigation into how rules actually are. An observation that some non-occurring pattern is phonetically implausible is not an observation about phonology itself but about factors outside of phonology which disfavor the inception of that pattern.

The view that typological patterns of phonetic naturalness are a reflection of performance obviates the need for markedness or other forms of formal naturalness. Since languages can vary in arbitrary ways—e.g. the segments produced by epenthesis processes—phonological grammar must be in part arbitrary (Hale & Reiss 2000b). In other words, phonological theory must allow for variation and describe a computational system with a set of primitives that is not predetermined to yield particular results, but that can be altered in accordance with the evidence a child encounters while learning a language.

In line with FP, any theoretical device meant to synchronically explain an LSG is an object which exists and can only be attributed to UG after any other potential source of explanation has been exhausted; it should explain "a persistent and otherwise inexplicable consistency in languages" (Odden 1988: 461). Blaho (2008: 8) argues that patterns resulting from UG do so as emergent phenomena, the product of independently motivated properties of representations and computations. In this view, all constraints are absolute, in the terms of Kiparsky (1972). As such, markedness constraints are not a reflection of anything actually in UG, and do not belong in a theory of phonology (Reiss 2008). With no markedness or other relative constraints, near-universals, or strong typological tendencies, do not constitute LSGs for which phono-

logical theory is responsible; in *SFP* a rare or phonetically implausible rule $D \rightarrow T / V_V$ is as natural as the phonetically plausible $T \rightarrow D / V_V$.

Recalling the set-hierarchy in (11) described by Hale & Reiss (2008: 3), the remit of phonology is possible languages. In order to predict the properties of the set of possible languages, however, there must be a method of establishing which absolute universals are within the remit of phonological theory, such that the properties of impossible languages can be predicted. For example, an absolute universal is the fact that there are no pharyngeal nasals—this does not constitute a fact about phonology however, since it is a mere fact of anatomy. The greater our understanding of the computational system of phonology, the better our predictions about possible and impossible languages will be.

4.4.2 *Substance-free representations*

In *SFP*, the primitive unit of phonological representations are features (see §1.1.3). Since the introduction of features, phonology and phonetics have been intertwined. In canonical generative theory (Chomsky & Halle 1968), features have an articulatory label such as [voice] and a value for that label \pm . Theories have taken different stances on just how phonetic correlates are encoded, Jakobson et al. (1952); Jakobson & Halle (1956) viewed features as being primarily acoustic in nature, while Chomsky & Halle (1968) cast them as being articulatory. The principle difference between these theories and *SFP* is that substance-free features have no intrinsic content whatsoever: they are neither articulatory nor acoustic in nature⁷ (Hale & Reiss 2000b, 2008).

In part this is because it is not clear that contrasts based on features are expressed phonetically in a one-to-one fashion (Fudge 1967; Ladefoged 1971). Acoustic cues can be created with more than one articulatory configuration (Halle 1983; Hamann 2004; Ladefoged 1980), meaning that the expression of a feature can happen in more than one way so long as its role as a contrastive unit in a system, or as a natural-class marker, can be carried out. For example, the feature [\pm voice] may serve to distinguish between [p t k] and [b d g], and to unite [b d g v z] in a natural class, but there are several ways for voicing to arise phonetically (Avery & Idsardi 2001; Boersma 1998; Honeybone 2005a; Iverson & Salmons 1995). Any contrast built on a feature [voice], then, is not in a fixed relationship with a single articulatory configuration, meaning that a given contrast does not depend on any specific phonetic correlate (Ohala 1992).

Substance-free features are purely symbolic counters with no intrinsic phonetic content: $\{F_\alpha F_\beta F_\gamma \dots\}$. Expression of substance-free features as phonetic objects happens only after transduction at the in-

⁷ This is not without precedence: Fudge (1967: 26) argued that “phonologists (above all, generative phonologists) ought to burn their phonetic boats and turn to a genuinely abstract framework.”

terface. In computation their only property is Saussurean: each one is different from every other, and their function is to represent contrasts and to unite natural classes (Dresher 2009). Regarding valency, the binary view of melodic primes in generativism is widespread though not unanimous; primes that are privative in nature have been proposed (Backley 2011; Harris & Lindsey 1993; Kaye et al. 1985) (see van der Hulst 2016 for an overview of the various arguments for and against bi- and monovalency). I adopt the FP view that features are privative, though nothing crucial to this discussion hinges on this decision (see Lombardi 1995 for discussion).

4.4.2.1 *Substance-free natural classes*

Natural classes regroup the targets or triggering segments of a phonological rule and are defined by some feature *F* shared by all members of the class. However, as elsewhere in phonology, the criteria by which natural classes are to be established has been subject to debate. In the classic view articulated by Chomsky & Halle (1968), natural classes could be constituted by the substantive properties of the segments in them. A class [i y u] could be immediately identified as sharing the feature [+high], since each member is a high vowel.

In the SFP literature, the view that phonological computation is phonetically arbitrary is consensual. However, when it comes to the nature of phonological features and their phonetic exponence, there are two incompatible positions. The first position, defended in Hale & Reiss (2008) and extensively argued for in Reiss (2018); Volenec & Reiss (2017, 2020), sees features as objects with no phonetic substance within computation, but with a UG endowed link to phonetic exponence in the interface and drawn from a universal set. That is, that the exponence of phonological features is “lawful”, rather than being “random or arbitrary” (Volenec & Reiss 2020: 4), and as a property of UG does not emerge.

In this view, phonological features are imbued with substance during transduction. In the system argued for by Reiss (2018); Volenec & Reiss (2017), features themselves are symbolic objects in brains/minds that have neither acoustic nor articulatory correlates but that are linked to specific substantive cues by UG. That is, features cannot cheat destiny: [+labial] must be realized with specific neuromuscular correlates even if in phonology itself [+labial] does not mean anything at all, being invisible to computation except as a symbol which can be operated over.

The reasoning hinges on what Volenec & Reiss (2020: 17) call a logical argument based on a philosophy of rationalism: in order for learning to take place, the human mind must contain innate knowledge of basic units which cannot themselves be learned. This is the antithesis of the Aquinian Peripatetic axiom which says there is nothing in the mind which did not first pass through the senses, a kind of extreme empiricism. Instead, there must be some innate relationship between features and their phonetic expression. In this conception of phonology,

features look much like those of Chomsky & Halle (1968) in that they form a universal set with fixed phonetic correlates. Indeed, Volenec & Reiss (2020: 40) argue that in a language with [i y u], if there is a rule that refers to [i u], it must also apply to [y], since all three share the feature [+high].

This view of featural determinism was challenged not long after the publication of SPE, as when Wheeler (1972: 101), argued “decisions about which classes are natural should be taken first, and the features then supplied to cater for them, according to some concept of relative simplicity, rather than first to observe some physical property and then to conclude that all segments sharing that property form a natural class.” This view, although intended for Chomsky & Halle (1968), is just as apt where SFP is concerned. That is, it is not an inspection of surface properties which reveals phonological features; rather processes which share structural properties (identical structural descriptions or identical structural changes) are functionally united (Kisseberth 1970). Thus, a natural class can be defined through participation in a unified rule, which presumably targets a feature common to each member of the class.

Indeed, if learners or analysts relied on phonetic properties to determine the phonological identity of segments, there are good reasons to suggest they risk being led astray. While phonetic properties often correspond to phonological identity (i.e. *coronality* in a surface segment is a meaningful phonological category, constituting the basis for contrast or membership in a natural class), there are cases where the phonetic properties of a surface segment do not correspond to its phonological identity, as Clements (1999) argues is true for affricates. Examples of such *phonetics/phonology mismatches* (Hamann 2014) are frequent: fricatives that act like glides in Argentine Spanish (Harris & Kaisse 1999), a voiceless glottal fricative that acts like a non-laryngeal consonant in Yucatec Maya (Orie & Bricker 2000), a sibilant that acts like a vowel in Blackfoot (Goad & Shimada 2014), a sonorant that acts like a stop in Quechua (Gallagher 2019), a fricative [ð] that acts like a sonorant in Woods Cree (Starks & Ballard 2005). In all of these languages, there are segments whose phonological properties are belied by their phonetic garb.

Phonetics/phonology mismatches show that in some cases the phonetic properties of a segment are misleading in the discovery procedure of phonological identity. Logically, if this is the case for some segments, the analyst can never know whether any particular case is a mismatch or not. The lack of bi-uniqueness between phonetic properties and phonological identity means that phonological analysis cannot be conducted on the basis of surface properties, rather it must be done as a part of a systematic analysis of the entire phonological system. As Gussmann (2001: 242) puts it, “the phonological properties of segments are determined not only by an inspection of their phonetic characteristics but also by considering the way they behave in the system of a language. If there is a conflict between the phonetic and phonological clues, it is the latter that get the upper hand.” For Gussmann, phono-

logical behavior is the final arbiter in analytic decisions concerning phonological identity.

4.4.2.2 *The Phonological Epistemological Principle*

The primacy of phonology leads to *the phonological epistemological principle* in Kaye (2005: 283) (163):

- (163) *Kaye's Phonological Epistemological Principle:*
The only source of phonological knowledge is phonological behavior.

This is the way the discovery procedure must work in a SFP where features are not in a one-to-one relationship with phonetic expression, and phonetic properties cannot be used to predict the phonological properties of any given segment. That is, neither learners nor analysts can use phonetic properties such as *stopness*, *rhoticity*, *length*, or *nasality* to make inferences about the phonological identity of a segment articulated as a stop, a rhotic, long, or nasal, and so forth (Chabot 2019; Gussmann 2004; Kaye 2005; Ploch 2003; Purnell 2009).

More generally, there seems to be no universal implementation of phonological features cross-linguistically; Cohn (2011) notes that what we transcribe as [i] is only approximately the same across different languages, while “high front vowel” represents a specific position within a phonological system⁸. The use of contrast and distributional properties to build phonological identity is dependent on the interaction of a segment with the system in which it is embedded, an essentially structuralist point of view that was more or less sidelined in Chomsky & Halle (1968). However, Drescher (2009) argues that generativism needs to be reconciled with notions of the system in structuralism; what Scheer (2010a) calls the interaction of static (the system, inventories, contrast) and dynamic (phonological computation) properties of phonology.

The orthodox argument that the basic units of phonology must be innate for learning to take place has been challenged both indirectly in Boersma (1998: 161) and Cowper & Hall (2015: 160), and directly in Odden (to appear), where it is argued that phonology can be acquired without requiring innate phonological features or phonetic correlates. In this second view, the phonetic expression of features is not fixed by UG, but rather emerges based on environmental information which learners are exposed to during acquisition (Blaho 2008; Drescher 2014; Iosad 2017; Odden 2006, to appear; Samuels 2011) (see Scheer 2019a

⁸ Pierrehumbert (2001: 137) notes that “it is not possible to point to a single case in which analogous phonemes in two different languages display exactly the same phonetic targets and the same pattern of phonetic variation in different contexts.” That is, the phonetic exponence of objects which represent equivalent phonological relationships varies in detail. Learners of any language need a language-specific means of phonetically implementing phonological features (Boersma 1998; Cowper & Hall 2015; Cyran 2014; Keating 1985, 1988; Kingston & Diehl 1994; Pierrehumbert 2003).

and Samuels et al. to appear for a overviews). In this view phonological behavior and contrast alone allow learners to learn phonological categories; phonetic cues are insufficient and unnecessary, and features are contentless in every respect.

In the algebraic view of phonology being developed here (§4.4.4), features are symbolic variables and membership in natural classes cannot be established on the phonetic properties of segments. In line with Kaye's epistemological principle, only phonological behavior can be used to determine natural classes. In turn, it is not some shared phonetic property that determines natural-class membership, but rather the presence of a variable shared by all members of a class, F_α , or F_β , or F_δ , etc.

4.4.2.3 *Unnatural classes*

Empirically, the existence of unnatural classes (§3.1) suggests that features are not fixed with universal substantive correlates, but rather emerge through the process of acquisition, based on generalizations made by learners from phonological patterns in the ambient language (Mielke 2008: 9). In this view, since features and their phonetic exponence are not universal, there is no reason to think they are part of UG endowed FL. Indeed features, being symbolic counters, are like any other symbolic object in the perceptual system: *blue*, *smell of cumin*, and so forth. As in other perceptual systems (see §1.2.2), domain general symbols are used by the phonological module to interface with the real world. This is entirely in-line with third-factor thinking, since assuming that universally endowed features determine phonological patterns is not necessary. Instead, the exigencies of external phonetic factors shape phonological patterns, which learners can then generalize over in whatever way required to account for the pattern at hand (Boersma 1998; Cowper & Hall 2015; Dresher 2014; Mielke 2008, 2009).

Following Dresher (2014) and Odden (to appear), in the model here features emerge as a function of natural classes, when a class of segments functions together in the structural description of a rule, it is because they share some feature. Natural classes are determined on the basis of phonological processes rather than any surface properties, and features are assigned to triggers and targets in order to account for the pattern. In the case of Lakota (§3.1), /p l/ have a feature F_n which marks them as targets of nasalization.

4.4.2.4 *Unusual segments*

Another reason to suppose that features are not universal comes from phonetically unusual segments with conventional phonological properties. In the phonological and phonetic literature there are scattered accounts of unusual, typologically rare segments, as for example clicks (see Halle 1995 and Miller 2011 for example). Some segments are exceedingly rare indeed as noted by Ladefoged & Everett (1996) who describe the case of a "voiceless apico-dental plosive [followed by a]

voiceless labio-labial trill” in the Chapakuran languages Wari’ and OroWin, spoken in Brazil. This sound, at least in the context of its native phonological system, is entirely conventional, with a conventional phonological identity: it is contrastive, it is not limited in the word forms it can be realized in, and it is a regularly produced and recognized sound by speakers of Wari’ and Oro Win. Ladefoged & Everett (1996: 799) make an interesting observation to this effect:

All the Chapakuran languages are severely endangered. It seems likely that [tʙ] will not occur in any of the world’s languages in the latter part of the next century; but that is no indication that this sound will not develop again elsewhere. Some high elitist group in England may decide that babies are [tʙatʙa], and the word may catch on and spread to other things. So we can never really tell what features will be needed for describing languages. In principle it is the complete set of human vocal sounds that can be integrated into the flow of speech, and that are sufficiently distinct from one another; but this is too cumbersome a notion to be of practical value for working linguists describing languages.

Chapakuran [tʙ] is likely the result of an unusual sequence of diachronic events, and rare for reasons of performance rather than anything to do with UG. In contrast, if the set of phonological features were universal with limited variation of phonetic exponence, then we would expect exceedingly rare segments to appear with greater frequency in the typological records, since speakers would all be drawing from the same well of possible features. Why should whatever feature or set of features that is expressed as [tʙ] be unexploited by speakers of Greek or Tibetan? Yet, typologically rare sounds tend to be restricted, as isolated or areal phenomena. Further, if features were universal, the set of rare features would have to be inflated whenever a rare segment was encountered. Halle (1995) is an example: the feature [±suction] was introduced to account for clicks.

A weaker version of a universal substantive-feature theory is still possible by arguing for some “slack” in phonetic realizations of features: a phonological feature may, within limits, vary in its realization. In fact, this is a necessary condition of any theory of features, as shown by phonetics/phonology mismatches. Admitting slack into the system is not sufficient—for a given segment, there is no theory-independent way for deciding when a phonetic form necessarily entails one phonological form or another.

As an example, in the Kabyle Berber vowel system (Figure 4.1), the three vowels /i a u/ are realized variably in the vowel space⁹, such that /a/ may be realized as [æ], or /i/ as [ɛ] (Kossmann & Stroomer 1997). If each phonemic vowel is built from a set of universal features, then

⁹ The phenomenon of *vowel dispersion* is well recognized (see Boersma & Hamann 2008 and Hall 2011, for example). Vowel dispersion explains an observation about phonological facts, but it is not phonology itself (see Vaux & Samuels 2015).

those features must admit a certain flexibility of phonetic expression, but there is no non-arbitrary way of determining what the limits of that flexibility are, The Kabyle Berber /a/ could also be realized as [y], or [u] (see [Scheer 2019a](#): 110f.).

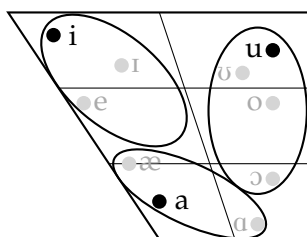


Figure 4.1: The vowel space of Kabyle Berber.

4.4.2.5 *On the modality independence of phonology*

In a modality-independent model of phonology, substance-free emergent features provide a solution to several problems. Sign language phonologies organize gestures and operate over discrete, meaningless units of contrast ([Brentari 2011](#); [Marshall 2011](#); [Sandler 2012](#); [Stokoe 1960 \[2005\]](#))¹⁰. If oral language phonologies used a set of universal, articulatory or acoustic-based features, then the set of features would be modality dependent, with one set of features for spoken languages and one set of features for signed languages. Each set would presumably lie dormant in the brains of speakers using only one of the modalities. A dual system is an unnecessary postulate if features are empty and emergent, since emergent, phonetically-empty features can be used across modalities. [Sandler \(2014\)](#) shows that in Al-Sayyid Bedouin Sign Language there is reason to suppose that features are in fact emerging, and not innate; if this is true of signed languages, it is worth assuming the same is true for spoken languages.

In neurolinguistic terms, [Poeppel et al. \(2012\)](#) provide several neurological correlates implicated in both spoken and signed languages, bolstering the position that language processing is modality independent (see also [Mayberry & Kluender 2018](#): 15 for an equivalent argument). From a minimalist standpoint, it is unclear how evolution could have resulted in sign-language features given that signed language is a relatively infrequent mode of expression. Since signed language phonology is cognitively and neurobiologically parallel to oral language phonology, this suggests that both are using the same symbolic features, and that the mapping between those symbols and their exponence in the real world emerges based on language-specific patterns. In a modular view, phonology is a singular computational system which obviates the need for a dual ontology.

The modality independence of phonology also means that no grammatical accommodations have to be made to account for whistled languages (see [Meyer 2005](#); [Rialland 2005](#)). An example is Silbo Gomero,

¹⁰ [Sandler \(2014\)](#) provides a thorough bibliographic review.

a whistled language on the island of La Gomera in the Canary Islands. Silbo Gomero is not an independent code generated by a specific whistled phonology, but rather is a transposition of Gomero Spanish into the whistled modality (Rialland 2005: 239). Generally speaking, the F2 formants of both consonant and vowel segments in Gomero Spanish are expressed with specific whistles which correspond to phonemes.

Samuels et al. (to appear) suggest that Silbo Gomero shares the same phonological processes as Gomero Spanish, such as coda /s/ deletion, manifest in the whistled language as deletion of the rise-fall whistled equivalent of [s] in the appropriate context. Samuels et al. argue that for speakers of the whistled language Silbo Gomero, the mapping between the whistled language and the grammar is not a metalinguistic device strapped onto the spoken language, but rather there is a single phonological grammar underlying both Gomero Spanish and Silbo Gomero. The phonological grammar is transduced by oral modality or whistled modality in accordance of the needs of speakers, but this is done through the interface, not through the phonological grammar itself.

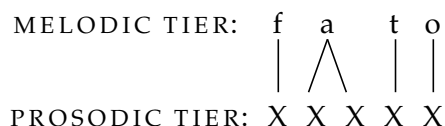
Finally, if features are not universal, and instead emerge based on linguistic patterns, there is no ontological difference between crazy rules and natural rules inside of phonological computation itself. From the point of view of the formal system, all rules are just processes operating over empty symbolic objects. In this view, “crazy rule” is nothing more than a descriptive device; in the phonology there are no crazy rules or conventional rules since they all have the same formal status.

4.4.2.6 *Suprasegmental (prosodic) structure*

Symbolic features constitute the *melodic* properties of phonological representations, bundled together into segments. It has been long recognized that certain features such as stress and tone are relatively independent with respect to melodic properties (see Goldsmith 1976, 1990). A diverse set of phenomena, including non-concatenative morphology (McCarthy 1981a), compensatory lengthening (Clements 1986; Clements & Keyser 1983), and the behavior of geminate consonants (Clements 1986; Hayes 1986) all serve to independently motivate a suprasegmental representational tier that is *prosodic* in nature (see also Prince 1984), distinct from the melodic tier. The prosodic tier, also known as *the skeleton*, formalizes the intuition that temporal properties are different from articulatory features and organizes segments into higher-order structures such as syllables, the smallest common denominator of all generative theories of phonology (see Scheer 2015b for an overview).

In this view, all melodic features are the properties of one tier of representation, and all prosodic features are the properties of a separate tier of representation, as in the graph for the Italian word *fato* [fa:to] ‘fate’ (164):

(164)



In (164), the melodic tier contains all segmental information in the form of features, interpretable along the articulatory axis in terms such as *friction* and *nasality*. The prosodic tier consists of timing slots, each one of which is linked via an association line to the melodic content on the melodic tier. In order to be expressed, melodic content must be associated with a timing position on the melodic tier. Long segments, such as geminate consonants or the long vowel in *fato*, are doubly associated to two timing positions.

Thus, the representational system sketched here has two major components: a melodic tier on which substance-free features reside, and a prosodic tier to which features are associated. I leave the question of how the prosodic tier is further organized in syllable structure to Chapter 5.

4.4.3 Substance-free computations

The other wing of phonology is the dynamic computational aspect, manifest as surface alternations of underlying forms. These alternations are the result of processes which map the underlying input to the output, interpreted as phonetic objects. A rule is a formal description of a phonological alternation which is taken to represent an LSG. The ambition of phonological theory, as conceived here, is to provide an explicit account of what phonological rules are like and what they do (see §2.1). I adopt a view of computation as articulated in Odden (2013, to appear), where rules are feature changing operations with an input and an output. A number of other ways of representing phonological computation in SFP have been presented in the literature, see Bale et al. (2014, 2020); Reiss (2022); Samuels (2011); Volenec & Reiss (2020). The task of comparing these theories is outside the scope of the present thesis.

In order to demonstrate the kinds of feature changing operations used here, consider the following pattern in Tuareg, a Berber language of the Sahel, in (165)¹¹:

(165) ROOT	WORD FORM	GLOSS
√blbɔ	t-ɑ-bælbɔt-t	'grain sack'
√mšɣ	t-æ-müşæq-q	'Tamashek woman'
√šg	t-ë-šek-k	'chase'
√dk	t-à-wdək-k	'settling down'

11 Data from Heath (2005: 44).

In (165), the initial consonant of the 3rd person feminine object clitic morpheme is realized at the same place of articulation as the root-final consonant. This generalization can be expressed as in (166):

$$(166) \quad C \rightarrow C[\alpha \text{ place}] / C[\alpha \text{ place}]_-$$

The rule in (166) says that a consonant will be realized with the same place of articulation as the consonant which precedes it. In addition to the pattern of place assimilation in (165), there is also a pattern of voice assimilation where the realization of the root-final consonant is realized voiceless when the voiceless consonant of the clitic follows it (167):

$$(167) \quad C[+\text{voice}] \rightarrow C[-\text{voice}] / _C[-\text{voice}]$$

In (167), the change from [+voice] to [-voice] is the structural change, and the context $_C[-\text{voice}]$ is the structural description. In a substance-free framework, the tags [+voice] or [-voice] are only useful shorthand and cannot be considered to be formal devices, since they indicate phonetic properties. As discussed, in FP, feature content is not determined by phonetic properties but rather by phonological behavior. In the case of the voice assimilation rule in (167), a feature $[F_\alpha]$ lexically specified in the melodic representation of the morpheme spreads back to any preceding skeletal position and is thus associated with the preceding consonant as in (168)¹²:

$$(168) \quad \sqrt{\text{ʃg}} \rightarrow \text{t-ě-šek-k 'chase'}$$

g	F_α	→	k	F_α
X	X		X	X

The result is that $[F_\alpha]$, realized as voicelessness (see §4.4.5), is associated with the underlying representation for /g/ which is thus realized as [k]. The linking process in (168) associates the feature $[\alpha]$ with /g/, which is realized as [k].

In this account, autosegmental diagrams such as that in (168) are equivalent to formal rules such as (167) in that they represent the structural changes and descriptions necessary in rule formalism. Following Odden (2020), this approach places the emphasis on concepts over notation; notation is an expression of the theory, and theory does not “interpret” the notation. As such, it is a theory of objects with homologues in FL, not of notation as objects that exist.

Rules can also remove melodic material present in underlying representations, as in the process of debuccalization in Yucatec Maya (Orie & Bricker 2000). In Yucatec Maya, all roots and words must begin and

¹² In these representations, substantive notation such as [g k] stands in for substance-free notation for the sake of exposition.

end in a consonant. Morphological processes frequently result in underlying consonant clusters. When two identical stops or ejectives are adjacent across a morpheme boundary, the first consonant in the sequence is debuccalized, resulting in a surface laryngeal fricative [h] as in (169a) or glottal stop [ʔ] as in (169b), respectively:

(169)	a.	INPUT	OUTPUT	GLOSS
		páap ^h p'àak	páah p'àak	'spicy tomato'
		b'òof fájak'	b'òoh fájak'	'black spice'
		lof f-ah	loh f-ah	'twist, bend'
	b.	INPUT	OUTPUT	GLOSS
		?éek' k'at	?éek'at	'black clay'
		f lab' pak'	f la?pak'	'old wall (fallen)'
		b'ac co?oc	b'a?co?oc	'wrap up hair'

This process can be represented as a rule which targets stops and ejectives and disassociates the relevant feature—which is phonetically interpreted at the interface—from the prosodic tier, resulting in the surface forms (170):

(170)	
	$ \begin{array}{cc} F_{\alpha} & F_{\alpha} \\ \diagdown & \\ & X & X \end{array} $

An account of what sorts of structural changes are performed by rules and their structural descriptions is needed to define the set of possible phonological rules. A basic desideratum in rule formulation is simplicity, given two rules which can account for an alternation pattern, the rule which involves the least amount of features is to be preferred. The observation that segments may assimilate the place features of a following segment suggests that rules can insert features into the representational matrix of other segments, as in (168)¹³.

A further aspect of the theory of rules is determining if rules that function on the melodic tier of representation also function on the prosodic tier, or if the two tiers are subject to different kinds of rules. One important observation of crazy rules, reflected in the census of crazy rules in Chapter 3, is that crazy rules only operate over melodic properties (Scheer 2015a, 2019b, to appear(a)): there seem to be no cases of prosodic crazy rules (§3.16). $\epsilon \rightarrow d / h_$ is a possible rule, but rules of closed-syllable lengthening or tonic vowel shortening are not. This suggests that the rules that operate over the two tiers of phonology are different: computation at the melodic level is arbitrary, while computation at the prosodic level is not. Put in other terms,

13 Odden (to appear) points out that “change” as a primitive operation is a conceptual anomaly, since any change may be nothing more than a kind of deletion or insertion, or a combined process of insertion followed by deletion. The simplest theory dispenses with change and has only operations of insertion and deletion.

rules that operate over the melodic tier can change any segment into any other (through insertion or deletion of features in any context and its reverse), but any rules that operate over the prosodic tier are comparatively less powerful.

As an illustration, let us examine the process of front/back vowel harmony in Hungarian discussed in §2.1.4. In Hungarian, the vowel in certain affixes agrees in frontness/backness with the vowel in the root to which it is concatenated, as in (171):

- (171) ty:z 'fire' ty:z-nek 'to the fire'
 bika: 'bull' bika:-nak 'to the bull'
 ke:r 'beg' ke:r-etik 'be begged'
 ad 'give' ad-atik 'be given'

In (171), a lexically determined feature in the final stem vowel, $[F_\alpha]$ spreads to the vowel of the suffixal morpheme (172):

- (172) ty:z-nek 'to the fire'
-

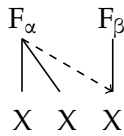
This process of vowel harmony then can be conceptualized as a process of feature spreading¹⁴, where a feature $[F_\alpha]$ which is a part of the lexical representation of /y/ is spread over a number of non-target timing positions to the timing position of the vowel in the affix¹⁵, which is then realized as [e] (173):

14 The formal system established in Goldsmith (1976) included a constraint against association lines crossing as they do in (172), known as the *No Crossing Constraint*. This constraint was meant to further refine the notion of well-formed representations and thus constrain the generative power of the formal system. It stated that representations with lines that cross are ill-formed.

However, the No Crossing Constraint is essentially stipulative, since there is no explanation in the theory for why association lines do not cross, only the declaration that they do not (Sagey 1988). In fact, the No Crossing constraint is an effect of *planar graphs*, an emergent property of a representation in a 2D space; an effect of a picture of a linguistic object rather than a linguistic object. As such, it may have properties of pictures—perspective, color, etc.—that are not properties of phonological representations (Coleman & Local 1991). The No Crossing Constraint thus has no role to play in a *multiplanar graph*, in which autosegmental representations could exist in a 3D space. Coleman & Local (1991) demonstrate that graphs must be multiplanar to handle a pattern of harmony interaction in Guyanese English, and thus by Occam's razor determine that since the No Crossing Constraint has no function on a multiplanar graph, and multiplanar graphs must be a property of some representations, the No Crossing Constraint has no status in any graphs. In the SFP approach adopted here, there is no such constraint on line crossing, which is viewed as a mere artifact of 2D representations with no formal function or status.

15 See Odden (1994) for more on non-adjacency in non-linear formalism.

(173)



As can be seen in (171), length is not spread from root vowels to affix vowels, although the feature F_α is. The distinction between melodic features such as F_α and prosodic structure allows for a clear generalization to be made: while melodic features can spread according to rule as in (173), there is no equivalent rule operating over the prosodic tier. Given the absence of length harmony from the empirical record, there is no need to recapitulate it in the formal theory. Thus, there is no reason for the formal theory to be anything other than agnostic about length harmony—there is no formal device that could spread timing slots.

I claimed in §4.3.2 that length harmony is subject to a kind of analytic bias and thus is a systematic gap, a characteristic of impossible languages. The formal distinction between melodic and prosodic tiers, each with its own computational properties, provides an explanation for the absence of length-harmony patterns in the typological record which falls out from the formal system without the need to impose any top-down constraints: there is no formal mechanism that could spread a prosodic timing position, and length harmony does not happen.

Conversely, since rules that operate over the melodic tier can insert or delete any feature in any context, the model has no trouble generating crazy rules. The formal model sketched here then makes predictions by defining a set of possible languages and excluding a set of impossible languages.

4.4.4 Phonological computation as an algebra

Since Jakobson et al. (1952) and later Chomsky & Halle (1968), in virtually every theory of phonology that makes use of features those features are imbued directly with phonetic substance, corresponding to some articulatory or acoustic trait: [+labial] in phonology corresponds to lip rounding in articulation. In the earliest theories of feature organization where unordered bundles of feature matrices were reconceptualized as hierarchical structures (Clements 1985; Sagey 1986), those structures reflected anatomical facts about human articulation, thereby building substance into the organizational structures themselves. Natural classes, being comprised of features, were in turn classes of phonetic properties; a natural class of labials predicts that a rule targeting the feature [+labial] will target all segments involving articulation by the lips. Theories of underspecification (see Archangeli 1988; Steriade 1995) further refined class membership to only those segments where a given feature is phonologically active, but the phonetic primacy of natural classes survived.

In the [SFP](#) program phonology is a formal system, behind a modular bulkhead, blind and deaf to phonetics, with which it interacts only at the interface through a process of transduction. The formal system manipulates purely symbolic objects; in this view, phonology is abstract in the Saussurean sense: the emphasis of theory is not on the physical world, but rather the symbolic nature of linguistic objects: “[l]a langue est pour ainsi dire une algèbre” ([Saussure 1916 \[1967\]](#): 168). The connection between the real world of gradient, physical phenomena and the categorical, symbolic objects of mental computation is a function of the interface, such that within the computational system itself, phonological features are devoid of inherent phonetic information.

[Berent \(2018\)](#) sees phonology as having three essential properties of an algebraic system:

1. Algebraic rules operate on variables: Phonological features unite natural classes and form the basic operational units of computation; that is, phonological rules target symbolic features and operate changes over those features, not over sounds themselves. In this sense, phonological rules operate over variables such as F_α , targeting all members of the set containing F_α , not the labial obstruents /p φ f/. Phonological features are translated into phonetic vocabulary at the interface (§4.4.5).
2. Algebraic rules apply to equivalence classes that are potentially open-ended: The requirement for class membership is the presence of the feature relevant to the operation of a rule; classes are equivalence classes in that [p] is computed just like [φ], regardless of relative frequency, ease of articulation, perceptual salience, and so forth.
3. Algebraic rules support unbounded generalizations: The equivalent nature of class members is the same at all levels of phonology, for example all syllables are good representatives of the set of syllables regardless of their other structural properties. Since rules apply to classes based on features, they apply to potentially unbounded classes of segments.

In this algebraic view of phonology, natural classes are identified not by the phonetic properties they have in common, but by the featural representations shared by members of the class. In line with the [CR](#) theory of cognition established in [Chapter 1](#), in [SFP](#) the basic conceptual objects are rules and representations. Since phonological rules operate over natural classes, they are sensitive only to the features out of which they are built, not to the phonetic correlates of those features. Thus, rules can potentially operate over phonetically arbitrary classes and effect phonetically arbitrary structural changes (see [Chapter 3](#)). Ontologically, there is no difference between crazy rules and phonetically conventional rules because the rules are operating only over symbols which have no phonetic content in either case. As a consequence, an algebraic phonology with no substance cannot ask the model to account for facts to which it is blind and deaf.

4.4.5 *The phonetics/phonology interface*

In an algebraic model of phonology in which physical properties are irrelevant to computation, there must be a way for the discrete, symbolic representations of phonology to be mapped onto the continuous, gradient physical objects of speech—either oral or gestural—in the real world. Since, in a modular framework, phonological vocabulary and phonetic vocabulary are only interpretable within their respective modules, one of the functions of the interface must be of transduction (see §1.3.2.1). At the interface phonological features are translated into phonetic vocabulary for production and *vice versa* in perception (see Cohn 1998; Keating 1988, 1996; Hamann 2011; Kingston 2007, 2019; Reiss 2007 and Scobbie 2007 for discussion concerning the interface, as well as Boersma & Hamann 2008; Scheer 2014 for specific proposals). One of the functions performed by the interface is to establish the modular bulkhead between phonology and phonetics; once the interface is defined, then phonetic naturalness in phonological processes can be established as an extra-phonological property (Hamann 2011). Inside phonology, however, there are no naturalness effects, and phonological computation can generate crazy patterns which have the same ontological status as natural patterns.

A principal question for any theory of the interface, then, is exactly what the nature of the translation process between phonology and phonetics is. In Chomsky & Halle (1968), there was no substantial difference between phonological features and phonetic features themselves, [labial] in phonology corresponded to [labial] in phonetics; the difference was found in the *values* for each kind of feature, where phonological features are specified in binary terms and directly interpretable by phonetics as a numeric scale. In this view, features themselves serve as a kind of interface between phonetics and phonology, and phonetic values are read directly off the corresponding phonological structure. In turn, that scalar value is translated directly into a physical object as a function of universal, invariant interpretation of phonological structure. This model of the interface was shown to be inadequate, as there are a variety of language-specific phonetic effects (Keating 1985, 1990), such that at least some properties of phonetic exponence must be learned (Kingston 2019; Kingston & Diehl 1994).

Features, then, are not themselves in the interface, but are interpreted by the interface as a function of speaker knowledge acquired in language-specific contexts. Some form of an interface is a necessary property of any substance-free theory of phonology. In one model, referred to here as *post-phonological spell-out*, an interface has four essential qualities (Scheer 2014):

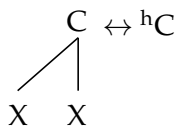
1. The mapping between phonetic realizations and phonological objects is done via *lexical access*.
2. The interface is not subject to interference from computation, nor is it itself computation. Spell-out may operate over one or several timing units, but only segmental material associated to

timing positions is transmitted to the interface; floating melody, for example, is not.

3. The mapping between phonological objects and their phonetic correlate is arbitrary and language specific; only phonological behavior determines phonological identity.
4. Only alternations that are exceptionless can be the result of post-phonological spell-out; in English there is no rule that turns /p/ into [p^h], rather the consonant is spelled-out as either aspirated or unaspirated in a given context.

Spell-out is a lexicon of instructions that map from underlying forms to surface forms; as such it works like a dictionary and each entry must be learned during acquisition—mappings are not innate. While phonological computation works over phonological features, the transduction process changes one type of representation in one vocabulary into another (Hale et al. 2007: 647). Spell-out functions once all phonological computation has been carried out; it is purely translational and performs no computation itself. For example, it cannot insert or remove features or change association lines or prosodic structure. An example of a translational process is the realization of Icelandic pre-aspirated stops [hC], which only occur word-medially after short vowels, a distribution shared by geminate consonants (Árnason 2011: 220ff.); underlyingly [hC] are also geminate, spelled out as pre-aspirated consonants (174):

(174)



Spell-out also removes from phonology proper some of the work done by computation in other models. For example, it shoulders the burden of “low-level” phonetic rules in rule-based frameworks (Keating 1985), or some of the work done by post-lexical phonology in derivational frameworks where a dichotomy of rules is established, notably Lexical Phonology (§2.2.3.2) and Stratal-OT (Bermúdez-Otero 2003, 2018). In these frameworks, there are two sets of processes that are active in different morpho-syntactic environments, both operating within their own overlapping domains, with their own constraints, and to varying degrees of exceptionality. In LP, for example, post-lexical rules are said to be rules that are exceptionless and capable of transforming phonemes into allophones. Spell-out merely makes explicit the long standing observation that not all phonological rules are equal: phonetic rules are relegated to the interface, and are not a part of the computational module of phonology.

What is of interest here is how spell-out interacts with phonological features. As suggested by phonetics/phonology mismatches (§4.4.2)

and crazy natural classes, one-to-one mapping between phonological features and phonetic exponence cannot always be assumed: phonological features and phonetic properties do not map back to each other invariably (Keating 1988), see for example Hamann (2004) for retroflexivity, Kingston & Diehl (1994) and Honeybone (2005a) for voicing, and Clements (1990) for sonority. Phonetic realizations of phonological objects are not only learned, but they may vary in unexpected and unpredictable ways (see Chapter 5). That is, the mapping between phonetic objects and phonological features is arbitrary.

4.4.5.1 *On the arbitrary nature of phonology at the interface with phonetics*

Scheer (2014) points out that a trivial property of the interface between morpho-syntax and phonology is its lexical nature. That is, translation is not lawful nor does it follow from any principles in synchrony. Instead, it is arbitrary and works like a look-up table: in morpho-syntax there is an object in English marked PAST (WEAK VERBS), and this object is translated into phonology as *-ed*. The lack of invariance in phonetic expression of phonological features suggests that the interface between phonetics and phonology is also lexical in nature.

In a modular theory of mind, an arbitrary interface is to be expected, since nothing inherent in domain-specific vocabulary entails any sort of lawful translation process; the representation of the *smell of cumin* has nothing in common with the volatile molecules of the seeds of *Cuminum cyminum*, and the association between the two is learned. Regarding the interface between phonology and phonetics, there is no reason to believe that it is any different. A phonological feature is an abstract cognitive symbol, correlated to a physical object located in time and space.

Spell-out converts one set of vocabulary into another, shunting phonological material to the phonetic module where the abstract, symbolic structures can be given neuromuscular instructions. Spell-out does not work according to any universal principles of phonetic expression, it performs a language-specific translation operation; as such, the mapping between phonological features and their phonetic expression does not have to be encoded into UG. That is, spell-out works like a look-up table, where the relation between the symbols in the different vocabularies is arbitrary; any input can map to any output, and vice versa. For example, in a language where /b/ is represented featurally as $F_\alpha F_\beta F_\gamma$, each feature has its own index in spell-out: $F_\alpha \leftrightarrow$ labiality; $F_\beta \leftrightarrow$ full occlusion; $F_\gamma \leftrightarrow$ voicing.

In spell-out the interface is by nature arbitrary, but arbitrariness is also a property of the interface model in Boersma & Hamann (2008), in which a language-specific mapping between auditory forms and phonological representations translates between production and comprehension. One consequence of such a model is that while most phonetics/phonology mappings will seem to be one-to-one, this is just another property of extragrammatical influence in phonology mirror-

ing phonetic properties. This argument is made at length in [Chabot \(2019\)](#) concerning the class of rhotics, where it is shown rhotic phones are especially prone to phonetic variation, giving rise to especially salient many-to-one mappings expressed at the interface.

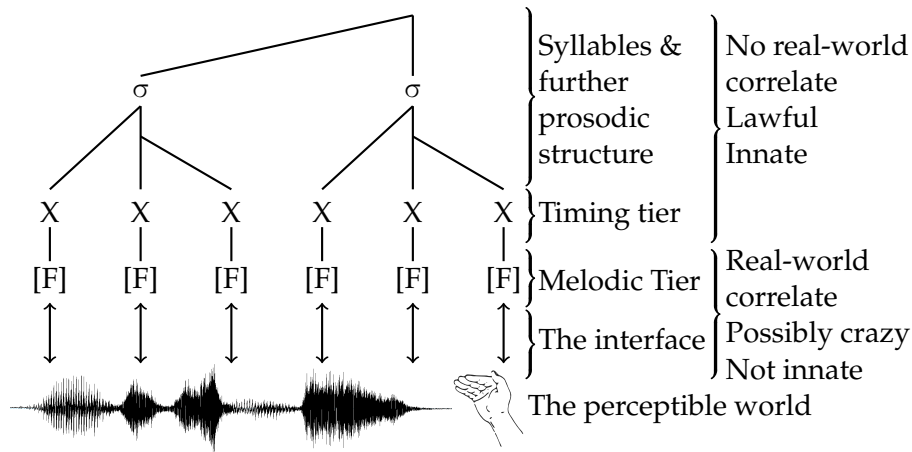
4.4.5.2 *On the lawful nature of phonology above the skeleton*

The census of crazy rules in Chapter 3 confirms an observation made by [Scheer \(2015a: 333f.\)](#): the structural description of crazy rules always concerns melody, and never higher-order prosody. There is, for example, no documented case of compensatory shortening, onsets branching by rule, or vowel lengthening in closed syllables (see [Dresher & Kaye \(1990: 149f.\)](#)). For [Scheer](#), this is the essence of Saussurean *langue* and Chomskyan competence: those items which are above the skeleton are innate, universal, and the product of **UG**. In this domain, well-formedness and ill-formedness make sense, grammar places restrictions on what can happen and where, and processes are lawful. Below the skeleton in the domain of melody, craziness reigns (see §4.4.3); there may be a remote island for any unattested melodic process, but not for syllabic and stress-based processes [Scheer \(2019b\)](#).

[McMahon \(2003, 2005\)](#) anticipated this division, suggesting that **OT** computation is only active over the prosodic domain, since this is where it has had the greatest analytic success. In contrast, it provides less insight into melodic phonology where phonetic naturalness and markedness constraints are contravened. In a modular model this has an obvious explanation: phonology is composed of (at least) two sub-modules, each of which with its own vocabulary, set of rules, and interfaces [Scheer \(to appear\(a\)\)](#). The “upper” module is the domain of prosodic structure and processes that manipulate it: compensatory lengthening, syllables, and so forth. It interfaces with morphology and the “lower” domain of phonology. The latter is the domain of melodic objects and processes which manipulate them: rule-based, feature-manipulating alternations (see Figure 4.2). Objects at this level of phonology do not interface with the real world and have no phonetic properties, being entirely symbolic ([Scheer to appear\(a\)](#)). While a feature $F_\alpha \leftrightarrow$ [labiality] has a physical correlate after translation at spell-out, objects such as syllables or timing positions do not have any direct physical correlate—their existence is purely as mental objects perceived by human beings.

The lower domain of phonology makes use of domain-general symbolic representations to interface with the real world of gradient and continuous physical objects, only objects in the melodic domain can have a phonetic correlate. The associations between melodic representations and their physical correlates are learned and arbitrary—as is the case elsewhere in cognition where symbolic representations are used. It is in this lower domain where phonetic effects enter into phonology through phonologization, and where features can be manipulated to produce crazy rules. The origin of craziness in the melodic domain is less a product of rules themselves than of the domain being the lo-

Figure 4.2: The melodic and prosodic domains of phonology with the interface.



cus of the interface with the real world in post-phonological spell-out. The symbolic nature of features, in conjunction with their expression through a look-up table in which associations are acquired rather than being innate, means that a limited number of rules can produce crazy results.

The architecture in Figure 4.2 emphasizes the role of representations in phonological computation, and entails several predictions regarding the nature of possible and impossible languages. More specifically, it circumscribes the interaction of phonology with other domains of grammar. In this view, the interface between the melodic domain and the prosodic domain means that morpho-syntax does not communicate directly with melody (Scheer 2016). That is, rules of allomorphy can be sensitive to phonology, but only to prosody: stress, syllable structure, tone, and so forth. The other is that, as reflected in the census in Chapter 3, crazy rules only reference melodic structure.

The strict division of phonology in Figure 4.2 precludes a great number of storable languages from being possible languages. Remote islands may hide any number of undiscovered processes which operate over the melodic domain, but not over the prosodic domain. With no rule to harmonize skeletal positions, length harmony, for example, is an impossible process and cannot exist.

In addition, the division of phonology into at least two computational modules—each with its own vocabulary and computational processes—has interesting repercussions for the distinction made by Fitch et al. 2005 and Hauser et al. (2002) between FLN and FLB, as well as the claim made in that that phonology is not a part of FLN but rather a property of FLB (see §1.1.1). This distinction is based on an assumption that phonology is a part of the sensory-motor system, being nothing more than a mapping between narrow syntax and the real-world. In this view, phonology has the same status as any general sensory-motor system, while FLN is a computational system that operates over symbolic objects which have no real-world referents.

The response given by Jackendoff & Pinker (2005) focuses on the questions of evolution, adaptation, and properties unique to human language, without questioning the conceptualization of phonology as a sensory-motor interface for syntax. According to the architecture in Figure 4.2, however, the position defended by Fitch et al. (2005) and Hauser et al. (2002) is based on an insufficiently fine-grained view of phonology. Figure 4.2 makes clear a distinction between the “lower” portion of phonology which is a mapping between the symbolic and the real world and which does rely on general cognitive capacities, and the “upper” part of phonology above the skeleton built of higher-order structures which organize those objects, have no real-world correlates, and are not a mapping to the sensory-motor system. The former are exaptations of mechanisms available to other cognitive domains, while the latter are domain-specific to phonology, having no obvious homologue elsewhere in cognition; this is the product of the human genome, part of FLN, and thus a part of UG. Thus, the distinction between FLN and FLB does not lay between syntax and phonology, but between the upper and lower parts of phonology itself.

4.4.6 *Overgeneration in substance-free phonology*

As recalled in Chapter 2, after explanatory adequacy, a second major impetus for formalizing naturalness in grammar was an effort to avoid overgeneration of unattested forms. This followed from an assumption that the set of attested languages is isomorphic with the set of possible languages, and as such formal theory should account only for attested languages. Restrictions on formal grammars are imposed to exclude empirically unattested patterns, a kind of data-fitting (Blaho & Rice 2014; Hale & Reiss 2008). Formal naturalness serves as a constraint on grammar, a way of outlawing unattested forms and of explaining not just the *what* but the *why* of attested forms. The implicit assumption is that a theory which generates unattested patterns makes empirically invalid predictions about what possible languages look like.

Hale & Reiss (2008: 206) argue that this assumption is unwarranted, since FL is embedded within a system of other cognitive and phonological modules with which it interfaces, and the interference from performance factors preventing possible languages from being attested is not only plausible, but likely. Following Hale & Reiss (2000a, 2008); Reiss (2008); Odden (2013) the ambition of a theory of phonology is to categorize computationally phonological systems and to reveal facts about the CR system underlying the phonological component of UG. In line with that ambition as few assumptions about the formal system are made as possible, in particular assumptions about universal tendencies—even if the result is a theory of phonology which generates unattested forms. If the set of overgenerated patterns falls out from the minimal formal machinery needed to account for attested languages, then those overgenerated patterns are taken to be possible languages, within the remit of phonological theory. Thus, Hale & Reiss allow for

the possibility of remote islands where as yet unattested patterns may be discovered (see discussion in §4.3.2).

However, [van Oostendorp \(2013: 281\)](#) argues that allowing phonological theory to overgenerate means that there can be no theory of phonology, since phonology is essentially recast as a Turing machine. That is, allowing for generation of *any* pattern means there are no predictions to be made: phonology is reduced to a descriptive formalism with no explanatory power (recall again the discussion in §4.3.2). The only thing to be said about possible languages is that they are the way they are and not some other way because they are all subject to the same phonetic pressures, but they *could* be some other way.

The phonological architecture in Figure 4.2 restricts overgeneration to the melodic domain, where it is not a property of computation *per se* but rather a consequence of the arbitrary nature of post-phonological spell-out and the absence of phonetics and hence naturalness from phonology. That is, there *are* systematic gaps in phonological typology, analytic bias *does* constrain the set of possible languages, and an understanding of the formal system allows predictions to be made about that set. In particular, while rules that manipulate melodic features can produce any kind of alternation, the kinds of operations permissible at the prosodic tier are much more limited.

This conclusion is not a reflection of top-down constraints on the formal system, but a natural consequence of the formal architecture itself. This follows from a principle argued for by [Odden \(2013: 250f.\)](#): a theoretical claim must not only be unfalsified by empirical facts, but must also be the conceptually-simplest proposition in line with those facts. Since phonological theory is about phonological computations and phonological representations, overgeneration is not a valid basis for the evaluation of a theory.

The diachronic account of phonetic naturalness discussed in §4.3.3 provides an explanation for the typological distribution of crazy rules, meaning that the formal system is responsible for replicating phonetic naturalness within the grammar itself. The result is a grammar which can perform any kind of melodic operation with only a limited number of formal rules. This expansive computational power on the melodic tier emerges from the arbitrary relationship between features and their phonetic exponence in post-phonological spell-out and the absence of phonetic naturalness. Where grammar is restricted, as in the prosodic domain, overgeneration is managed not by excluding unattested patterns via specific theoretical devices, but through the same formal mechanisms which generate existing patterns. There is no need to explicitly bar unattested patterns if the formal system cannot generate them in the first place.

4.5 CONCLUSIONS

The current chapter has presented a discussion of empirical and conceptual issues inherent in naturalness theories. I argued that from the

perspective of minimalism and going beyond explanatory adequacy, a theory of phonology that abandons phonetic naturalness, containing only categorical symbolic markers at the melodic level and operations that compute over those markers is a more plausible model of phonology. Third factor explanations, it is argued, may provide a great deal of explanation for why phonological patterns are as they are and not some other way.

In this light, I discussed the distinction made by [Moreton \(2008\)](#) between channel bias and analytic bias, suggesting that channel bias and the diachronic view of phonetic naturalness could provide a plausible explanation for the preponderance of seemingly phonetically natural patterns attested in the typological record, while also providing explanation for the distribution of crazy rules. This, I argued, paves the way for removing formal naturalness from typological theory.

The central theme of this thesis is the nature of possible phonological rules. The diachronic account of phonetic naturalness means that phonological computation, unconstrained by formal naturalness, is free to potentially produce a great many patterns that are not attested in the typological record. As discussed in §4.3.2, if phonological computation is unbounded and there are no limits to the set of possible languages then phonological theory cannot be used to make predictions about possible languages. If there is no reflection of analytic bias in the typological record, then the argument that phonology is a specialized cognitive module is seriously undermined, and the very status of phonology as a scientific pursuit is questionable, since it makes no predictions and cannot be falsified.

However, this thesis argues that there is analytic bias in the architecture of [UG](#). I outline a model of phonological computation that is composed of dual tiers: one melodic and one prosodic. The former interfaces with the real world in an arbitrary fashion, meaning that melodic computation is also arbitrary and can change any input to any output in any context and its reverse; in short, it can generate crazy rules. The latter, however, is much more limited in the kinds of patterns it produces. In sum, there are thus impossible languages: the nature of both possible and impossible languages falls out from the formal system of computations and representations. These computations and representations are modular in nature and thus deaf and blind to phonetics—nothing more than a good understanding of that formal system is needed to provide an explanation for possible and impossible languages.

STRENGTH IN CAMPIDANESE SARDINIAN AS
SUBSTANCE-FREE PHONOLOGY

Reality is the raw material, language
is how I look for it—and how I do
not find it.

CLARICE LISPECTOR

In this chapter I put into practice the phonological architecture outlined in §4.4 to analyze an intricate pattern of spirantization and gemination in Campidanese Sardinian (CS), modeled as properties of the melodic domain and the prosodic domain, respectively. Spirantization and gemination are examined through a substance-free lens, where computation is purely formal and realized phonetically after interpretation at the interface. The pattern of spirantization and gemination in CS makes an interesting case study for the algebraic, substance-free theory of phonology outlined in §4.4 since spirantization is frequently seen as a manifestation of *lenition*, or weakness, while gemination is frequently seen as a manifestation of *fortition*, or strength (Honeybone 2008). However, in a model of phonology without substance, it is not clear what strength and weakness mean in a phonological sense, or how they are manifest phonetically. I will argue that both weakness and strength represent phonological generalizations, but that they cannot be understood as a reflection of surface patterns—they can only be understood in phonological terms.

This chapter will present a crazy rule in CS, strengthening in the form of gemination which surfaces as spirantization. This is shown to be a prime example of a phonetics/phonology mismatch (§4.4.2.1), and the first known case of a crazy rule in the domain of lenition-fortition. The process is also interesting because it is syllable driven, presenting a possible counter example to the generalization that craziness is a property of the melodic domain. In fact, on careful analysis, it is shown to be a normal phonological process of strengthening resulting in geminate structure, where craziness is introduced in the interface when voiced geminates are spelled-out.

5.1 THEORIES OF STRENGTH AND WEAKNESS

5.1.1 *Strength and weakness in Campidanese Sardinian*

This chapter proposes a demonstration of the phonological status of strength and weakness through the examination of a data from CS. In any surface-oriented view of strength and weakness the nature of the output of a process is the final arbiter of what constitutes weakening

and strengthening: each is identified according to the articulatory properties of the output. For example, *any* spirant realization of a stop is weakening. In CS, a surface-oriented view engenders a number of acute problems, since describing all cases of spirantization as lenition cannot do justice to the pattern observed.

The data show two things: that a model of phonology needs some way of showing positional effects (syllabic effects) and that positional effects cannot be reliably understood in phonetic terms. That is, surface properties, neither articulatory nor temporal, cannot be used to reliably identify weakness and strength: only phonological properties are useful in the discovery procedure and only in phonological terms can strength and weakness be understood.

Contra Bauer (2008), *inter alia*, I argue a theory of lenition and fortition cannot ignore positional effects; in fact, this is the only way that “strength” and “weakness” may be understood in a formal, Substance-Free Phonology (SFP) account. In such an approach, there is no primitive assumption made about how strength and weakness should be expressed phonetically, and it is impossible to make any conclusions about strength or weakness based solely on the phonetic properties of phonological output.

In CS, two different processes—one of lenition and one of fortition—neutralize voiceless and voiced stops as surface spirants. The consequence of this neutralization is that some spirant realizations of voiced stops cannot be viewed as the product of lenition, and must rather be seen as the product of fortition. In turn, surface length is not a reliable correlate of geminate consonants, since in CS geminates are not always realized with phonetic duration. I argue that the only way to make sense of this data is a formal, substance-free account where the structural change and structural description are purely phonological.

The basic pattern of lenition (§5.2.2.1) operates in certain intervocalic positions and spirantizes voiceless stops /p t tʃ k/ → [β ð ʒ γ]. The basic pattern of fortition (§5.2.2.4) applies in complementary intervocalic contexts, and lengthens voiceless stops: /p t tʃ k/ → [p: t: tʃ: k:]. In those same intervocalic contexts, voiced stops are realized as spirants: /b d ɖ g/ → [β ð ʒ γ]. The alternation between underlying voiced stops and surface spirants is unexpected in a process of fortition, though since the entire set of stops is targeted by a rule with a single structural description, this case of spirantization must also be considered to be fortition.

This process thus results in neutralization between surface geminates {p: t: tʃ: k: β ð ʒ γ} and surface spirants {β ð ʒ γ}. Both sets contain [β ð ʒ γ], even though the structural description which results in each set is distinct; there is more than one kind of intervocalic context.

5.1.2 *Strength and weakness in substance-free phonology*

One question for SFP is how output oriented processes such as strengthening and weakening can be understood. The lenition trajectory is

defined in phonetic terms: stops are stronger than fricatives, voiceless segments are stronger than voiced. In a substance-free framework, phonetic terms have no meaning, and nothing in the feature-changing domain of melodic phonology prevents a strengthening trajectory $p \rightarrow f$. From this perspective strength and weakness must either be given a phonological basis independent of phonetic notions or be viewed as metaphorical concepts with no formal status.

There are good reasons that do not depend on phonetics to incorporate both strength and weakness into a theory of phonology. For example, scholars have observed that geminates resist the application of rules that apply to the equivalent singletons in parallel contexts (Hayes 1986; Kenstowicz & Pyle 1973; Steriade & Schein 1984), a property that Hayes (1986: 321) calls *geminate inalterability*; if a segment /k/ is realized as [g] intervocally, the geminate /kk/ will be realized as [kk] instead of *[gg]. This can be understood as a kind of phonological strength—stated in purely formal terms—where geminancy bestows strength on a segment, usually manifest as immunity from the effect of processes which affect singletons (Honeybone 2005b: 178). This is a notion of strength stated in prosodic terms as a melodic item associated to two timing positions.

Given that such notions of “strength” seem to capture an LSG regarding widely attested phenomena, how can the same LSG be captured in a framework where phonetic correlates are of no use in the discovery procedure? If a theory of lenition and fortition is viewed as more than just a catalog of phonetic correlates, it can potentially provide an explanatory connection between the effects of lenition and fortition and the contexts in which they are observed (Cyran 2008: 448). As such, Szigetvári (2008: 124) argues that a theory of lenition has three goals:

1. Provide a simple definition that enables the analyst to decide of any phonological phenomenon whether it falls within the domain of lenition.
2. Give a clearly defined set of contexts where what is categorized as lenition is “natural” to happen.
3. To correlate the change and the contexts, i.e., to show that it would be “unnatural” if lenition occurred elsewhere.

Strength and weakness are viewed in this chapter in terms of phonological representations. Lenition and fortition are always driven by position¹. Since position is determined by syllabic structure and thus

¹ The view of weakness as a structural rather than a substantive property has been argued for previously (Escure 1977; Foley 1977). Escure (1977: 57) argues that lenition must be a structural property since initial consonants do not lenite while medial consonants do, and proposes a hierarchy of the relative strength of consonants and their status as defined by major class and manner of articulation features. While Bauer (2008) shows that this hierarchy is empirically incorrect, Escure crucially argues for a hierarchy of positional strength where lenition is more likely to operate in some positions than in others. The hierarchy suggests there is a kind of relative strength between positions, with some positions more likely to host lenition processes than

a property of the prosodic domain (§4.4.5.2), it is lawful. In this analysis, *SFP* makes predictions about what is weak and what is strong: each is determined by position in syllabic structure. Here, strength and weakness are relative, strong items are strong only relative to an item in a weak position. How strong items are realized phonetically is determined at the interface, not by universal fortition scales.

Lenition is not a metaphorical term, but rather is a specific context in which a phonological process applies, resulting in a weaker segment in that the output contains fewer phonological primes than the input (see also Harris 1990, 1994; Harris & Lindsey 1995). This analysis uses melodic and prosodic structure to show that a process of spirantization which targets voiceless stops in *CS* is true lenition, entailing the loss of melodic primes in a specific prosodic position. In this view, lenition can have only one definition: any process which removes melodic primes in a phonologically weak position, regardless of its surface output. This characterization of weakness is phonological, since it says nothing about the phonetic exponence of lenition.

The representation of strength adopted here is equally phonological: it is defined by position and syllabic structure. Any segment which is associated to two positions on the skeletal tier is strong. The unexpected conclusion of this view is that the process of spirantization which targets voiced stops is a result of fortition, where the melodic material associated with a single timing position becomes associated to two. Consequently, surface-oriented correlates for strength are unavailable, since doubly-associated voiced geminates are phonetically expressed as short, voiced spirants. Strength and weakness are identifiable not through surface properties, but through phonological behavior.

Finally, this chapter will argue that while both lenition and fortition in *CS* are processes of phonological computation operating at the melodic and prosodic domains respectively, the output of lenition is produced through the changing of melodic content, while fortition spreads melodic content but does not directly manipulate it; the spirantization of voiced geminates is a result of spell-out, not of melodic computation. Thus, both processes depend crucially on representational structure in both domains. The neutralization of stops to spirants then is due to a computational effect in the case of singletons ($/p/ \rightarrow [\beta]$ in intervocalic position), while geminates are spelled-out as spirants ($/bb/ \leftrightarrow [\beta]$).

others. In turn, Foley (1977) argues that segments are defined by strength relations established between major classes of segments, with some segments being inherently stronger or weaker than others. While both Escure and Foley make reference to surface properties that determine a segment's relative strength or weakness, the structural view in which lenition is defined positionally marks a clear break from the substantive view, leading to a vision of weakening processes which are not directly related to the phonetic properties of segments.

5.1.3 *Substantive conceptions of strength*

Anderson's paradox (Chapter 4) says that most phonological patterns are phonetically natural and the mapping between underlying forms and surface forms is usually transparent, while also acknowledging the existence of arbitrary or unnatural patterns. This paradox can also be applied to lenition and fortition. The vast majority of lenition² and fortition patterns are phonetically natural.

Weakness *qua* lenition is manifest in a reduction in articulatory effort (see Kaplan 2010 for an overview), a surface-oriented description which has been amply espoused in the literature (Bauer 1988; Bybee & Easterday 2019; Kaplan 2010; Kirchner 1998, 2000; Lavoie 2001), a view that is inherent in theories where phonetic naturalness is given formal status. Lenition, in this light, is seen as a deterministic, sequential process—operating diachronically or synchronically—which results in a reduction of articulatory effort (Bauer 1988). Intervocalic voicing of voiceless stops, for example, results from the fact that devoicing in that context would require extra effort to stop the glottis from vibrating—it is easier to voice the entire sequence (Kingston & Diehl 1994; Westbury & Keating 1986).

Strength *qua* fortition depends on “the status of its various phonetic components, including duration, intensity, voicing, and degree of formant structure” (Lavoie 2001: 8). A surface oriented view of strength is argued for by Bybee & Easterday (2019: 270f.) and Fougeron & Keating (1997: 3737), among others.

Lavoie (2001), in a census of treatments of lenition, gives a synthesis of four related definitions, all of them surface oriented (175):

(175) *Lavoie's four definitions of lenition:*

- i A step on the way to deletion
- ii An increase in sonority
- iii A decrease in effort
- iv A decrease in the duration and magnitude of articulatory gestures

Bauer (2008: 622) goes further and argues that lenition is distinct and untethered from positional identifiers. Bauer (2008: 611) then argues that if lenition is defined in uniquely environmental terms—such as V_V—a generalization is missed since there is a unity to processes of lenition in their “failure to reach a phonetically specified target: articulatory undershoot or under achievement.” In this view, the substantive properties of lenition outweigh any positional effect. The most that can be hoped for is that position “can be seen as one of the influences on what phonetic changes are likely to occur” (Bauer 2008: 619).

² See Honeybone (2008) for an in depth review of the use and meaning of the term *lenition*, and Gurevich (2004) for a census of lenition processes, including intervocalic voicing.

However, as discussed in Chapter 4, phonological theory is not about what is likely or probable. Further, I will show that Anderson's paradox holds for lenition and fortition in CS: while most patterns of lenition and fortition are phonetically natural, they can also exhibit craziness and defy surface-oriented approaches that derive strength and weakness from surface properties. In a SFP based view, both strengthening and weakening must be seen in purely phonological terms, since phonological computation is deaf and blind to phonetic substance.

5.2 A CASE STUDY OF SUBSTANCE-FREE LENITION AND FORTITION

5.2.1 *Some words on the data*

The data used were collected as part of a fieldwork project conducted in and around the village of Genoni, in the province of Sud Sardegna, located on the high plane of the Giara di Gesturi in south-central Sardinia in mid-February of 2020. Guided conversations were conducted with 23 inhabitants of Genoni, all of whom were born and raised in the village or nearby. The interviews were conducted in Sardinian by two native speakers. All participants were adults, between the ages of 36 and 91, and native speakers of CS with a high level of competency and strong judgments about grammaticality, for whom many CS is their first language though all are bilingual in CS and Italian. The recording sessions took place in various informal settings including the village cultural center and in participants' homes.

In some cases, participants were alone with the interviewers, in others two or more participants were interviewed together. The sessions typically lasted around 45 minutes, and focused on subjects such as childhood, home life, village life, folktales, stories, and traditions and history of Genoni. This format relies on chance to elicit words, but was intended to reduce the use of Italianisms and to gather a wide variety of basic vocabulary related to day-to-day life. The data were recorded on a Zoom multi-track hand recorder, using the built-in microphone and recorded at 96 Khz sampling rate in 32 bits. Segmental realizations are transcribed as heard by myself and Simone Pisano. The pattern in the data conforms with the pattern described in Bolognesi (1998), whose data is used to supplement examples when needed.

5.2.2 *The empirical situation: Lenition and gemination*

CS³, spoken throughout the southern portion of Sardinia (see Mentsching & Remberger 2016 for a general overview of the linguistic situation in Sardinia), presents an intricate pattern of interaction between lenition and gemination. At a superficial descriptive level, in a classic case of lenition word-initial voiceless [p t tʃ k] and voiced [b d ɟ g] are

³ Described previously in Bolognesi (1998); Contini (1986); Jones (1988); Lai (2021); Viridis (1978); Wagner (1950 [1997]).

both realized as stops when following a consonant final word and as spirants [β ð ʒ γ] when following a vowel final word in external sandhi, where phonology works as it does word-internally as though there were no boundary. Complicating this description is the fact that [p t ʃ k] sometimes lengthen intervocally, and [b d ɟ g] are not always affected by spirantization.

This superficial description, then, misses several important generalizations that come out only after careful inspection of the phonological system, notably concerning how prosodic structure is built in CS and the interaction between that structure and phonological computation. In very broad terms, voiced and voiceless obstruents are subject to a pattern of alternation, but the rule C[-cont] → C[+cont] / V_V does not make the correct predictions, because while the structural change of each process is the same, the structural description is not reducible to the simple intervocalic context.

Careful analysis of each process shows that there are in fact two complementary intervocalic contexts, distinct in their prosodic structure (§5.3.2). In fact, voiceless stops spirantize in weak positions and are thus subject to a true process of lenition, while voiced stops only spirantize when in strong positions, becoming phonological geminates. Interestingly, in CS, geminate identity cannot be derived from length alone, since phonological geminates can be realized in free variation as phonetically long or not. This presents an interesting case study for substance-free phonology, since the output of weakening and strengthening is neutralized on the surface across stops, and each process can only be understood in phonological terms.

In intervocalic external sandhi, voiceless stops and voiced stops show a clear disjunction: while [p t ʃ k] are realized as the spirants [β ð ʒ γ] as in (176a), the voiced stops [b d ɟ g] are either dropped entirely (176b) or, more commonly, unaffected (cf. Bolognesi 1998: 36ff.):



Figure 5.1: A map of Sardinian dialectal areas.

- (176) a. [puɖ:a] ‘hen’ [s:a βuɖ:a] ‘the hen’
 [tɛ:ra] ‘earth, soil’ [s:a ðɛ:ra] ‘the earth, the soil’
 [ʃivraʒu] ‘durum bread’ [s:u ʒivraʒu] ‘the durum bread’
 [kwat:ru] ‘four’ [dɛ ɣwat:ru] ‘of four’
- b. [bentu] ‘wind’ [s:u entu] ‘the wind’
 [dominiɣu] ‘Sunday’ [s:u ominiɣu] ‘the Sunday’
 [ɕjara] ‘kind of hill’ [s:a jara] ‘the hill’
 [gaŋga] ‘throat’ [s: aŋga] ‘the throat’

The pattern in (176)⁴ is characteristic of a classic process of lenition: stops are simultaneously voiced and spirantized in a trajectory that ends in zero. While for voiceless stops this process of lenition is systematic and invariable, the same is not true of the voiced series, since they are frequently unaffected by the lenition process. Thus, the alternations in (176b) are optional and /ssu bentu/ may be realized as [s:u bentu] as well as [s:u entu].

Curiously, however, while the context in (176) never triggers spirantization of voiced stops, there are intervocalic contexts in which voiced stops do alternate with spirants (177):

- (177) [biɖ:a] ‘village’ [a βiɖ:a] ‘to the village’
 [dɔmu] ‘house’ [kus:a ðɔmuzu] ‘those houses’
 [gat:u] ‘cat’ [trɛ ɣat:uzu] ‘three cats’

Complicating the surface pattern further is the fact that voiceless consonants have a dual behavior in surface intervocalic contexts where rather than spirantizing they lengthen (178):

- (178) [piʃ:i] ‘fish’ [bendia piʃ:i] ‘sell-3SG PST fish’
 [tɛmpus] ‘time’ [kustu tɛmpuzu] ‘in those days’
 [kojai] ‘to marry’ [ɔβia k:ojai] ‘want-3SG PST to marry’

Voiceless stops thus exhibit a dual pattern of behavior in the intervocalic context, spirantizing as in (176a) but lengthening as in (178). In traditional terms, these two surface output patterns correspond to weakening and strengthening, respectively. In sum, the surface pattern of CS stops presents several disjunctions, with voiced stops either surfacing faithfully, falling, or spirantizing, and with voiceless stops either spirantizing or lengthening, and all of this in the intervocalic context.

In order to understand this pattern, it is necessary to understand that surface intervocalic contexts have distinct phonological identities. These distinct structural representations allow for the different contexts in which each alternation occurs to be distinguished, and provide explicit contexts for the computational operations underlying each of them (§5.3). To properly understand the distribution of stops and their allophones, the data relevant to spirantization and lengthening is thoroughly examined.

⁴ Items from the first column are citation forms, as they would be realized in isolation or following a consonant-final word.

5.2.2.1 *Lenition*

In CS, voiceless obstruents in word-initial position exhibit a pattern of allophony, typically described as weakening or lenition (Bolognesi 1998; Contini 1986; Lai 2021; Mensching & Remberger 2016; Viridis 1978; Wagner 1950 [1997]). Lenition, for the moment, is a descriptive term used to refer to the process which produces alternations of the kind in (176a)—it does not as yet have any formal, theoretical status. The primary ambition of this section is to lay out the facts concerning lenition in CS, such that the disjunctions pointed out in §5.2.2 can be given an explanation.

In (176a), it was shown that lenition targets stem-initial consonants when they are preceded by a vowel. The same position also triggers lenition of the fricatives /f s/, manifest as voicing (179):

- (179) [foɣu] ‘fire’ [s:u voɣu] ‘the fire’
 [sɔβi] ‘sun’ [s:u zɔβi] ‘the sun’

LENITION also operates on the first member of TR clusters (180):

- (180) [prũã] ‘plum’ [s:a βrũã] ‘the plum’
 [trõũ] ‘thunder’ [s:u ðrõũ] ‘the thunder’
 [kroβu] ‘crow’ [s:u ɣroβu] ‘the crow’
 [fraði] ‘brother’ [s:u vraði] ‘the brother’

In this same position, /l/ is also in an allophonic relationship with [ɸ] (see also Molinu 2009, and the discussion in §5.4) (181):

- (181) [luzi] ‘light’ [s:a βuzi] ‘the light’
 [lũis] ‘Monday’ [s:u βũizi] ‘every Monday’
 [leç:u] ‘ugly msc.’ [ɔmini βeç:u] ‘ugly man’

Since this alternation has the same structural description as those in (176a) and (179), following the argument from Kisseberth (1970) concerning the functional unity of phonological rules, I will consider all these alternations to be the result of a singular process of LENITION, which must be given formal status (see §5.4.3).

5.2.2.2 *Non-targets of LENITION*

LENITION, however, does not target all of the consonantal segments in CS. Voiced stops may variably be reduced to zero in this context, but unlike for /p t ʃ k f s l/, which are always targeted by LENITION when in the proper context, voiced stop alternations are variable, with a number of lexical exceptions in which voiced stops never fall under any circumstances. In the description given by Bolognesi (1998: 36 ff.) voiced stop/zero alternations are more common in careful speech than in casual, subject to lexical exceptions, and “frequently” simply unaltered in this context. Even in northern varieties of Sardinian, where loss of consonants is systematic, only words from the native lexicon

undergo it; recent loanwords do not show any weakening (Lai 2021). I thus suggest that this pattern of voiced stop alternations is lexically conditioned, and will not consider it further.

Furthermore, the voiceless fricative /f:/ and the voiceless affricate /ts:/, both geminates, never undergo LENITION, even when in the proper context (Bolognesi 1998: 33). Additionally, /ð:/, /v/ and /d:/ are never deleted or lenited (Bolognesi 1998: 39). While /r/ does not occur in word-initial position, it does occur in word-medial position, where it also seems to be immune to any alternation processes (see Lai 2015b for further discussion, and an analysis compatible with the present one).

The final class of segments to be discussed are the nasals /n m ɲ/, which never lenite in intervocalic position created by external sandhi: [s:u niu] ‘the nest’. In word medial position, /n/ does seem to lenite, nasalizing adjacent vowels, but only when following the main-stress bearing vowel (182a)⁵, and never when following an unstressed vowel (182b) and (182c):

- (182) a. pil'lɔ̃i ‘bird’
 'mãũ ‘hand’
 'tēĩði ‘have-3SG’
 b. pillo'n-eq̄ɖu ‘bird-DIM’
 ma'niɣ-eq̄ɖa ‘hand-DIM’
 te'niaða ‘have-3SG PST’
 c. 'omini ‘man’
 fe'nuɣu ‘fennel’
 ko'nillu ‘rabbit’

Given the essential role played by stress in the structural description of N-deletion and the fact that there are no alternations in intervocalic positions created by sandhi, this process is not the same as LENITION.

The word-medial position also merits some discussion regarding the effect of LENITION. In this position, there are no alternations, but the distributional facts show a preponderance of spirants and voiced fricatives: [zriβɔ̃i] ‘wild boar’, [diðu] ‘finger’, [foɣu] ‘fire’. However, Bolognesi (1998); Lai (2015b, 2021) argue that these are the result of lexicalized sound changes, and not the result of synchronic lenition as in (176). Lai (2015a: 275) provides the most explicit argument to this effect, saying that since word-medial obstruents in items such as [proku] ‘pig’ are not realized as spirants, it shows that by the time the diachronic process which changed Latin PORCU > 'porku > 'proku was completed, any synchronic rule of lenition was already non-productive.

This position introduces a number of difficulties. The first is that it establishes an active synchronic process which targets only word-initial onsets in intervocalic contexts, while word-medial onsets in the same context are spared. Nothing in the theory so far justifies making a distinction between these positions or forcing rules to recognize word boundaries, V#.C as distinct from V.CV.

⁵ Data from (Bolognesi 1998: 26)

The second is that it introduces a number of phonemes, including /β ð γ/ which are distributionally limited to the intervocalic context, the very context which targets stops for spirantization and fricatives for voicing. This includes the spirants but also /z/, which is not a phoneme in CS (Lai 2021: 10), since per Bolognesi (1998: 28) it does not occur in absolute word initial position. Words such as [kazu] ‘cheese’ suggest that there is an underlying /s/ which is being voiced, thus an active process of lenition targeting intervocalic obstruents.

Further, if there is no word-medial lenition process, it is difficult to understand the output of another process in CS—that of spirantization after the epenthesis of “copy vowels”. In CS, any consonant-final morpheme, such as verbs in the 3SG in /pappa-t/ ‘to eat 3-SG’ or the plural /-s/ /faula-s/ ‘lies’ is in free variation—it may be dropped or surface with a following epenthetic copy-vowel, such that they appear as [pap:aða] and [fauxaza] respectively. In such cases, the coda consonant is followed by the copy vowel, meaning it is intervocalic, and subject to lenition (Bolognesi 1998; Lai 2021). This is a word-medial context in which lenition is active, meaning that the non-productiveness of LENITION in other word-medial contexts is even more surprising.

A grammar which accounts for these facts, but still does not target word medial consonants is significantly more complex, with a complex rule of lenition and an increase in the size of the phonemic inventory. If the rule that targets word-initial obstruents in external sandhi is also active in word-medial position, the rule itself is much simpler, the distribution of spirants does not require recourse to the lexicon, and the behavior of word-final consonants spirantized by copy vowels is straightforward. For this reason, this analysis considers LENITION to be active in word-medial positions. I will take up the case of [proku] in the following section.

5.2.2.3 *Resistance to LENITION: Virtual Geminates*

In this section I argue that gemination is a manifestation of strength in that geminate stops *never* undergo LENITION, meaning that objects which would otherwise be expected to undergo LENITION are in fact geminates. Recall that one of the arguments against synchronic word-medial LENITION is that words such as [proku] do not have word-internal spirants (Lai 2021). I argued in §5.2.2.1 however that the same process of LENITION that targets word-initial obstruents in external sandhi is in fact active in word-medial position.

In order to understand why LENITION does not target voiceless stops in words such as [proku], consider the data provided by Bolognesi (1998: 149) in (183), in which voiceless obstruents are realized in surface forms.

- (183) ma[k:]u 'crazy'
 tu[p:]a 'bush'
 ma[t:]a 'tree'
 pu[ts:]u 'well'
 bru[ʃ:]a 'witch'

Immediately, what stands out is that all of the lenition-resisting objects in (183) are phonetically long geminates. Lai (2015b, 2021) notes, however, that for obstruents in CS—as in (183)—phonetic length is not contrastive. Even for words such as those in (183), geminates may be realized with no phonetic duration, meaning that duration is not a reliable correlate for geminancy in CS (Bolognesi 1998; De Iacovo & Romano 2015). In CS, the status of phonemic geminates is uneven: only for the sonorants /r n l/ does phonetic length *always* correspond to an underlying contrast between geminates and singletons (Bolognesi 1998; Viridis 1978). Bolognesi (1998: 161) provides some minimal pairs (184), which suggest that lexical geminates are present in CS, at least for contrasts based on sonorants. :

- (184) a. [mãũ] 'hand'
 [karu] 'dear-MS C'
 [pala] 'shovel'
 b. [man:u] 'big-MS C'
 [kar:u] 'carriage'
 [pal:a] 'straw'

One of the principle questions regarding the treatment of geminate consonants is how to formally distinguish between geminate and singleton consonants (Davis 2011). While most theories of phonological representation view geminates as having some kind of prosodic existence on the suprasegmental tier, either as timing slots or moraic weight, the predominant view is that geminancy is reflected by an increase in phonetic duration. In this view, geminancy bestows strength, and since geminancy is equivalent to phonetic duration, one manifestation of strength is phonetic duration. Another manifestation of strength is resistance to spirantization as in CS.

However, while it seems obvious that an increase in timing slots should result in an increase in duration, phonological timing is above all a matter of phonological representations, and many factors related to performance can impact the manifestation of timing as duration (Clements 1986: 39). In Italian, for example, length is not always the primary phonetic correlate of gemination (Payne 2005, 2006). Geminates which are not expressed as phonetically long are what Ségéral & Scheer (2001a: 311ff.) refer to as *virtual geminates*, objects whose surface realization is identical to a corresponding singleton, but which is doubly associated to positions on the skeleton without entailing an increase in phonetic duration.

With no phonetic correlate on the consonant itself available for identifying gemination, strength can only be identified through phonological

behavior. Since words such as [mak:u] ‘crazy’ never undergo LENITION, regardless of the phonetic length of the medial consonant, it must be geminate since the principle characteristic of geminates is that *they never lenite* (see Jones 1988: 321 and Bolognesi 1998: 33)⁶. Geminate resistance to LENITION is a manifestation of *inalterability of geminates* (Hayes 1986), a structural property inherent in geminates which protects them from LENITION.

Recall Kaye’s phonological epistemological principle (§4.4.2): only phonological behavior can be used in the discovery procedure, and phonetic properties do not reveal phonological identity. Since obstruents such as those in (183) are exempt from LENITION, they *must* be phonologically different objects from those which are not. Voiceless stops which are realized as short but which also resist LENITION are virtual geminates⁷, the minimal condition for which is that they should be discoverable by learners. In the case of [proku] for example, the resistance to lenition of word-medial stops is enough for learners to recover geminate structure. Whether a voiceless stop is realized as long or short does not affect its phonological status: speakers perceive them as the same object.

This means that CS exhibits an interesting contrast based on phonological strength. Bolognesi (1998: 149) notes that [z] is not phonemic in Campidanese, since it does not occur in all positions; rather, it is the lenited realization of /s/. However, while the words in (185a) undergo lenition in external sandhi as expected, the words in (185b) resist lenition, and surface as voiceless. Resistance to lenition gives rise to a surface contrast based on leniting and non-leniting obstruents:

- (185) a. [kazu] ‘cheese’
 [tɛzi] ‘thesis’
 [mɛza] ‘table’
 [bazai] ‘kiss-INF’
 b. [kas:a] ‘hunt-1SG’
 [tɛs:i] ‘weave-INF’
 [mɛs:a] ‘harvest-IMP’
 [pas:ai] ‘pass-INF’

While diachronically the surface length-contrast between singleton and geminate obstruents has been obscured, it remains as a synchronic contrast between lenitable and non-lenitable obstruents (186). In phonological terms, nothing has changed in the evolution from Latin to CS—only the phonetic expression of the contrast in spell-out has changed; that is, the underlying contrast is between geminates which resist LENITION and singletons which are targeted by LENITION (186)⁸:

6 See Ladd & Scobbie 2003, for whom “geminate” is equivalent to “not-lenited” in Logudorese.

7 See, among others, Lowenstamm 1991; Faust 2014; Faust & Lampitelli 2020 for examples of phonologically long vowels which do not surface as phonetically long.

8 Data from Bolognesi (1998: 163).

- (186) a. /kaputu [kaβu(ðu)] ‘end of a rope’
 /mutu/ [muðu] ‘mute’
 /lɔku/ [lɔɣu] ‘place’
- b. /kappu/ [kap:u] ‘clog’
 /muttu/ [mut:u] ‘kind of traditional song’
 /lɔkku/ [lɔk:u] ‘stupid’

This suggests that any word such as [proku] which does not manifest surface length but which resists LENITION is a virtual geminate. Descriptively, in the diachronic evolution of PORCU to [proku], a process of metathesis caused the coda /r/ to move to the onset, resulting in compensatory lengthening of /k/ as it spread into the vacated coda position, resulting in the following underlying form /prokku/⁹. The result is a phonological geminate which is not realized with phonetic length, recoverable through its resistance to LENITION.

5.2.2.4 Fortition

As shown in (176), in LENITION contexts which trigger spirantization of voiceless stops, voiced stops are never spirantized. Yet, as argued in §5.2.2, (177) exhibits a pattern of alternation in which voiced stops are realized as spirants. This is what Bolognesi (1998) calls “pseudo-lenition”; in order to discuss this alternation, I will provisionally adopt the term FORTITION, the effect of which is most apparent where voiceless stops are concerned since they are generally realized with phonetic length. Ultimately, I will argue that FORTITION affects voiced stops, as well as voiceless stops, fricatives, and sonorants, though only members of the latter must be realized with phonetic duration. Unexpectedly, voiced stops are realized as spirants when subject to FORTITION. This will be shown through the examination of three related contexts in which FORTITION in CS is active.

The first context to consider is word-initial following a final stop in a preceding word, such as the plural marker /-s/ or the 3SG verbal marker /-t/. In such cases, the final obstruent cannot surface as coda, triggering either the insertion of a paragodic copy-vowel if realized, or subsequent lengthening of the word-initial stop if elided (Contini 1986; Jones 1988; Molinu & Pisano 2016; Lai 2021). In the description given by Jones (1988: 322), in such circumstances initial consonants are “reinforced” or given a “geminate pronunciation”. Bolognesi (1998: 190) sees this as a fortition manifest as surface gemination, and provides the following examples (187):

- (187) a. /bendia-t piʃfi/ ‘sold-3SG. fish’
 [bendia pi:ʃi]
- b. /nomɛna-t fattu fattu/ ‘mention-3SG. every now and then’
 [nomɛna fiat:uvatr:u]

⁹ In this work I will indicate phonological geminates as /CC/ and phonetic geminates as [C:], although it should be kept in mind that phonetic length is variable and phonological geminates /CC/ can be realized without phonetic length as [C].

- c. /ia-t defendiu/ ‘had-3SG. defended’
[ia ðefendiu]

The examples in (187) represent a sub-case of FORTITION, which I will refer to as *compensatory lengthening*. Lai (2021) calls this a synchronic process of fortition, by which an obstruent /p/ is realized with increased length, [p:] as in (187a). The same is true of fricatives, as in (187b).

When a voiced stop is realized in parallel contexts, the result is a spirant, as shown in (187c). What (187) and (177) show is an interesting disjunction: in compensatory lengthening contexts, voiceless stops geminate, while voiced stops spirantize.

The second context of FORTITION is created in CS through a process of metathesis. Diachronically, metathesis characterizes the evolution of Latin to Sardinian generally (Molinu 1999), but its effect was particularly salient in CS (Virdis 1978). Lai (2013, 2014, 2015a) identifies three kinds of metathesis, each of which affects the rhotic phoneme /r/:

- (188) (i) Long-Distance Metathesis: the liquid moves from a word-medial branching onset to a word-initial branching onset
CVCrV → CrVCV
(ii) Local Metathesis: the liquid moves from a branching onset to a coda CVCrV → CVrCV
(iii) South-Western Metathesis: the liquid moves from a coda to a branching onset CVrCV → CrVCV

While (188i) and (188ii) are diachronic processes, (188iii) is active *synchronically* in words that begin with a vowel and are disyllabic: VrCV (Bolognesi 1998: 419). This process is key for understanding how FORTITION works in CS, and for what it tells us about prosodic structure and the synchronic lenition process (189):

- (189) a. /ssu arku/ → [s:rak:u] ‘the bow’
/ssu orku/ → [s:rok:u] ‘the ogre’
/ssu ortu/ → [s:rot:u] ‘the garden’
b. /kusta ɛrba/ → [kustɛβa] ‘this grass’
/ssu orɕu/ → [s:roʒu] ‘the barley’
/ssu argu/ → [s:raɣu] ‘the sour one’

As in the process of compensatory lengthening in (187), the movement of /r/ from coda to onset creates a context for lengthening. Movement of /r/ triggers lengthening of following voiceless stops (189a) and spirantization of following voiced stops (189b); a parallel disjunction to that of (187).

The third context occurs after certain vowel-final prepositions and connectives which have lost an etymological final consonant as a result of diachronic processes (Jones 1988): e.g. /a/ (<AD or AUT), /ɛ/ (<ET) and /nɛ/ (<NEC). Lengthening is thus triggered by unstressed monosyllables with etymological coda consonants: *no* ‘not’, *a* ‘to/at’,

e “and”, o “or”, and a handful of others (Bolognesi 1998; Lai 2021). The etymological lost-consonant is what Bolognesi (1998) refers to as a *ghost consonant*, since it appears to mark the context for a certain subset of FORTITION processes. As in other Italo-Romance languages, this appears to be a kind of Raddioppimento Fonosintattico (RF)¹⁰. That is, following Fanciullo (1986: 67), an initial consonant is realized as geminate if immediately preceded by an item specified in the lexicon to trigger RF, as in (190a):

- (190) a. [prẽũ] ‘full’ [ɛ p:rẽũ] ‘and full of’
 [ti] ‘you’ [nɔ ti] ‘not you’
 [tʃɛʋu] ‘heaven’ [a tʃ:ɛʋu] ‘to heaven’
- b. [bokizi] ‘put out’ [nɔ βoɣizi] ‘don’t put out’
 [dɔmo] ‘house’ [a ðɔmu] ‘to the house’
 [graðes:u] ‘satisfaction’ [a ɣraðes:u] ‘to have-3SG satisfaction’

RF is common to all varieties of Sardinian and represents a kind of strengthening (Contini 1986). In RF, as in compensatory lengthening, there is a disjunction between voiced and voiceless stops: voiceless consonants are realized as geminate (190a), while voiced consonants are realized as spirants (190b)¹¹. In all cases of FORTITION, target segments have a vacated position at their right edge.

5.2.2.5 Summary of the empirical situation in Campidanese Sardinian

To summarize, CS is characterized by a process that spirantizes voiceless stops in external sandhi, LENITION, which does not target voiced stops. There are three processes, however, which do result in voiced stops being spirantized: compensatory lengthening triggered by the loss of a preceding word-final consonant (187c), compensatory lengthening induced by metathesis (189b), and RF (190b). In addition, these latter three processes all result in lengthening of voiceless stops, and so I refer to all three processes as FORTITION. The pattern of lenition and gemination is schematized in Table 5.1.

Considering the distribution of spirants and stops in Table 5.1, there is a direct link between the context of lengthening in voiceless stops and spirantization in voiced stops. FORTITION, then, is a process which geminates /p t tʃ k/ and /b d ɟ g/, the latter of which are realized as spirants dispute this identity as phonological geminates. To suppose otherwise is to interpret as an accident the fact that RF, compensatory lengthening, and metathesis induced compensatory lengthening all have complementary scope over voiceless and voiced stops. I argue they are the result of a singular process of strengthening which is reflected in prosodic structure (§5.3.2).

10 See Loporcaro 1997; Passino 2013, and Russo 2013 for an overview of RF, and Fanciullo 1997 for RF in central and southern Italo-Romance languages.

11 In contrast, in Logudorese voiced stops are realized as surface geminates as a result of RF (see Ladd & Scobbie 2003). In some southern varieties of Sardinian there is variation where voiced stops are realized as geminates instead of spirants in this context (Molinu & Pisano 2016).

Table 5.1: A summary of spirantization and lengthening patterns in Campidanese Sardinian.

	/p t tʃ k/	/b d ɟ g/
Left edge intervocalic (176)	[β ð ʒ γ]	[b d ɟ g]
Word-medial intervocalic	[β ð ʒ γ]	[b d ɟ g]
Compensatory lengthening (187)	[p: t: tʃ: k:]	[β ð ʒ γ]
Metathesis induced CL (189)	[p: t: tʃ: k:]	[β ð ʒ γ]
RF (190)	[p: t: tʃ: k:]	[β ð ʒ γ]

In a surface-based approach, this conclusion is surprising for several reasons. The first is that spirantization is a classic case of lenition, though in CS it is a correlate of both lenition and gemination—the latter of which is a manifestation of strength (see §5.2.2). [Kirchner \(2000: 510\)](#) suggests that spirant realizations of geminates are suboptimal and violate OT constraints which select output candidates for articulatory ease as well as perceptual faithfulness, and therefore can never be selected by a grammar¹².

This is no doubt what leads [Bolognesi \(1998: 165\)](#) to argue that voiced stops spirantize precisely because “they cannot give rise to geminate structure”; voiced post-lexical geminate structures being ill-formed. In order to prevent the grammar from producing such structures, [Molinu \(1999: 169\)](#) imposes a constraint on the grammar blocking voiced geminates in post-lexical phonology, arguing that the RF process which produces geminates in Lugodrese gives rise to “variantes non-géminées et spirantisées” in Campidanese. That is, a spirant is explicitly not a geminate, since a constraint in the grammar interdicts the gemination of voiced obstruents.

I argue that this is a classic case of substance abuse, with two unfortunate results. The first is the loss of generalization entailed by analyzing spirantization and gemination in a disjunctive way, as a function of the output. The second is the bloating of the synchronic grammar in order to prevent voiced stops from geminating in CS. The solution to these problems, I argue, is to recognize that RF, compensatory lengthening, and metathesis-induced compensatory lengthening produce geminate structures from all stop inputs, voiceless and voiced alike. The correct view is to analyze all three FORTITION processes as a singular, unified process that results in a phonological geminate, resistant to LENITION in the case of voiceless stops and surfacing as spirants in the case of voiced stops. This conclusion discards entirely the phonetic proper-

¹² [Kirchner \(2000: 513\)](#) argues that spirant outputs of geminates are possible so long as the geminate segment first degeminates. This leaves room for some ambiguity of interpretation. On the one hand, CS represents a counter example to the universal generalization made, since phonologically it does not degeminate. On the other, it does not represent a counter example since the phonetic output is not accompanied by a durational increase. This ambiguity is a consequence of the scrambling trope and threatens [Kirchner’s](#) claims with empirical vacuity.

ties of the segments in question, and depends only on phonological structure and behavior.

Following a general principle established by Hyman (1970), the advantage of positing such abstract structures is the explanatory value they provide¹³: patterns of spirantization and gemination are the result of two prosodic effects, one of LENITION and one of FORTITION. LENITION is a *melodic* process that targets voiceless stops in a weak prosodic position, triggering the loss of melodic material. FORTITION is a *prosodic* effect that spreads melodic material and results in phonological gemination *in all cases*. The result is a unified analysis of strength and weakness in CS, summarized in Table 5.2.

Table 5.2: A summary of positional effects in Campidanese Sardinian.

	/p t tʃ k/	/b d ɖ ɡ/
LENITION	[β ð ʒ γ]	[b d ɖ ɡ]
FORTITION	[p: t: tʃ: k:]	[β ð ʒ γ]

In this view, both weakening and strengthening are still metaphorical notions—their formal status is in their prosodic representations, and how each process falls out from prosodic structure (§5.3). The essential difference is in the underlying representations of the two surface intervocalic contexts, each of which corresponds to distinct underlying structural configurations, explicitly defined in §5.3.

Thus, in the CS facts, we have a notion of *weakness* manifest in obstruent lenition, and *strength* manifest in resistance to LENITION and geminate status. However, the observation that objects which do not undergo LENITION are geminates does not in itself constitute an explanation for their exceptional status, it merely provides an explanation for the distribution of CS surface consonants. Nor does it satisfy the requirements for a theory of lenition as in §5.1.2. In order to provide an explanation, the CS facts must be examined through the lens of a theory of representations.

5.3 PHONOLOGICAL REPRESENTATION IN CAMPIDANESE SARDINIAN

5.3.1 *The representation of timing positions*

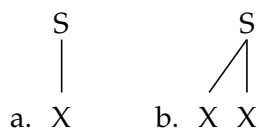
The examination of the empirical situation reveals an intricate pattern of spirantization, lengthening, and resistance to spirantization. In this section, I will elaborate an analysis of the prosodic structure of CS which shows this pattern can be understood to fall out from the effects of phonological computation in different prosodic positions. I argue that

¹³ Further examples of the explanatory power of virtual geminates in CS can be found in Lai (2015a,b), where it is shown that they allow for a deeper understanding of the behavior of certain word-initial obstruents, and a process of vowel epenthesis which occurs preceding s+C clusters and virtual geminates.

there are two processes at work, which I have called *LENITION* and *FORTITION*. *LENITION* is the result of a phonological process that works on melodic representations, but which crucially depends on the prosodic structure as a part of its structural description. *FORTITION* is the result of a phonological process which spreads melodic material by associating it to two timing positions, resulting in phonological geminates.

Here, singletons are represented as a single melodic segment associated to a single timing position (191a) while geminates are represented as a single melodic segment associated to two timing positions, as in (191b):

(191)



Any autosegmental theory (Archangeli & Pullyblank 1994; Clements 1986; Clements & Keyser 1983; Goldsmith 1976, 1990; Lowenstamm & Kaye 1985) with a skeleton can build structures like those in (191). The objective here is to make a connection between the structural associations of segments to timing positions in the prosodic structure and how phonological computation is influenced by them; in this way explanation for the facts in §5.2.2 can be provided.

The basic intuition is one based on phonological strength and weakness, where a segment being associated with two timing positions results in prosodic strength through *FORTITION*, and is thus immune to *LENITION*. The analysis thus presents two levels of representation, one prosodic and one melodic. I will begin by outlining the level of prosodic representation, with a particular emphasis on how prosodic structure interacts with *LENITION* and *FORTITION*.

5.3.2 Prosodic representations

To show this, let us first consider what kind of positional strength effects are attested cross-linguistically. Ségéral & Scheer (2008b: 135) provide a schematic view of the various configurations of consonant and vowel sequences and their characteristic positional strengths, reproduced in Table 5.3.

Table 5.3 suggests that as far as strength and weakness are concerned, three different positions need to be distinguished. The first is the word-initial and post-Coda position, which is a position of strength. In CS this strength is manifest in several ways—the power to license the realization of the full set of phonemic obstruents, and resistance to *LENITION*, as seen in all citation forms in §5.2.2. This protected position, {C,#}_, has been dubbed the *Coda Mirror* (Ségéral & Scheer 2001b; Scheer 2004a; Ségéral & Scheer 2008a; Scheer 2012). Diachronically, this posi-

Table 5.3: The five linear configurations of strength and weakness (Ségéral & Scheer 2008b: 135).

POSITION	USUAL NAME	
a. #_V	word-initial	} strong position
b. VC._V	post-Coda	
c. V_.CV	internal Coda	} Coda } weak positions
d. V_#	final Coda	
e. V_V	intervocalic	

tion has exhibited strength in the preservation of its Latin homologues in **CS**, shown in Table 5.4.

Table 5.4: Diachronic onset positional effects in Campidanese Sardinian.

a. #_		b. post-Coda	
p	petra(m) pɾɛða	corpus	krop:uzu
b	bucca buk:a	barba(m)	braβa
t	terra(m) tɛ:ra	dente(m)	denti
d	digitu(m) diðu	cardu(m)	kraðu
k	cane(m) kãĩ	concha(m)	kõnka
g	gattu(m) gatru	largu(m)	largu
f	focu(m) foɣu	infernu	inferru
v	vinu(m) bĩũ	servire	sreβiri
s	saeta(m) seða	*excursura	skissura
r	rana(m) ar:ana	magistrum	maistru
l	lacte lati	merula(m)	meurra
n	nocte(m) not:i	fornu(m)	forru
m	mare mari	formica	fromiɣa

The second position in Table 5.3 is the internal Coda and final Coda position, a position of weakness. Coda weakness is manifest in **CS** as severe restrictions on what segments are licensed¹⁴ in that position. In lexical forms, the full set of possible Codas is /r s t/, a nasal consonant homorganic for place with a following consonant, and the first element of a geminate (Jones 1988; Bolognesi 1998; Molinu 1999; Lai 2021). Generally, /s/ and /t/ codas are the result of morphological concatenation, as in for example PLURAL nouns or 3SG verb endings. On the surface, however, /s/ and /t/ trigger either the epenthesis of a copy vowel identical to the final vowel in the stem, as in /kanna-s/ [kan:a-z(a)] ‘reeds’, or are deleted in final position, as in (187). In turn, /r/ is subject to a number of processes of metathesis which means its distribution as Coda is restricted to word-medial position in a limited

14 See Itô (1986, 1989) for the notion of *coda licensing*.

number of lexical items, as in the examples in (189). This leaves the set of surface Codas limited to word-medial /r/, /s/ in s+C clusters, homorganic nasals¹⁵ and the first element of geminates. Diachronically, this position is distinguished from the strong position in that Latin Codas have mostly been lost in CS (Virdis 1978), as in Table 5.5.

Table 5.5: Diachronic coda positional effects in Campidanese Sardinian.

	_.C		C#	
p	nepta(m)	nɛ:ta		
b	subtīlem	sut:ili	de ab	dɛ
t			venit	bɛni/bɛniði
d	adventura	av:entura	ad	a
k	lectu(m)	let:u	illoc	ɖ:oi/ɖ:ui
g	cognatu(m)	kon:au		
s	canistellu(m)	kāistedɖ:u	cras	krazi
r	porcu(m)	prok:u		
l	albescere	obɾɛʃ:i		
n	cantare	kantai		
m	comprehendere	kumprendiri	jam	ɖʒa(i)

The third position is the intervocalic position. Weakness in this position is synchronically evident in that this position is targeted by LENITION. Diachronically, voiced obstruents in this position were mostly lost, while voiceless segments were preserved (Virdis 1978), as shown in Table 5.6.

The review of diachronic positional effects in CS is conform with the observations made by Ségéral & Scheer (2008b: 135) that there are two ways of being weak—pervasive generalizations which should be reflected in theory. Looking at synchronic effects in CS, we can establish three position effects:

1. Strong—the Coda mirror: LENITION is inert, host to the entire consonantal inventory
2. Weak—Coda: severely restricted licensing power
3. Weak—Intervocalic: target of LENITION

The different synchronic and diachronic effects exhibited in each of the three positions correspond to the intuition that weakness is a manifestation of loss or erosion, while strength is resistance to those processes. The three different positional effects also require prosodic structure that recognizes each of them. A hierarchical syllable with an

15 Two words in the native lexicon end in /N/, the prepositions *in* ‘in’ and *kun* ‘with’. In both cases, the nasal is realized homorganic with a following C, or as a nasal vowel if the following word begins with a vowel.

Table 5.6: Diachronic intervocalic positional effects in Campidanese Sardinian.

V_V		
a.	p	ape(m) aβi
	b	nube(m) nui
	t	acetu(m) azeðu
	d	pede(m) pɛi
	k	ficatu(m) fiɣau
	g	nigellu(m) niedɻu
	f	trifoliu(m) trivul:u
	v	ovu(m) ou
	s	pausare pazai
b.	l	sole soβi
	r	cera(m) tʃɛra
	m	femina(m) femiã
	n	luna lũã
c.	pp	appellare ap:edɻai
	tt	gutta(m) gut:a
	kk	vacca(m) bak:a
	bb	sabbatu(m) saβuðu
	dd	adducere bat:iri
	ss	tussire tus:iri
	ll	sella(m) sɛɻ:a
	rr	carru(m) kar:u
	nn	annu(m) an:u

onset and coda can distinguish between strong onsets and weak codas, but it cannot isolate the intervocalic position, which is typically viewed as an onset despite its distinct phonological behavior that contrasts with the onsets of the Strong Position.

5.3.2.1 *The analytic tool: Strict CV phonology*

In order to capture the three distinct prosodic positions, this analysis makes use of the basic machinery of Strict CV phonology (Lowenstamm 1996; Scheer 2004b, 2012), a development of the GP program (Charette 1990; Harris 1990; Kaye et al. 1990; Harris & Kaye 1990). In Strict CV phonology, prosodic structure is built not out of hierarchical arborescent structures, but out of *lateral relationships* between constituents on a CV tier. This means that the three different positions of strength and weakness are distinguished by the different configurations of lateral relations between members of the CV tier (for Strict

CV analyses of related phenomena in other Italo-Romance languages see [Passino 2013](#), as well as [Scheer 2012](#): 208 ff. for Corsican, [Russo & Ulfsbjorninn 2020](#) for Neapolitan, and [Lai 2013, 2014, 2015b,a](#) for different effects in Sardinian).

The CV tier is built out of a fixed, invariable sequence of CV units: C positions are always followed by V positions, even if surface realizations do not reflect the same sequence of consonants and vowels ([Lowenstamm 1996; Scheer 2004b, 2012](#)). [Lowenstamm \(1996\)](#) marshals arguments from various languages which demonstrate that rigid CV structure allows for a number of generalizations concerning length and prosodic effects to be explained. C and V positions must be associated with melodic material in order to be realized on the surface, meaning that no feature can be given phonetic exponence without being part of the prosodic structure, and that CV positions may remain unrealized as empty prosodic structure.

Since the *only* prosodic information is CV units and the lateral forces, all morphological boundary information—information which communicates with the interfaces and is translated from morphology—is in the form of CV units ([Lowenstamm 1999; Scheer 2009, 2012](#))¹⁶. Here, C and V are substance free: they do not have any direct articulatory correlates, since they contain, in principle, no melodic material themselves. Features such as Consonantal and Vocalic do not have a single measurable property which can be used to distinguish between them ([Vennemann & Ladefoged 1973](#): 62). Thus, as [Clements & Keyser \(1983\)](#) argue, neither C nor V can be characterized in phonetic terms since neither has invariant phonetic correlates; instead they represent primitives whose justification rests on theory-internal principles and make a set of LSGs. In Strict CV, the difference between C and V lies in their distinct licensing powers: as will be shown, V positions may license and govern, but C positions may do neither.

A further desideratum of the theory is to explain geminate inalterability through emergent properties of the basic formal structure. Thus, rather than stipulating in the grammar that geminates are immune to LENITION, geminate inalterability should naturally fall out of basic prosodic structure.

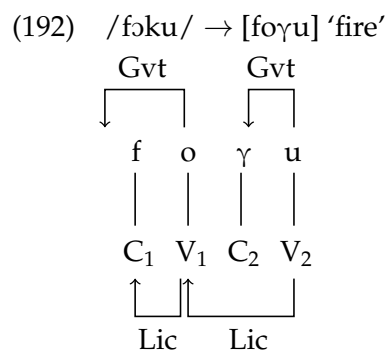
To that end, let us see how prosodic structure is built in Strict CV. CV relations are defined by two lateral forces: *government* and *licensing*. Thus, following [Kaye et al. \(1990\)](#), co-occurrence restrictions between adjacent segments are not due to hierarchical syllabic structure, but due to lateral relations between the segments; “branching onsets” or “onset and coda”, for example, are not in a relationship derived from an arboreal hierarchy, but one derived strictly in terms of the lateral relationships between them.

Syllabic structure then is not a phonological primitive *per se*, but a derived property of adjacency relations. Roughly speaking, *government* is a force which serves to weaken or inhibit melodic material, while *licens-*

16 The difference between a CV unit and a conventional # is that a CV unit is a true phonological object through which morphology is translated into phonology, while # is an arbitrary diacritic whose only function is to mark morpho-syntactic boundaries.

ing reinforces it. Both work from the right edges of words, propagating back—V positions with melodic material may govern and license constituents to their left. Following Scheer (2012), there is a hierarchical relationship between governing and licensing: they cannot both exert influence on the same segment. If a segment is potentially subject to both lateral forces, it will be subject to government. In turn, licensing will influence the next available segment. When a CV unit is full of melodic material, the V position will contract a relationship of licensing from any following licenser, while the C position will contract one of government.

The two forces can be seen in (192)¹⁷:



In (192) the final vowel V₂ governs the medial consonant C₂, while licensing the first vowel. In turn, V₁ has nothing to govern, and so licenses C₁. The result is a strong position: it is licensed and ungoverned. Thus, [+Lic] is a formal configuration of prosodic structure that reinforces and does not diminish melodic primes; in CS, this lateral configuration is phonologically stable. The position of the intervocalic C₂ is an onset like C₁, but has a distinct status in this representation, since it is governed, but not licensed: [+Gov]. This position is where LENITION occurs.

Since it is filled V positions which license and govern, and Codas are followed by empty V positions, they do not enter into any lateral relationship [-Lic -Gov]. The result is a position that cannot support and rather diminishes melodic primes. This weak position is subject to severe co-occurrence restrictions, with only /r/, homorganic nasals, or the first part of a geminate being allowed to surface as a Coda in CS.

5.3.2.2 Consonant clusters and the initial CV

In order to understand why C₁ in (192) is not governed by V₁ and thus not a target of LENITION, let us briefly consider two robust typological generalizations related to consonant clusters and what they tell us about prosodic structure. The first is the special relationship between

¹⁷ Note that in (192) and all Strict CV representations in this analysis, C and V positions are numbered only for expository purposes, such indexing has no status in the formal theory itself. Though see Raimy (1999, 2009) and Papillon (2020) who argue that precedence relations should have an explicit formal status that goes beyond a simple skeletal tier.

the two constituents of TR clusters, known in lateral phonology as *infrasegmental government*. (Scheer 2004b, 2012). Infrasegmental government (formalized as $T \leq R$) is a specific kind of government which holds between constituents of branching onsets, and has the effect of suppressing exponence of the V position between the two members, which remains empty. In contrast to other empty V positions the empty V positions in TR clusters are good lateral actors, and may contract government and licensing relationships with other CV positions.

In contrast, RT and TT clusters are *bogus clusters*, and do not show the same kind of cohesiveness as TR clusters. To see this, consider Meridional French, where mid-vowels are always realized as mid-open [ɛ œ ɔ] when in closed syllables, and as mid-close [e ø o] when in open syllables (Durand 1995) (193):

- (193) *sor.ci*[e] ‘wizard’
 sor.ci[ɛɸ] ‘witch’

Since the conditioning of mid-vowels is a syllabic effect in Meridional French, it is a reliable indicator of syllabic constituency: open vowels are conditioned by following tautosyllabic consonants, close vowels by following heterosyllabic consonants or the right edge of the word.

- (194) a. *p*[ø].*pli.er* ‘poplar tree’
 s[o].*bre.ment* ‘soberly’
 b. *p*[œl].*ven* ‘kind of stele’
 s[ɔɸ].*bet* ‘sorbet’

In (194a), the post-nuclear consonant clusters do not close the first syllable, they are tautosyllabic. In contrast, the same vowels in (194b) are mid-open, meaning the syllable is closed by the following consonant and that the clusters are heterosyllabic: there is a syllabic frontier between them.

The second typological observation concerning initial consonant clusters is articulated in Lowenstamm (1999): while languages which allow only TR clusters word-initially are attested, and languages which allow RT and TT clusters as well as TR clusters in this position are attested, a third possibility—languages which only allow RT clusters at the expense of TR clusters word-initially—is not attested. The non-arbitrary nature of this gap suggests it is systematic (see §4.3.2); phonological theory, then, should allow for TR-type languages and free-order languages while making RT-type languages impossible.

In formal, SFP phonology, this must be done without stipulating arbitrary restrictions on onset clusters. Lowenstamm showed that an object called *the initial CV* does just this: languages which allow TR clusters have an empty initial CV, while those which allow any kind of cluster do not. Since empty CV units represent morphological boundaries in lateral phonology¹⁸, lexical entries may contain an empty initial CV

18 This is coherent with a modular model of phonology, since it represents a translation of morpho-syntactic information into phonological vocabulary. This is in contrast

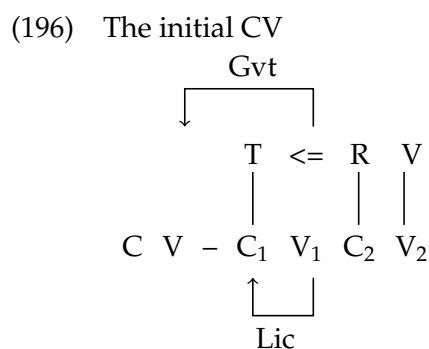
at the left edge of words, which enters into a lawful lateral relationship just like any other CV position. In free-order languages, there is no lexical initial CV, and the configuration of lateral relationships is correspondingly different.

CS is a TR-pattern language, permitting complex onsets as in (195):

- (195) kroβu 'crow'
 gruta 'cave'
 mraʒãĩ 'fox'
 ʃroβeɟ:u 'brain'

On the other hand, RT and TT clusters are not permissible onsets. Further, as for words in French such as *pol.tron* 'coward', words in CS such as /n.truʃi/ 'vulture' show that in sequences of three consonants, the latter two consonants must be a legitimate onset cluster: CTR is a possible cluster, but *CRT is not.

We are now in a position to see how infrasegmental government interacts with the initial CV to capture the generalization described by Lowenstamm (1999)—since the empty V position between TR clusters is subject to infrasegmental government while the one between RT and TT clusters is not, it can lawfully govern the C position in the initial CV (196):

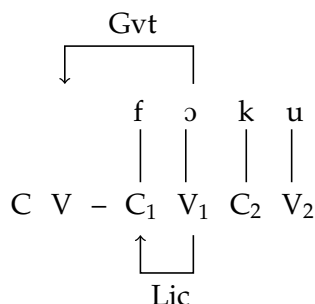


In contrast, in RT clusters, V_1 is governed by V_2 , and as such, would be unable to govern the V position in an initial CV—the resulting structure would be ill-formed. The presence or absence of the initial CV is a language-specific parameter: TR-type languages have it, while languages with free order do not. Its presence means that TR clusters are lawful, while its absence allows for free order, and no parameter can specify for the unattested RT-only type languages. The initial CV provides an account for several cross-linguistically prevalent effects—the cross-linguistic distribution of word-initial clusters just discussed, the stability of the first vowels in words, and the positional effects of the Coda Mirror for word-initial consonants (Scheer 2012: 146)—all effects which a theory of phonology must be able to account for.

Now reconsider the representation (197):

to objects such as #, which play no other role in phonology and *only* serve to mark morphological boundaries.

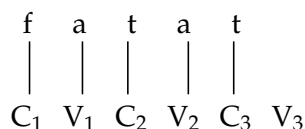
(197) /fɔku/ → [foɣu] ‘fire’



Here, V₁ governs the empty V position of the initial CV, while it licenses C₁. This means that C₁ is in the position of the Coda Mirror; being [+Lic], it is not subject to lenition.

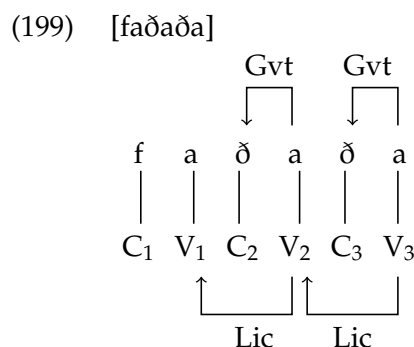
The nature of the strict ordering of CV elements in lateral phonology, along with CV-interpreted morpho-syntactic information, means that there is potential in any representation for several empty C or V positions—positions with no associated melody. However, it seems languages impose restrictions on the number of empty positions tolerated in a given prosodic representation. In CS, for example, a word such as /fatat/ ‘do-3SG’ has the following underlying representation (198):

(198) /fatat/



The representation in (198) has an empty V position in V₃; such objects are known as *empty Nuclei*. In lateral phonology, in order to remain unexpressed, positions must contract a lateral relationship of government, either with a following V or through infrasegmental government; if an empty Nucleus cannot contract a lateral relationship, it must be expressed¹⁹. In CS this restriction results either in the deletion of the Coda or in the realization of a paragogic copy-vowel identical to the stem-final vowel in ungoverned empty V positions. The representation in (199) is the surface realization of (198):

19 This appears to be another parametric choice; in some languages final empty nuclei can remain empty or even exert an effect on prosodic structure by being good licensors, see Scheer (2012).



As such, lateral relations not only effect phonological computation, but they also define the well-formedness of a string (Scheer 2012). As an example, consider the following forms in Moroccan Arabic (Kaye et al. 1986; Kaye 1990b) (200):

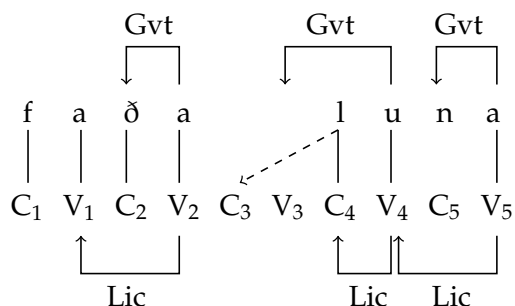
- (200) tan ktib 'I write'
 tan kitbu 'we write'

In Moroccan Arabic, there are no restrictions on the distribution of initial consonant clusters save the number of their members: no more than two (Lahrouchi 2018). A corollary to this observation is that while vowels may alternate with zero, there are never two adjacent zero-vowel realizations in a string. In Strict CV terms, this translates to an observation that there is never more than one empty V position nucleus in a given string. Empty Nuclei are argued to play a crucial role in the understanding of vowel/zero alternations in a variety of languages (Kaye 1990b,a; Charette 1990).

The observation that there are conditions on Empty Nuclei led to the formulation of the Empty Category Principle (ECP) (Kaye 1990a,b; Kaye et al. 1990), which states that a position may only stay uninterpreted if it is governed—a kind of well-formedness condition that says a string is ill-formed if it contains an ungoverned Empty Nucleus. In order to remain unexpressed, a V_1 must be governed by a following V_2 , if V_2 is empty, it cannot govern V_1 . This predicts that there may not be a sequence of two consecutive Empty Nuclei: an empty V_2 cannot govern a preceding V_1 , which thus cannot remain empty and must be phonetically expressed. In classical terms, the result is epenthesis. In this way, well-formedness does not come from outside of phonology in the form of arbitrary constraints—rather it is the result of lateral relations (see Lai 2015b,a for a discussion of ECP effects in Sardinian).

The second solution for the problem presented by lexical items such as /fatat/ is to delete the final consonant. This solution is available when there is a following C-initial word, since final and internal codas do not have the same status in CS. The latter precede a governed Nucleus, which thus cannot be expressed and so cannot contract any kind of lateral relationship with any final consonant. This consonant then falls and triggers compensatory lengthening of the following word-initial consonant, as for /fatat luna/ 'the moon is shining', represented in (201):

(201) /fatat luna/ → [faða l:ũã] ‘the moon is shining’



In (201) it can be seen that V₃ is governed by V₄, and remains empty. Additionally, it is obvious that Codas, as in C₃, do not enter into any lateral relationships, being unlicensed and ungoverned. This position, [-Lic -Gov], imposes severe distributional restrictions on segmental material in CS, licensing only /r/, /s/ in s+C clusters, nasals homorganic with the place of a following consonant, and the first part of geminates.

What is the content of this restriction on Coda licensing? Harris (1990) and Cyran (2008, 2010) argue that the amount of melodic material in a segment corresponds to its *substantive complexity*; the more melodic material in a segment, the more complex it is. Cyran (2010) argues that substantive complexity has consequences for prosodic structure, since the more melodic material a segment has, the more licensing strength it requires. Such *complexity scales* mean that positions which are not licensed cannot host as much melodic material as those which are.

In CS, positions which contract no lateral relationships—Codas—are weak, licensing only minimally complex segments. In particular, Codas may license nasal segment homorganic for place and the first part of geminates, structures which have in common the “sharing” of melodic material with following segments. In these cases the strength of the structures is reflected by the sharing of segmental material that would otherwise be prohibited in [-Lic -Gov] positions (Honeybone 2005b).

In sum, lateral relations define the three positions of prosodic strength, with each receiving a unique prosodic identity. Importantly, they define the Coda Mirror as a position which is [+Lic], making it formally distinct from the intervocalic position, which is [+Gov]. Finally, since Codas do not contract any lateral relationships, being [-Lic -Gov], their power to license contrasts is reduced. The three positions are summarized in Table 5.7.

Table 5.7: The lateral relations of the three positions of strength.

	Strength	Governed	Licensed
The Coda Mirror	strong	no	yes
Intervocalic	weakest	yes	no
The Coda	weak	no	no

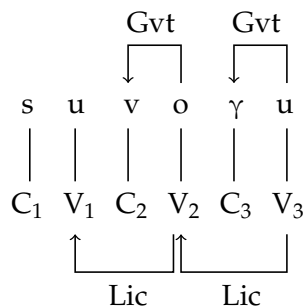
In the theory of lateral phonology elaborated above, both licensing and government have particular effects on melodic material—the former tends to protect melodic material while the latter erodes it. Distinguishing between the three positions means that the context of LENITION in CS can be given a unified context: [+Gov]. Only segments with this lateral configuration can be targeted by LENITION, any other configuration is exempt from its effects.

5.3.2.3 Prosodic position and geminate inalterability

We are now in a position to see how prosodic position interacts with LENITION, FORTITION, and gives rise to geminate inalterability—and how the notions of *strength* and *weakness* may be understood in SFP.

First, let us consider the case of LENITION, which targets intervocalic obstruents (202)²⁰:

(202) /ssu foku/ → [s:u voɣu] ‘the fire’



In (202), V₃ licenses V₂, which in turn licenses V₁, leaving both C₃ and C₂ [+Gov], making them weak positions. Since those positions are associated to voiceless consonants, LENITION takes place, and each consonant is realized on the surface as the corresponding allophone.

One prediction made by this theory is that intervocalic positions which are word-medial, such as C₃, are also [+Gov], and thus potential targets for LENITION. While I presented conceptual arguments for considering spirants in this position to be the result of lenition in §5.2.2.1, to those arguments can now be added a theoretical one—this position is weak by virtue of its prosodic structure; any potential target in this position will be subject to LENITION. This is exactly how a learner is able to recover singletons in this position, since any surface stop in a word-medial position is a geminate, any surface spirant is a singleton²¹. Thus, the simplifications to the grammar that come from

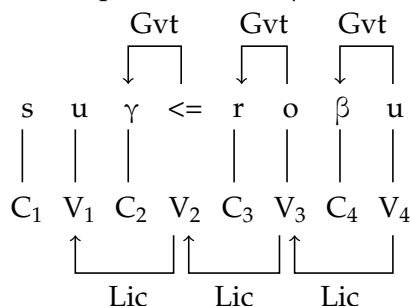
20 As noted previously, /ssu/ in fact contains a geminate structure. This is not represented in (202) for practical, expository reasons, and does not change the outcome for LENITION.

21 Since voiced geminates and voiceless singletons are neutralized to spirants, one question is if the underlying representation of word-medial surface spirants could ever be a voiced geminate and how a learner would ever know. Following the tenets of FP, it is hypothesized that when confronted with cases of absolute neutralization, learners make the simplest assumptions possible regarding underlying representations. In this

assuming LENITION is active in this position falls out from the lateral relations of intervocalic consonants.

In (203), it can be seen that the same prosodic structure [+Gov] triggers LENITION in branching onsets.

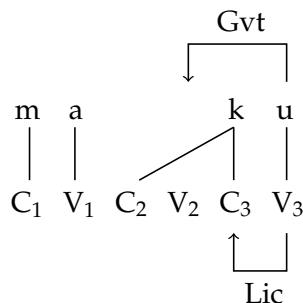
(203) /ssu krɔpu/ → [s:u ɣrɔβu] ‘the crow’



Here, V_2 is circumscribed by infrasegmental government, leaving it empty and making it a good licenser: it licenses V_1 , leaving C_2 [+Gov], and thus a target of LENITION.

As argued in §5.2.2.3, in CS phonetic duration is not a correlate of phonological geminates, it is rather resistance to LENITION that is the defining characteristic of phonological geminates. Strict CV predicts that any C position which is [+Gov] is weak, and since geminates are not a target of LENITION, they must have a different lateral configuration, corresponding to prosodic strength. We can see this is in fact the case for lexical geminates, as in *makku* ‘crazy’ (204):

(204) /makku/ → [mak:u] ‘crazy’



As in all geminates, there is an empty V position between the two C elements of the geminate consonant. This empty V must be governed to remain empty. In (204), V_3 governs the empty position V_2 and licenses C_3 , leaving C_3 in the strong position, [+Lic], and rendering it thus immune to LENITION. C_2 , in turn, contracts no lateral relationship, leaving it in the Coda [-Lic -Gov], which is also immune to lenition. Since in the case of (204) the Coda is the first element of a geminate, the weak position C_2 is able to license the melodic material inherited from C_3 . This gives us a formal representation of *strength* inherent in lateral relations, and their interaction with multiply-associated segments determines where LENITION is active and where it is not.

case, faced with the choice between a singleton /p/ and a geminate /bb/, learners assume the singleton is the underlying representation.

5.3.3 *Melodic representations*

Before coming to an examination of the computational wing of CS, an examination of the organization of the consonantal system is in order. I do not address the vocalic system because it is not implicated in LENITION or FORTITION, but a full analysis of CS phonology would require such an analysis. In this section, I will introduce a system of formal representations and their organization as relevant for LENITION and FORTITION. The principal ambition of this section is to show how LENITION modifies melodic structure.

Table 5.8 is a phonological schema of the phonemic consonants in CS. A few precisions are in order. The segments /ɖ/, /v/ and /ɲ/ are exceedingly rare, and found only in recent loan-words from Italian (Lai 2021); their rarity however does not preclude them from analysis. The retroflex /ɖ/ is only ever encountered as a geminate, and with the exception of the object proclitics [ɖ:a(s)], [ɖ:u(s)], [ɖ:is], is only found word-medially. All other consonants in Table 5.8 are phonemic word-initially.

Table 5.8: The consonantal segments in Campidanese Sardinian.

	STOPS	FRICATIVES	LIQUIDS	NASALS
LABIAL	p b			m
LABIODENTAL		f v		
DENTAL	t d			
ALVEOLAR	ts ɖ	s	l r	n
POSTALVEOLAR	tʃ ɖʃ	ʃ		ɲ
RETROFLEX	ɖ			
VELAR	k g			

The organization of Table 5.8 deserves some discussion, especially as regards the decision to place the coronal stops /t d ts ɖ/ at distinct places of articulation. This follows from two principles: the first is one that says affricates are phonological singletons, simple stops with no continuant element or friction (Clements 1999; Scheer 2003). Indeed, in CS, when /tʃ/ geminates, it is the stop portion which becomes long, as in [frattʃi] ‘sickle’ and [kruttsu] ‘short’. Though the articulatory configuration of affricates is much like that of fricatives, phonologically they pattern with stops (LaCharité 1993; Berns 2008). Kehrein (2002: 5) is explicit on this point, arguing that nothing in their underlying representations allows for stops to be distinguished from affricates, which he terms the *Generalized Stop Approach*. Two predictions fall out from this: affricates do not constitute a natural class, and neither do affricates and fricatives; in contrast, stops and affricates do (LaCharité 1993).

For LaCharité (1993); Clements (1999) and Kehrein (2002), the difference between affricated and non-affricated stops is one of place distinctions. This is because affricates rarely have a corresponding plosive

at the same place of articulation, while they frequently share a place of articulation with fricatives (Berns 2008: 102). LaCharité (1993: 75ff) refers to this as the *stop-affricate dependency*: where stops and affricates occur at the same place of articulation, and where they are contrastive, there must be a feature distinguishing the class of stops from the class of affricates; the place distribution of affricates is dependent on the distribution of stops, and affricates and stops are in complementary distribution with respect to place of articulation.

For example, in the post-alveolar place, there is a fricative [ʃ] but no stop; [tʃ] can step into the breach and serve as a stop in phonology. In this sense, affricates are the phonetic representatives of stops in places where stops cannot be realized (Scheer 2003). In this view, affrication is a phonetic characteristic, not a phonological feature. To distinguish between /t d/ on the one hand and /ts ɖ/ on the other, each pair is assigned a distinct *phonological* place of articulation.

An additional comment can be made on the distribution of stops, fricatives, and liquids, especially where each contains a voiced and voiceless member. There is a voluminous literature on how voicing contrasts are represented in phonology and implemented phonetically (Halle & Stevens 1971; Keating 1984; Iverson & Salmons 1995, 2006, 2011; Lombardi 1995; Avery & Idsardi 2001; Honeybone 2005a; Cyran 2014). What is important here is that, with the exception of /ts/ which is always a geminate, each place of articulation has a leniting member (on the left), and a non-leniting member (on the right). Each segment on the left in Table 5.8 is a member of the exact class targeted by LENITION. However, LENITION cannot be targeting just voiceless segments, since it also targets /l/. I suggest that the distinction between voiceless and voiced obstruents in CS can be profitably conceived as being one of fortis and lenis, respectively. Consequently, the target of LENITION is the set of fortis segments: /p t tʃ k f s l/.

Here, applied to CS, fortis and lenis are labels of convenience, based on the observation that the articulation of /p t tʃ k f s l/ is stable throughout the process of FORTITION, while that of /b d ɖ g/ is not, resulting in spirants. Conversely, /p t tʃ k f s l/ are realized with phonetic voicing after LENITION, a property of lenis articulations. The contrast between fortis and lenis in CS is not expressed phonetically the way it is in Germanic, but as true voicing as is typical in Romance (cf. Cyran 2014 for Polish and Iosad 2017 for Bothoa Breton, where it is argued that the relationship between phonetic voicing and phonological voicing is arbitrary). In CS, lenis is realized with active closure voicing, and fortis realizations are not realized with aspiration (Keating 1984).

The final question to be treated in this section is the content of melodic representations, and how that content is determined by learners. In §4.4.2, it was argued that phonetics/phonology mismatches mean that inspection of the surface qualities of segments does not reveal their phonological identity. Instead, following Kaye's epistemological principal (recall §4.4.2.1), phonological knowledge comes from phonological behavior.

In a theory without a set of universal, UG determined features, knowledge of featural specifications comes from the examination of how a segment functions in a phonological system Odden (to appear). In FP, features specifications are arrived at through a process of induction, based on what is required by the grammar. The grammar requires two things of features: that they mark contrast (§1.1.3.1), and that they define those classes of segments and how they pattern in phonological rules (§1.1.3.2). Substantive, phonetic properties are irrelevant to this discovery procedure²².

5.3.3.1 *The role of contrast*

As the minimal units of *difference* in phonology, Hall (2007); Dresher (2009) suggest that phonological computation operates *uniquely* over contrastive features—non-contrastive aspects of phonology are invisible to phonological computation. This is what Hall (2007) terms the *contrastivist hypothesis* (205):

(205) *The Contrastivist Hypothesis* (Hall 2007: 20):

The phonological component of a language ℓ operates only on those features which are necessary to distinguish the phonemes of ℓ from one another.

The contrastive hypothesis emphasizes the important role contrast plays in defining phonological systems. Because every language has a particular system of contrasts, every language uses different features, organized in a language-specific way. In a theory in which this system is not innate, it must emerge over the course of acquisition. As a corollary, the *contrastive hierarchy theory* says that learners arrive at a set of hierarchically ordered features that allow all phonological contrasts in their language to be expressed (Dresher 2009, 2014, 2018). Dresher (2018) argues that the theory imposes strong constraints on the number of features that can be posited in a given system.

Dresher (2009, 2014, 2018) further argues that contrasts are organized hierarchically by ordered features, an organizational scheme which can be expressed as a branching tree. Those trees are generated by what he calls the *Successive Division Algorithm* (206):

(206) *The Successive Division Algorithm*:

Assign contrastive features by successively dividing the inventory until every phoneme has been distinguished.

The successive division algorithm selects and orders features based on the phonological activity in a language, where active features that play a role in computation and are contrastive are phonologically active. Learners thus construct a set of hierarchically ordered features that distinguish between every phoneme in their language. Since such

²² For expository purposes a feature may be called [dental], but this is not a formal claim about articulatory or acoustic properties, since the interpretation of features is learned and a function of post-phonological spell-out.

hierarchically ordered systems limit the number of features available in a given language, they explain why phonological systems reuse the same features, rather than having a single feature for every segment (see Clements 2003).

The successive division algorithm begins with a single undifferentiated phoneme. As learners discover contrasts, say between a stop specified for [voice] and a stop without that specification, that single phoneme splits into other phonemes as a function of contrasts in the language, so the stop specified for [voice] may split into /b d g/ and the stop without [voice] may split into /p t k/, each specified for some distinguishing feature, say [labial], [alveolar], or [velar]. Upon completion of the hierarchy, all segments in a language have a unique feature specification that serves to distinguish each one from the others.

While Hall (2007) and Dresher (2009) view contrast as the principle marker of phonological activity and thus the most important determining factor in the construction of feature systems, they recognize that how segments pattern in phonological activity can also determine the features used in a phonological system. Odden (to appear) argues rather that it is principally through phonological computations that features emerge. In this view, as in the contrastive view, the set of feature specifications in a phonological system is the simplest possible, with only the minimal number of features needed to account for phonological processes emerging. The two views are by no means incompatible. Indeed, in a language such as Hawaiian or Vietnamese, where patterns of segmental alternation are insufficient to provide adequate computational evidence for features, contrast must step into the breach so that every phonemic segment can be distinguished from every other.

Before discussing how the successive division algorithm can account for the organization of consonantal features in CS, a brief review of segmental processes that reveal phonological activity and feature specifications is in order. The relevant processes are as follows:

1. Lenition
2. s+C voicing
3. Nasal place assimilation

Each will be discussed in turn.

5.3.3.2 LENITION *and melody*

The process of LENITION has been extensively covered already in this chapter (§5.2.2.1). I argued in §5.3.3 that LENITION targets the class of segments /p t tʃ k f s l/, and that this class of segments may be referred to as fortis, specified by a feature [fortis]. Those segments which are not targeted by LENITION do not have any specification for [fortis].

5.3.3.3 *s+C voicing and melody*

The next phonological process that must be account for is a process of voice agreement in s+C clusters. In CS, the sibilant in s+C clusters always agrees in voice with the following consonant, as when the negative morpheme /s-/, meaning approximately ‘to undo’, is affixed to a stem word, as in for example *zvenai* ‘to bleed out’ [z-vənai]. This process is synchronically active (Bolognesi 1998: 62, 172), and is responsible for a systematic distribution of voiceless [s] before voiceless consonants (207a), and voiced [z] before voiced consonants (207b):

- (207) a. [st]allai ‘to remove an object’
 [sp]untau ‘blunt’
 [sk]onkau ‘senseless’
 [stʃ]rebeddai ‘to drive mad’
 [sf]ilau ‘frayed’
- b. [zb]allju ‘mistake’
 [zd]orrobba ‘to rob’
 [zg]annai ‘to cut someone’s throat’
 [zn]uai ‘to unknot’
 [zm]oviri ‘to remove’
 [zl]umbai ‘to cripple someone’
 [zr]olotai ‘to unroll’
 [zv]aporau ‘a scent or taste that fades’

Since /s-/ is realized as [z] when preceding /b d g n m l r v/, the latter are united by [voice] which spreads back to /s-/. Forms of /s-/ before /f ʃ ɕ ɖ ɲ/ seem to be unattested. This is probably a fact about distribution rather than representations, though since these segments never produce voice assimilation, they are assumed to not contain the feature for [voice], since there is no evidence a learner could ever be exposed to that would suggest they contain the feature active in the assimilation process in (207b), despite their interpretation at spell-out as phonetically voiced segments.

5.3.3.4 *Nasal place assimilation and melody*

There is an additional distributional fact in CS which can be accounted for with a synchronic phonological process: there are no cases of N+C clusters where the place specifications for the two segments differ. That is, a nasal segment followed by a consonant will always agree in place with a following consonant, both in monomorphemic words and across word-boundaries in external sandhi, as when for example the word *kun* ‘with’ precedes some other consonant-initial word (208)²³.

²³ Data from Bolognesi (1998: 62, 128).

- (208) a. i[mp]ari 'together'
 ku[mm]ama 'with mother'
 i[mb]iɖ:a 'in the village'
- b. u[ɲf]rau 'swollen/offended (of person)'
 i[ɲv]ecia 'instead'
- c. ko[nt]anta 'tell-3PL.PST'
 i[nd]omu 'at home'
 ku[ns]oli 'with sun'
 [nts:]aras 'in front'
 fru[nɖ]a 'slingshot'
 ku[nl]atti 'with milk'
- d. fawa[ɲt]u 'liars'
 me[ɲɕ]anu 'morning'
- e. pra[ɲɖ:]i 'to have lunch'
- f. i[ɲg]uni 'there'
 ka[ɲk]u 'some, any'

Since only nasals undergo this process of assimilation, they can be united into a natural class through the specification [nasal]. Nasal assimilation further provides valuable evidence to the learner that some feature spelled-out as place of articulation is a part of the lexical representation of consonants. Those places of articulation are [labial] (208a), [labio-dental] (208b), [dental] (208c), [post-alveolar] (208d), [retroflex] (208e), and [velar] (208f). In addition, as per the discussion concerning the organization of Table 5.8, there are distinct places of articulation for the sets of coronal stops /t d/ and /ts ɖ/. The former are specified as [alveolar], while the latter are specified as [dental]. This specification, which is not apparent in surface patterns, is due to the fact that there is no phonological process or pattern which could be used to distinguish between these sets, despite their contrast.

In line with the contrastive hypothesis, there *must* be something to distinguish between them in their representational specifications. While the process of place assimilation will produce [n] for both /t d/ and /ts ɖ/, all that [alveolar] and [dental] need to express is a *contrast*, their exact phonetic expression is determined at spell-out, and there is nothing that prevents spell-out from interpreting the phonological labels [alveolar] and [dental] as phonetically identical places of articulation. The contrast between /t d/ and /ts ɖ/ is recorded in their distinct melodic content. In turn, since place of articulation features are above all markers of contrast, /ʃ/ can be indexed to the feature [velar]. In this sense, these place of articulation features indicate nothing more than a difference (Saussure 1916 [1967]: 166).

5.3.3.5 *The contrastive hierarchy in Campidanese Sardinian*

Having surveyed the above evidence for phonological activity, a feature hierarchy that produces the feature system of CS can be determined:

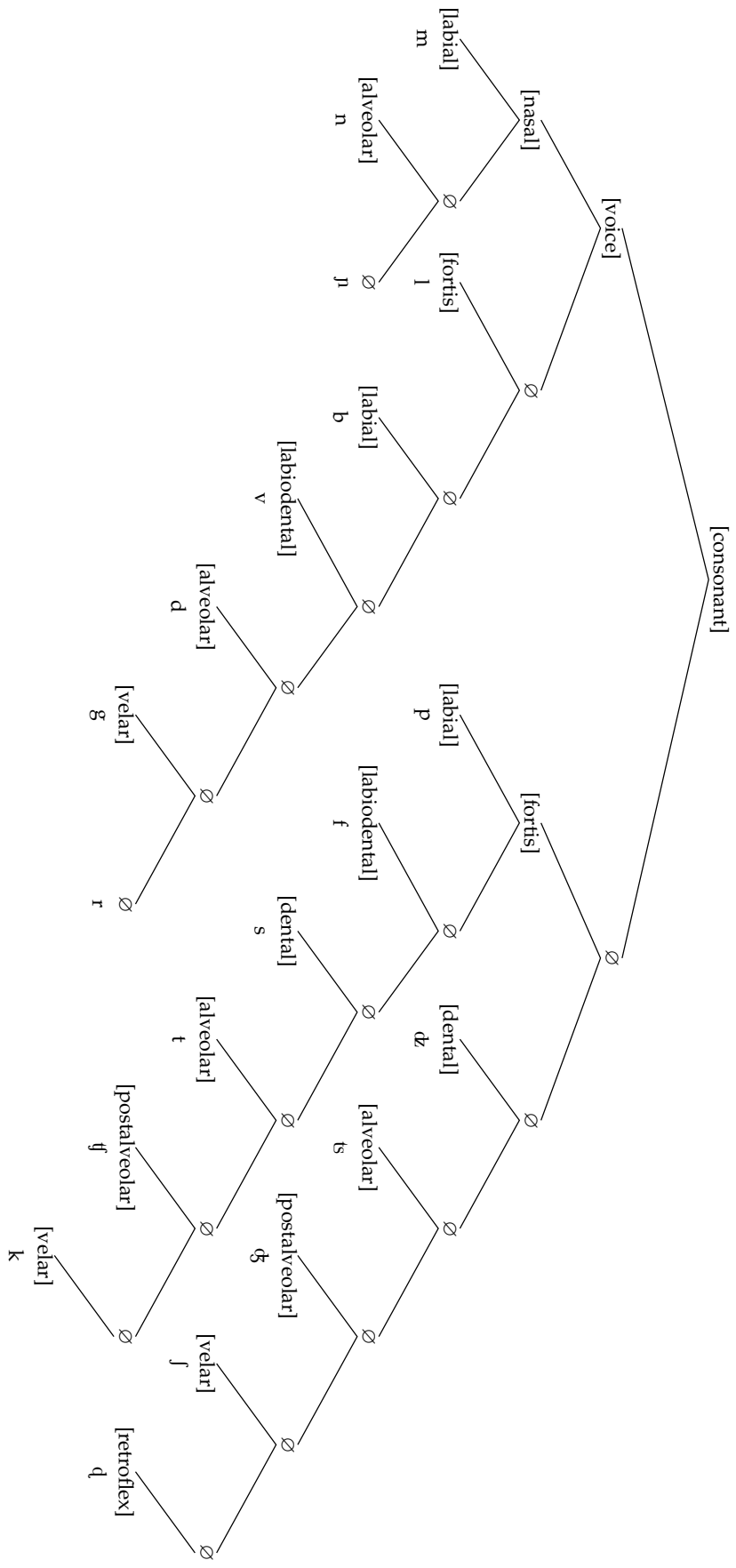


Figure 5.2: The contrastive hierarchy of Campidanese Sardinian.

[voice] > [nasal] > [fortis] > [labial] > [labiodental] > [dental] > [alveolar] > [postalveolar] > [retroflex] > [velar]. The corresponding tree diagram is shown in Figure 5.2.

The feature specifications in Figure 5.2 allow every segment to be given a unique featural identity, which is then spelled out at the interface. Here, labels in brackets are mere notational devices used for expository clarity; within phonology they are substance-free features [α β γ]. For example, the segment specified [+voice +labial] is spelled out as [b], while the segment specified [+fortis +labial] is spelled out as [p]. This system of feature specification results in each segment being specified for the absolute minimum number of features—the segment for example /r/ is specified only for [+voice].

The diagram shows that /l/ is [+voice +fortis]; [+fortis] marks the class of segments targeted by LENITION. Since [fortis] is lower in the feature hierarchy than [voice], it can appear in both segments which have a feature [voice] and those which do not. This explains why /l/ is subject to *Lenition*, though every other member of the target class is voiceless. In sum, the organization of features in CS consonants shows that all active features play a contrastive role. Importantly, it explains why each segment participates or does not participate in the phonological processes active in CS, something a simple inspection of their phonetic cues cannot do.

5.4 COMPUTATION IN CAMPIDANESE SARDINIAN

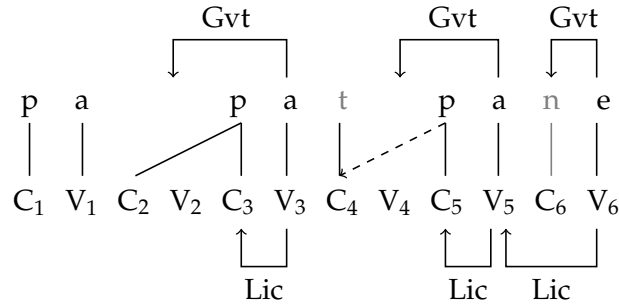
5.4.1 *Two computational domains*

I have identified two computational processes in CS, which I have referred to as FORTITION and LENITION. This section will provide an analysis of how both computational processes operate in CS, showing that FORTITION is a process which operates at the prosodic level, associating melodic material with additional timing positions, while LENITION is a process which operates at the melodic tier, active in a particular prosodic context, [+Gov], and resulting in the loss of melodic material.

5.4.2 *A formal account of FORTITION*

Let us examine FORTITION through the lens of the prosodic structures established in §5.3.2. In §5.2.2.4, it was shown that the loss of a final consonant preceding a voiceless consonant triggered a process of compensatory lengthening by which the voiceless consonant is both exempt from LENITION and realized with phonetic duration as in *pappat pani* ‘eat 3SG bread’ (209):

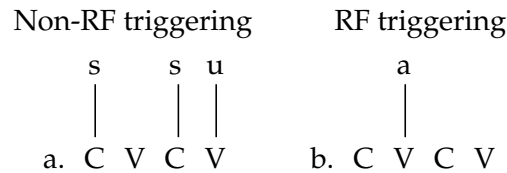
(209) /pappat pane/ → [pap:a p:ãĩ] ‘eats-3SG bread’



In (209), several processes are at work. C_4 is [-Lic, -Gov], and thus subject to strict licensing requirements. Since /t/ does not meet those requirements in CS, it is not associated to the prosodic position, and cannot surface. However, the melodic material associated to C_5 is [+Lic], and associated with C_4 by FORTITION. The difference between post-lexical geminates and lexical geminates is seen in the difference between the structure in C_4C_5 in which the double association is derived through FORTITION and C_2C_3 , in which the double association is part of the lexical representation, respectively.

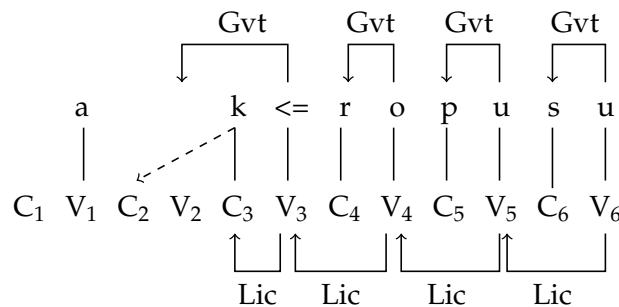
This brings us to the second kind of FORTITION discussed in §5.2.2.4, that of RF. On the surface, the positional description of RF is intervocalic, yet LENITION is never triggered. Recall that in RF a closed class of lexical objects triggers gemination of a following consonant. Representations for this set of lexical object contain an empty CV in their underlying representations (Chierchia 1986; Larsen 1998; Passino 2013). In this way, they are representationally distinguished from non-RF triggering lexical-objects (210):

(210)

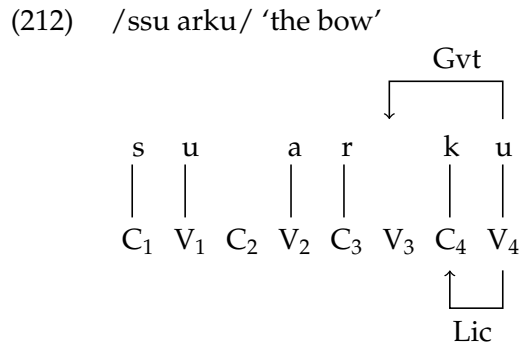


The effect of this empty CV position can be seen in (211), where C_2 is linked to the melody of C_3 , resulting in a geminate structure.

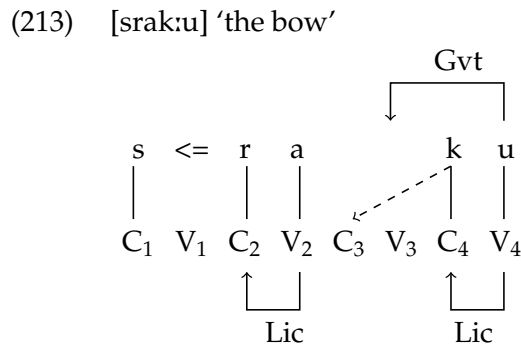
(211) /a krɔpus/ → [a k:roβuzu] ‘to crows’



This brings us to the third and final kind of FORTITION discussed in §5.2.2.4, metathesis-induced compensatory lengthening. Consider the representation in (212):

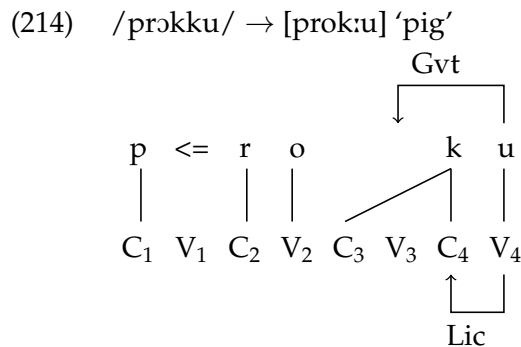


In (212), there is a lexical /r/ associated with the C₃, through metathesis, /r/ moves to C₂, vacating the Coda position; the resulting empty C position is associated with the melodic material of the following C, resulting in a geminate (213):



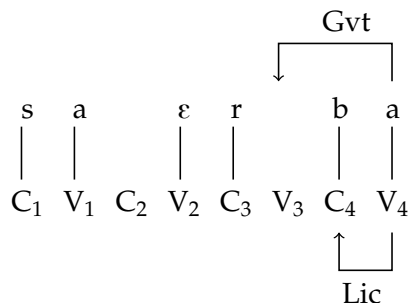
In (213), the movement of /r/ out of C₃ results in the melodic material associated lexically with C₄ being associated with the now vacant C₃, resulting in a geminate structure.

This account of FORTITION explains why objects such as *proku* ‘pig’ resist LENITION, without stipulating that LENITION is inactive in word-medial position: the word-medial consonant is geminate. It is possible that diachronically, this gemination was a result of FORTITION, but synchronically, in the absence of metathesis-based alternations, it is a lexical geminate.



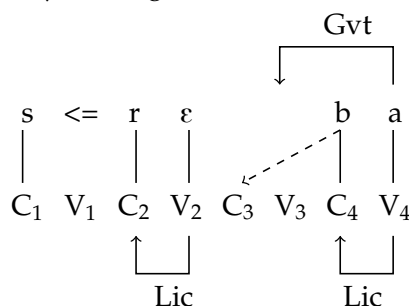
Finally, this account demonstrates that voiced stops are also geminated by FORTITION, despite their surprising phonetic exponents as spirants. Consider for example the process of metathesis. The representation in (215) shows the underlying form of a metathesis context:

(215) /ssa ɛrba/ ‘the grass’



In (215), the lexical /r/ associated with the C₃ moves to C₂, vacating the Coda position; the resulting empty C position is associated with the melodic material of the following C, resulting in a geminate (216):

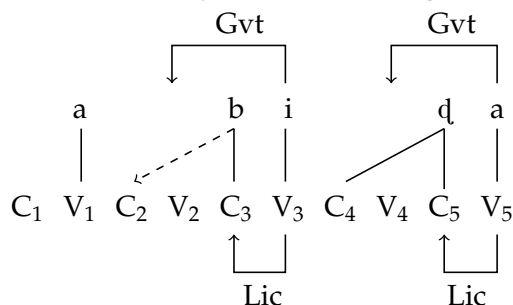
(216) [srɛβa] ‘the grass’



When metathesis removes the lexical /r/ from C₃, the melodic material from C₃, in this case /b/, spreads into the vacated C position. This results in the realization of [β]; the relevant spell-out instructions are as in (218).

In RF, the same FORTITION effect can be seen (217):

(217) /a bidɖa/ → [a βiɖ:a] ‘to the village’



In (217) FORTITION spreads the /b/ associated with C₃ to C₂, which becomes doubly associated and thus a geminate. In spell-out, this doubly associated /b/ is interpreted as [β] (218):

(218)

$$\begin{array}{c}
 \left[\begin{array}{c} +\text{voice} \\ +\text{labial} \end{array} \right] \leftrightarrow \beta \\
 \swarrow \quad \downarrow \\
 C_1 \quad V_1 \quad C_2
 \end{array}$$

5.4.2.1 FORTITION *and the interface*

The realization of geminate /b d ɡ g/ as spirants is a surprising conclusion in any theory where phonological structure is recapitulated in phonetic substance. In the SFP view adopted here, though, this is not relevant to phonology *qua* computation, rather it is an example of the realization of phonological structure being shaped by third-factor phenomena. Notably, this it is an effect the physical exigencies of voicing, which requires air to flow through the vocal cords, which accumulates in the oral cavity (Ohala 1997).

During stop production, all exit valves are closed, as air flowing through the glottis (a necessary condition for moving vocal chords) builds up in the buccal cavity, oral pressure nears subglottal pressure (Ohala 1983: 194ff.). When this happens, the air flow through the glottis is diminished and voicing is no longer possible. The longer the stop is held, the greater the likelihood for voicing to be extinguished. This results in a strong tendency for long voiced stops—geminate—to become voiceless. However, Ohala (1983) notes that the tension between voicing and stops can be relieved in other ways, notably by “unstopping” the stop—by changing it to a voiced fricative or approximant (see Giannelli & Savoia 1979 for an account of a similar phenomenon in Tuscan Italian, where geminate stops are spirantized as an effect of register and rate of speech).

This third-factor effect would have been an actor on voiced geminates at a diachronic stage when voiced geminates were realized with increased duration. If spirantization is an effect of increased buccal cavity pressure that is phonologized (see discussion in §4.3.3), then it will produce a synchronic pattern such as the one in CS.

It is worth noting, however, that the realization of voiced geminates as spirants in synchrony is not an effect of melody. The phonological computation on the prosodic level spreads the melodic material, but does not change any feature values. In this way, the spirantization of voiced stops in FORTITION is not a fact about synchronic grammar. It is irrelevant to the formal theory since the only phonology in voiced stop gemination is the process that constructs association lines between the melodic material of voiced stops and the empty C positions; their realization as spirants is a fact about interpretation at the interface, not about phonological computation.

This is in contrast to the process of LENITION which targets voiceless stops. Since LENITION actually manipulates melodic material through phonological computation, it is a true phonological rule.

5.4.3 *A formal account of LENITION*

In contrast to FORTITION, which operates on the prosodic tier, LENITION in CS operates over the melodic tier, targeting /p t tʃ k f s l/ when they are in a [+Gov] prosodic context. While /p t tʃ k f s l/ share no obvious phonetic properties that would suggest they constitute a natural class, the fact that LENITION can be given a singular structural description suggests there is a single rule underlying LENITION in CS, effecting a single structural change. The first objective of the computational analysis is to define the structural change that results in /p t tʃ k f s l/ being realized as [β ð ʒ γ v z ʋ].

5.4.3.1 *Saltation and Artificial Grammar Learning*

The first four changes, /p t tʃ k/ to [β ð ʒ γ] are an example of *saltation*, an alternation where a category B is “jumped” over on the way from A → C (Minkova 1993; Lass 1997). In the case of the voiceless stops [p t tʃ k], a structural change which involved only a single dimension such as only mode or only manner would result in [b d ɖ g] or [f θ ʃ x], respectively. The actual alternation pattern, p, t, tʃ, k → β, ð, ʒ, γ / V_V, involves a structural change in *both* mode and manner, and seems to leap over [b d ɖ g], resulting in voiced fricatives. Hayes & White (2015: 267) define saltation in featural terms: for every segment A, B, and C, when some feature is shared by all three, but A alternates with C while B remains invariant. Saltatory alternations are rare cross-linguistically (White 2014).

The saltatory alternation in CS has been the basis for a number of claims, notably that it represents an unusual pattern by which a sound intermediate between the input and the output of a phonological rule is “skipped over” (White 2014, 2017; Hayes & White 2015; Smolek & Kapatsinski 2018). Such rules, it is claimed, are harder to learn because the phonetic changes involved are non-minimal (Skoruppa et al. 2011). In a series of AGL experiments, White (2014, 2017); White & Sundara (2014) found that saltatory alternations were harder to learn relative to non-saltatory alternations which do not “skip over” segments.

White (2017); Hayes & White (2015) claimed that since saltatory patterns clearly exist in natural language learners must be able to acquire them, but the experimental results in White (2014, 2017); White & Sundara (2014) constitute evidence for a UG bias against such patterns²⁴. In this view, the phonological grammar is provided with machinery

24 It has also been proposed that if there is a bias against saltatory alternations, this should be reflected in diachrony; Smolek & Kapatsinski (2018: 2) report experimental results which they argue suggest that saltatory alternations are difficult for learners to master, resulting in their “diachronic demise.” While it is not clear what kind of prediction is actually being made, or how it could be falsified, as discussed in §4.3.4, all phonological processes are inherently unstable over time, with several potential avenues by which they can pass out of phonological grammar. It is not clear what being more or less stable would mean, since a multitude of outside influences can affect the course of the life cycle of phonological rules. Furthermore, in the case of CS, saltation is a long-attested pattern, both diachronically and synchronically stable.

that makes some patterns harder to learn than others. This argument is built on two foundational pillars:

1. The conceptual argument that saltation involves, either articulatorily, perceptually, or featurally, a greater distance than non-saltatory alternations
2. The AGL reported in White (2014, 2017); White & Sundara (2014)

I argue that the conclusions reached by Hayes & White (2015) constitute substance abuse, and that the conclusion that phonological theory should be modified to include UG enforced constraints against patterns such as the one in CS is to be rejected.

The first foundational pillar is the conceptual argument, reflected in the intuitions of many phonologists, that a change A to C is somehow more extreme than a change A to B. That is, the notion of saltation depends on the structural properties of a phoneme inventory. For a phoneme to be “skipped” in an alternation pattern, it must already exist as a part of the inventory, and it must represent what linguists conceive of as a logical step in some process (in this case lenition). This logic depends on a continuum of changes, where lenition of a given segment entails that that segment will be realized in a strictly defined way (see Escure 1977 and Lass 1984), as for example in (219):

(219) $pp \rightarrow p \rightarrow b \rightarrow \beta \rightarrow \emptyset$.

The logic of progression in (219) suggests that segments have intrinsic properties independent of their context (as in SPE markedness), that is they are strictly ordered such that lenition progresses in an orderly way along a chain. When a saltation happens, the putative intrinsic ordering is thrown into disarray. For “saltation” to be more than a descriptive device, the progression in (219) must represent an LSG and be a product of UG.

Additionally, given an alternation $/p/ \rightarrow [\beta]$, the assumption that this is a saltation is made with no evidence that this particular structural change actually involves more than a single change of feature, such that $/p/ \rightarrow [b]$ involves a single change but $/p/ \rightarrow [\beta]$ involves more than one. The assumption seems to be based on the description of $/p/$ and $/b/$ in phonetic terms, but not in phonological ones. The definition of saltation used changes depending on the feature system used, while Dresher (2014) and Odden (to appear) hold that there is no single, universal feature system. Rather, phonological feature systems are language specific, and it may be that the structural change that maps $/p/ \rightarrow [\beta]$ is in fact a single feature. The assumption that $/p/ \rightarrow [\beta]$ is anything more than a conventional alternation rests on the assumption that the notation $[p \beta b]$ reveals phonological identity.

The second foundational pillar of the claim made in Hayes & White (2015) and White (2017) comes from a series of AGL experiments. White (2014) presented an AGL task to adult speakers of English, divided into two groups, each of which was exposed to a different pattern of alternation. The first group was exposed to alternations between $[p] \rightarrow [v]$ and

[t] → [ð], while [b] and [d] did not change. The second group served as a control and was exposed to alternations of [b] → [v] and [d] → [ð], while [p f t θ] did not alternate. White's results show that speakers in the first group generalized the pattern of alternation to include voiced obstruent triggers, while the control group did not extend their pattern to voiceless obstruents. White argues that this pattern constitutes an "error" which is due to an anti-saltation effect, biasing participants in the control group against extending the pattern of alternation to other obstruents. White & Sundara (2014) used a similar protocol on infants, where infants who "learned" [p] → [v] generalized the pattern to [b] → [v], but the opposite did not happen.

Following a proposal from Steriade (2001 [2009]), White (2014) suggests that speakers have knowledge concerning the relative perceptual similarity between pairs of sounds in phonological contexts, known as the P-map (see Mielke 2012 for a proposal to measure phonetic similarity). In this approach, a constraint of the form *MAP(x,y) disfavors alternations which involve a large perceptual distance, by assigning a violation to input from a natural class, *x*, if the corresponding output is another natural class, *y*. Hayes & White (2015) argue that this approach allows for marked patterns to arise in synchronic phonology if enough evidence in the ambient language requires a learner to re-rank constraints such that the UG imposed learning bias can be overcome.

The assumption seems to be that data collected from AGL experiments has equal epistemological value as natural language data. That is, as conclusions about the structure of UG can be made based on examination of natural language data, so too can they be made on AGL data. The primary weakness of this argument is that nothing in the AGL results obtained by White (2017) show that the cognitive faculty being employed by participants is in fact phonology, although this seems to be taken for granted.

There are two principle problems with this assumption. The first is the way acquisition proceeds in the two, the second is in the way results are interpreted (see §6.3.2 for further discussion). In a word, AGL data is not like natural language data, although they are treated as though they were and used to justify the claim that AGL results are the reflection of biases in the grammar. There are numerous other possible explanations for the AGL data, however: they could be the reflection of general pattern recognition, imitation, or any number of other cognitive processes.

From the perspective of FP there are no constraints or learning biases against saltatory alternations, and from the point of view of the computational system saltation is entirely conventional. The explanation for the relative rarity of saltatory alternations is found in diachrony: Minkova (1993) and Lass (1997) argue saltation is never the result of a single sound change, but rather the result of telescoping (see §4.3.4).

5.4.3.2 *The lateral*

Diachrony is also at the origin of the special case of lenition previously discussed in §3.10.4.1 (220):

(220) $l \rightarrow \text{ʁ}, \text{ɣ} / +\text{Gov}$

There is some diatopic variation between the uvular and pharyngeal realizations of the output segment, though [Contini \(1986: 521\)](#) describes the output as a distinct pharyngeal fricative. The rule in (220) is arbitrary in the sense that the input—a lateral coronal—and output—an uvular or pharyngeal fricative—segments are articulatory distant segments—a crazy rule ([Scheer 2015a](#)). This alternation is present in many, but not all varieties of CS (see [Viridis 1978](#); [Contini 1986](#); [Molinu 2009](#)). The informants we interviewed in Genoni are very aware of this alternation and their production of an uvular or pharyngeal phone, and consider it to be one of the distinctive markers of their dialect of CS (221):

(221) [l]ati ‘milk’ su [ʁ]ati ‘the milk’
 [l]ebiu ‘mild’ lebiu [ʁ]ebiu ‘very mild’
 [l]ũã ‘moon’ sa [ʁ]ũã ‘the moon’
 [l]imõĩ ‘lemon’ su [ʁ]imõĩ ‘the lemon’

[Molinu \(2009\)](#) also provides examples of this alternation in data from her own fieldwork in Genoni (222):

(222) [l]aðru ‘bacon’ su [ʁ]aðru ‘the bacon’
 [l]õŋga ‘long’ braβa [ʁ]õŋga ‘long beard’
 [l]imõĩ ‘lemon’ binti [ʁ]i’mõizi ‘twenty lemons’
 [l]ampaðaza ‘June’ εk:omintsau [ʁ]ampaðaza ‘June just started’

Given that this alternation takes place in external sandhi at word boundaries, any argument against it being phonological in nature seems doomed to fail, since it must be the product of phonological computation. In short, it is the result of phonological computation that defies phonetic explanation. In diachrony, however, it makes sense as a chain of sequential lenition. The first part of the explanation lays in the diatopically variable output of /l/ LENITION across the Campidanese dialectal area, as shown in [Table 5.9](#).

[Table 5.9](#) essentially matches the one in [Scheer \(2015a: 326\)](#). It suggests that diatopic variation corresponds to stages of diachronic evolution, intermediate steps of a diachronic progression between an etymological /l/ and the most distant reflexes. [Wagner \(1941 \[1984\]: §196-197\)](#) suggests that the first step in this diachronic evolution was the velar [ɫ], a not unreasonable hypothesis, given that in the dialect of Cagliari /l/ alternates with [ɫ] in intervocalic and preconsonantal contexts, as in [difiɫiti] ‘difficult’ ([Mereu 2020: 11](#)). [Scheer \(2015a: 328\)](#) suggests, given the proposed intermediate stages, a chain of successive phonological changes leading from l to ʁ (223):

context must contain information about morphosyntactic conditions. Scheer (2015a) points out that in NP, the situation is not as dire as in NGP, citing a p.c. from Patricia Donegan who suggests that in NP it is *expected* that conventional rules be morphologically conditioned, but this is not an absolute requirement.

In GrP, (220) has a somewhat different status. Since the change from /l/ → [ɮ] is an arbitrary one, it presumably does not correspond to any grounding condition. However, since in GrP rules interact with grounding conditions in specific ways, linking and delinking are licit paths of F-elements. There presumably is no way to carry out arbitrary computations in GrP, which excludes (220) from the realm of possible phonological processes.

GP's non-arbitrariness condition posits that there is a plausible relationship in phonological alternations between the triggering context and the structural change. The arbitrary nature of (220), where the intervocalic context has no plausible role to play in the realization of /l/ as [ɮ], excludes this alternation from the realm of phonology.

In most forms of OT²⁵, where input forms are weighed against the set of phonetically motivated markedness constraints, (220) is an implausible result. While computationally the alternation in (220) could be generated by sufficiently highly ranked constraints, the arbitrariness of the alternation means that it has no phonetic motivation, and the [ɮ] output will never be selected. Universal markedness is the hallmark of phonological computation: alternations not generated by markedness are not phonological (Green 2006).

In all of these theories, the exclusion of (220) from phonology seems mostly stipulative. Significantly, NP, NGP, and GP treat the rule as morpho-phonological, even though morphological vocabulary does not play any role in its structural description (§5.3.2). The exceptionless nature of the alternation is also a problem in NGP and GP, given that both require phonological alternations to be entirely productive: (220) seems phonological in this light. GrP and OT seem to fare a little better, being that both are at worst agnostic to (220). While in GrP nothing in the grammar prohibits (220), it simply cannot be generated. OT, finally, can computationally handle the alternation in (220), but it either cannot arise under classical markedness constraints, or is unlikely to arise in theories where constraints are not universal or innate.

5.4.3.3 *The phonological rule of LENITION*

The regularity of (220), the fact that it is triggered in external sandhi, and its well-defined phonological context all argue for its status as a phonological rule. I argue that any theory of phonology must be able to treat it as such. This is possible in a substance-free account of the general computational properties at work in processes of lenition. LENITION is a process that occurs in positionally weak contexts, re-

25 Notable exceptions are Boersma (1998) and Bermúdez-Otero & Börjars (2006).

sulting in the loss of melodic material from segments which undergo it.

This accords well with the diachronic observation that lenition follows a clear and well recognized trajectory towards the eventual disappearance of segments, as expressed in the famous personal communication from Theo Vennemann reported by Hyman (1975: 165), where lenition is given a teleological definition as segment's progression towards zero (see discussion in Honeybone 2008: 13f.). In the final step of this progression, when a segment is reduced to zero, there is a clear loss of melodic material. To account for this erosion of melodic material, Harris (1990, 1994); Harris & Lindsey (1995) propose that lenition is *always* the loss of melodic material.

Thus, a segment which finds itself in a [+Gov] context is subject to licensing restrictions: melodic material is removed in this position. The formal definition of LENITION in CS can now be given (224):

(224) Formal definition of LENITION
[fortis] → ∅ / [+Gov]

This rule says that the feature [fortis] is deleted when it is [+Gov]. In the CS system, then, the loss of a single feature causes three distinct structural changes: /p t tʃ k/ are voiced and fricativized, /f s/ are voiced, and /l/ is realized as an uvular or pharyngeal fricative.

5.4.4 Summary

Strength and weakness of [b d ɖ g] and [p t tʃ k] respectively are both manifest by their neutralization to [β ð ʒ γ] in a superficially identical intervocalic context. A substance-free analysis reveals that weakness is a positional effect in CS, exerting an effect when /p t tʃ k/ are realized in an intervocalic position. This is the context in which the process of LENITION is active, and the loss of melodic material is manifest in various ways, in particular in the spirantization of voiceless stops. Strength, on the other hand, is also manifest as spirantization of /b d ɖ g/ but a substance-free analysis reveals that voiced stops are spirantized when they are phonological geminates. Geminate structure is a manifestation of strength because it creates a strong position. Since this position is one in which LENITION is not active, not only is there no loss of melodic material, but geminancy means that melodic material is spread to empty prosodic positions.

This analysis of CS shows that both strength and weakness can be made sense of in SFP. In §5.1.2 I stated three analytical goals for a theory of lenition (Szigetvári 2008: 124). This analysis shows that LENITION and FORTITION are the loss of melody in [+Gov] contexts and the spreading of melodic material into empty skeletal positions, respectively. Thus, the pattern in CS is amenable to these three goals, provided the proper representational tools are used. To wit:

1. I provide a simple definition of both lenition and fortition.

2. I provide a natural context for each one of these processes.
3. I correlate the change and the contexts, thereby showing that LENITION would be “unnatural” if it occurred in a [+Lic] context, for example, while FORTITION would be “unnatural” if it occurred in a [+Gov] context.

In natural theories of phonology, lenition trajectories are always phonetically defined. On such a scale, a change $b \rightarrow \beta$ goes down the lenition scale, though in CS this change is in fact a manifestation of strength. But the consequence for phonological theory is not just another argument that phonetic inspection is inadequate as a discovery procedure. Strength and weakness in CS also show the intricate way in which computation, melodic representations, and prosodic representations can all interact to give rise to surface patterns. To approach explanatory adequacy, a theory of phonology must have an explicit definition of each—it cannot rely entirely on computation or entirely on representations (cf. Anderson 1985: 350).

5.5 GENERAL CONCLUSIONS

This section concludes the theoretical portion of this thesis. Thus far, I have argued that phonology is a kind of cognition, part of an innate mental organ that is universal to *Homo sapiens*. In Chapter 1 I laid out some of the basic assumptions of generative phonology, including the notions of phonological rules and representations. Phonological rules serve to map between representations—lexically determined distinctive cognitive objects—and their phonetic correlates realized as physical objects in the real world. I argued that a fruitful understanding of the CR system underlying phonology can come from viewing it as a kind of perception, a property of the mind. This chapter also argued for a modular phonological architecture that communicates with the domains of phonetics and morphology only through an interpretational interface, which can translate between phonological vocabulary and that of other cognitive modules. The conception of phonology as a CR system, a property of mind, and the modular theory of cognition provide a useful framework for the construction of a theory of phonology.

In Chapter 2, it is argued that an understanding of phonological knowledge always comes from a theory of phonology. Following Hale & Reiss (2008), I identified the remit of phonological theory as about *possible languages*. A basic desideratum for a theory of phonology, I argued, was that it permit us to distinguish between possible and impossible languages (or phonological grammars). In an overly powerful formal system built from rules and representations, there are few (or perhaps no) impossible languages, and the predictive power of such a theory is virtually nil where the question of possible and impossible languages is concerned. I suggest that an illustrative example of an impossible language is one with a pattern of length harmony—a

pattern entirely missing from the typological record, which is replete with examples of many other kinds of harmony processes.

The chapter then surveys some of the important developments in generative theory that lead to the use of naturalness as a tool to restrict the generative power of phonological theory, thereby clearly defining a set of possible and impossible languages. Naturalness is considered in three guises: symbolic naturalness, functional naturalness, and typological naturalness. When naturalness is formalized as a part of the grammar, it has important consequences for unnatural patterns—crazy rules. In a theory circumscribed by formal naturalness, there are strict limits placed on what kinds of patterns of alternation can be phonological in nature. Crazy rules, then, constitute an excellent trail for theories with formal naturalness: if even one crazy rule can be shown to be phonological, then the theory is falsified.

Chapter 3 provides an empirical overview of potential crazy rules reported in the literature. I argued that four kinds of craziness can be found in synchronic phonological patterns. Together, the census allows for a number of interesting generalizations to be made. Notably, the sample of crazy rules surveyed exhibits a total lack of craziness in patterns above the skeleton, in the domain of syllabic phonology. Thus, while in melodic phonology it seems the computational system is unconstrained by naturalness and can turn any segment into anything and its opposite in any context, phonological processes operating at the level above segmental phonology are non-arbitrary.

Chapter 4 examines the repercussions of the empirical survey in Chapter 3 in the light of theories with formal naturalness. Anderson's paradox is invoked to illustrate the tension between such theories and the empirical record, which presents rare but persistent cases of unnatural patterns. Though it is indisputable that naturalness shapes observed phonological patterns, including naturalness as a formal device in the grammar engenders several formidable empirical and conceptual problems. I argue that the effect of phonetic constraints is not a part of grammatical competence, and thus should not be accorded any formal status. Instead, naturalness exerts a powerful influence in diachrony that can be brought into grammar. Any phonological process that may have begun as a natural process, once phonologized and a part of the grammar, is purely symbolic. One beyond the veil, phonological processes are no longer constrained by naturalness, and crazy rules are computed just like natural ones.

However, that does not mean that phonology can perform any kind of computation at all. Such a conclusion would, in a stroke, rob phonological theory of any predictive power: anything goes in such a system. If there is no limit to phonology, then the status of phonology as a domain-specific cognitive module is threatened, and phonology as a scientific enterprise is devalued since it makes no predictions and cannot be falsified.

However, I argue that phonological computation does have limits, and that there are impossible phonological processes—length harmony being one. In order to reimpose order in phonology I adopt a substance-

free approach that splits phonology into (at least) two sub-modules. The first of these is the domain of segmental phenomena, where computation acts on melody, inserting, deleting, and spreading features. The second is the domain of suprasegmental phenomena, the realm of prosodic structure that builds syllables and organizes timing positions.

Each sub-module is a self-contained computational system with its own vocabulary and own computational processes. The melodic domain interfaces with the real world through spell-out, a dictionary-like set of instructions for the phonetic expression of phonological vocabulary. Because it works like a look-up table, spell-out can provide phonetically arbitrary correlates for phonological features. Since features have an arbitrary link to their phonetic correlates, and computation manipulates features, the computational system can produce phonetically arbitrary patterns. It is thus the arbitrary nature of spell-out that introduces craziness into phonology. The suprasegmental domain, in contrast, does not interface with the real world. It is purely symbolic, its representations and computational processes are entirely innate, and there is no craziness.

This distinction between sub-modules of phonology, each operating in its own domain, allows for predictions to be made about possible and impossible language, restoring order in phonology. Notably, such a theory requires no formal naturalness, since any apparent naturalness can be accounted for by appealing to diachronic influence. It thus does not enter into conflict with crazy rules and other phonetically arbitrary processes. The result is a theory that more closely reflects the empirical record.

The current Chapter put into practice the tools developed in Chapter 4 to examine an intricate pattern of lenition and lengthening in CS. The substance-free analysis examines strength and weakness in CS and presents an interesting alternation that seems to present a counter example to the generalization made in Chapter 3 that there is no syllabic craziness. The substance-free approach reveals a novel fact: in CS, a process of fortition causes underlying geminate voiced-stops to be realized at the surface as spirants, an apparent crazy rule in the domain of syllabic structure and timing positions. In fact, the phonological process that produces geminate structure is perfectly regular, but the expression of geminate voiced-stops happens at spell-out. It is here that arbitrariness is introduced, through the association in spell-out between underlying geminate voiced-stops and surface spirants. This is a case of a phonetics/phonology mismatch (§4.4.2.1), the first recorded case of a mismatch in the domain of lenition and fortition.

The next part of this thesis is concerned with empiry.

Part II

EMPIRY

Where is the short syllable by which I measure it? And where is the long syllable that I measure?

Both have sounded. They have fled and passed away. They no longer exist. But I do measure, and I answer with all the confidence that one can repose in finely-honed perception, that the short syllable is single and the long one double, in terms of the time they take. I cannot do this unless they have passed away and are complete. So I am not measuring the syllables themselves, which no longer exist; I measure something in my memory that stays imprinted there.

AUGUSTINE OF HIPPO

Reasoning from this, the Egyptians
acknowledged that the Phrygians
were older than they.

Herodotus

Chapter 2 identified three kinds of naturalness which have been formally instantiated in theories of phonology. Since a theory of phonology is a theory of knowledge that speakers have about their language, any formal naturalness represents an aspect of speaker knowledge encoded in Universal Grammar (UG), typically in the form of facts about articulatory or perceptual ease (Hayes & Steriade 2004). In Chapter 4, I argued that a theory of phonology should not formally encode phonetic naturalness, since phonology is a computational system which does not include facts about the physical world where articulatory or perceptual naturalness are properties.

Thus far, the respective arguments for both substantive and substance-free theories have been entirely based on natural-language data acquired from work of linguists in the field. However, one way of adjudicating between these incompatible positions is by adducing support for the substantive position through experimentation (Ohala 1986, 1987). There is a rich body of experimental work on substantive biases in phonology, constituting a sub-branch of Artificial Grammar Learning (AGL) studies. AGL experiments go beyond natural language documentation and analysis because their ambition is to create data which can be used to confirm or refute predictions; the elicited data, it is assumed, can be used to providing supporting evidence for the origin of typological gaps in some property of language acquisition or in historical transmission (van Oostendorp 2013: 284).

Acquisition of language, as discussed in §4.2, is obviously dependent on both the nature of linguistic input and the innate capacities of humans, in terms of domain-general capacities and specifically linguistic capacities. The relative contribution of each of these factors, however, is subject to debate (Jusczyk 1997). If there is a naturalness bias in UG favoring articulatory or perceptual ease in phonology, it should be apparent in language acquisition (Wilson 2006). In this view, natural phonological processes should be easier to acquire than unnatural ones, all else being equal. In AGL studies, the ambition is to control the data such that all else is equal during acquisition. Where naturalness is concerned, the ideal AGL experiment presents participants with formally comparable patterns that differ only in terms of naturalness. Where one

group has more success than the other in acquisition, this difference can be said to be due to a substantive bias against unnatural patterns.

A critical assumption underlying much AGL literature is that results obtained in laboratory settings are comparable to natural language data. In this view, the data obtained from AGL studies can be used to determine the architecture of grammar on the same footing as data acquired through fieldwork, in communities of native speakers. I will argue that this logic is flawed, and that while AGL studies are useful tools for understanding performance, their utility is limited as far as competence is concerned, and results must be interpreted with prudence.

This chapter provides a survey of AGL studies concerned with substantive biases in phonology. I begin by providing a brief discussion of the motivation behind using AGL to look for naturalness and how naturalness is conceptualized in these studies (§6.1). I next provide an overview of the structure of AGL protocols, with particular attention to ways in which acquisition in the lab differs from natural-language acquisition (§6.2). I then provide a summary of results, and discuss some important factors in interpreting those results (§6.3). Ultimately, I determine that AGL experiments do not show robust evidence for a naturalness bias in phonology, and are unlikely to provide insight into the nature of phonological computation, since there is no reason to think participants are exploiting phonology in laboratory settings. Instead, acquisition of phonological patterns in laboratory settings proceeds along the lines of L2 acquisition (Ettlinger et al. 2015; Moreton & Pertsova 2016), thus exhibiting important divergences relative to L1 acquisition (Moyer 1999; Oyama 1976; Schachter 1990) (see Schachter 1988: 223ff. for an overview of the principle differences).

6.1 LOOKING FOR PHONOLOGICAL NATURALNESS: ARTIFICIAL GRAMMAR LEARNING

6.1.1 *Artificial Grammar Learning and systematic gaps*

AGL studies have a long pedigree (Berko 1958; Esper 1925; Reber 1967); beginning with Schane et al. (1974) the scope of their application moved from basic investigation of speaker knowledge to efforts at distinguishing between systematic gaps and accidental gaps by identifying substantive biases in phonological acquisition (Nevins 2010: 230). Where naturalness is concerned, the primary ambition of AGL experiments is to compare the learnability of patterns by constructing patterns which are identical in as many respects as possible, except for naturalness (for a previous overview, see Moreton & Pater 2012a and Moreton & Pater 2012b).

The data from AGL studies is intended to complement natural language data by allowing for individual aspects of phonological patterns to be isolated and controlled for, for example by controlling for prior speaker knowledge by testing patterns which are not a part of partici-

pants' native competence. In practical terms, this means constructing very simple grammars which are phonologically inert—with no pattern of alternation—except for the pattern which is of interest to researchers. The grammars to be compared then differ along a single parameter related directly to that pattern, where the difference in this parameter constitutes the difference between natural and unnatural.

Unattested patterns can be presented to participants to test their ability to learn and reproduce those unattested patterns by comparing them to a formally comparable pattern predicted to be impossible in a given theory (van Oostendorp 2013: 285). Participants are taught one or another of the differing patterns, and the success of each group in learning their respective pattern is compared. If, all things being equal, a difference in successful acquisition between groups is found to be significant then that difference is assumed to be due to a substantive bias, which potentially can be traced back to the architecture of grammar itself (Becker et al. 2011; Berent et al. 2008; Hayes & White 2015; Lin 2019; White 2017; Wilson 2003).

In the AGL literature, the three kinds of naturalness discussed in §2.3.2 are represented, but the tripartite division is conceptualized as substantive bias against typological and phonetic naturalness on the one hand, and formal naturalness as complexity on the other. The distinction is significant, because results are not comparable across the three groups. There is significant convergence in the results of AGL which demonstrate a bias against formal complexity in the acquisition of artificial phonological patterns—as the number of symbols or operators in a pattern increases, acquisition becomes more difficult (Moreton & Pater 2012a provide an overview of complexity in AGL results, and see Culbertson & Schuler 2019 for a discussion of results in infants and children). In contrast, in two different surveys of AGL studies investigating phonetic naturalness, Moreton & Pater (2012b) and Glewwe (2019) find little support for the existence of substantive biases corresponding to typological or phonetic naturalness.

6.1.2 *Naturalness and complexity*

How naturalness is conceptualized is a necessary first step in discussing AGL protocols and interpreting their results. There are important bodies of work which identify naturalness biases and complexity biases as two kinds of distinct substantive biases (Carpenter 2010; Finley 2017; Glewwe 2019; Moreton & Pater 2012a; Pycha et al. 2003; Skoruppa & Peperkamp 2011). The distinction is not always carefully maintained, however: naturalness and complexity effects may be intertwined and reported results may confound one for the other. Further, as discussed in §2.3.2, one of the earliest formal definitions of naturalness was through the symbol-counting simplicity metric as outlined by Chomsky & Halle (1968: 400ff.), but complexity is not always analogous to phonetic or typological naturalness, since what is typologically

rare may be formally simple (deaffrication preceding high front vowels, for example, see §2.2.3).

The two kinds of substantive naturalness identified in §2.3.2—functional properties in articulation or perception and robustly-attested typological processes—are the loci of naturalness biases in AGL studies. When naturalness is equated with typologically recurrent patterns (Bergelson & Idsardi 2009; Carpenter 2010; Nevins 2010; Skoruppa & Peperkamp 2011; White 2014; Wilson 2003), it follows that unnatural patterns are those which are rare or unattested. The notion that typological frequency corresponds to naturalness is not universal: Greenwood (2016), for example, views typology as a reflection of functional factors, not as a manifestation of naturalness itself. Berent (2013: 133) regards typology as an effect of E-language rather than of I-language, while Glewwe (2019) rejects typology as a surrogate for naturalness conditions.

Naturalness is a functional property of articulation or perception in for example Finley & Badecker (2009: 168) and Pycha et al. (2003). Pycha et al. identify natural patterns as those with phonetic precursors (cf. Moreton 2008). In this view vowel harmony, since it has a robust phonetic precursor conferring a perceptual benefit (Finley 2012; Kimper 2017), is natural; in contrast vowel disharmony is unnatural, having no phonetic precursor. Unnatural patterns, thus, are those with phonetic correlates that defy perceptual or articulatory functional pressures (Beguš & Nazarov 2017; Beguš 2018b; Greenwood 2016). For example, there are strong functional pressures for the voicing of post-nasal consonants; a process which devoices post-nasal consonants (see Hyman 2001) would be unnatural, what Morley (2015a: e44) calls anti-natural. Beguš (2018b: 4) thus distinguishes between natural, arbitrary, and unnatural patterns, with the later being any which “operate against universal phonetic tendencies”.

More fraught in AGL studies is the question of formal complexity as the locus of naturalness (Cristià & Seidl 2008; Glewwe 2019; Hayes et al. 2009; Moreton 2008; Pycha et al. 2003; Saffran & Theissen 2003). Complexity is a well-known domain-general bias, having been found in vision (Shepard et al. 1961) and elsewhere in cognition (Bethell-Fox & Shepard 1988). Moreton et al. (2017) compare complexity in phonology to complexity in learning visual patterns with visual stimuli varying along three axes: shape, color, and size. In their visual-pattern learning protocol complexity corresponds to the number of differences along and across each axis, such that a pattern of identical shapes varying in size and color is more complex than one of the same shapes which varies along a single axis, such as only color. Moreton et al.’s results demonstrate an increase in learning difficulty of visual patterns commensurate with increased pattern complexity. In phonological terms (Moreton et al. 2017) suggest that difficulty in learning phonotactic patterns which vary along axes of place of articulation, voicing, and manner increases as the number of differences along and across axes increases. These results are interpreted as a domain-general property that biases learning of complex patterns.

Formally, complexity in phonology is manifest in two ways, as either the number of features implicated in a pattern, or the number of operators attached to features in a pattern. In the first case, a sequence of two segments, $S[+voice] S[+continuant]$, is more complex than $S[+voice] S[+voice]$, because two different features must be used to describe the former while a single feature suffices for the latter. In the second case, a sequence of two segments, $S[+voice] S[-voice]$ is more complex than the sequence $S[+voice] S[+voice]$ because two operators are needed in the former, while in the latter only one is needed.

Complexity is of particular concern in experimental design because it may be confounded for domain-specific naturalness, though it does not constitute a sub-category of typological or functional naturalness. That is, a functionally natural pattern is not necessarily less complex than an unnatural one, and formal complexity does not seem to correlate to typological frequency, as [Moreton & Pater \(2012a\)](#) note. However, complexity may be easily confounded with either kind of naturalness since less complex patterns are, *ceteris paribus*, typically easier to learn than more complex ones ([Do 2013, 2018](#); [Greenwood 2016](#); [Lai 2015](#); [Moreton & Pater 2012a](#)); a general cognitive bias for simplicity may be reflected in typology through an effect on what kinds of patterns are acquired and diachronically transmitted ([Culbertson & Schuler 2019](#): 366). If not carefully controlled for, the results of a study on patterns differing in complexity may, in error, be interpreted as instantiating a substantive naturalness bias ([Glewwe 2019](#) and [Moreton & Pater 2012a](#) identify a number of such cases, including [Becker et al. 2011](#); [Peperkamp et al. 2006b](#); [Skoruppa et al. 2011](#) and [Wilson 2003](#)).

[Peperkamp et al. \(2006b\)](#) for example set out to test a learning bias in natural rules versus unnatural rules. Their natural conditions are two patterns of intervocalic obstruent voicing: $[p t k]$ and $[f s ʃ]$ alternate with $[b d g]$ and $[v z ʒ]$ respectively. In the unnatural conditions, $[p g z]$ alternates with $[ʒ f t]$ and $[ʃ v d]$ alternate with $[b k s]$ when between two vowels. In the natural condition, the structural change is uniform across the two sets of target segments, voiceless segments alternate with voiced segments. In contrast, the change in the unnatural condition is more complex: the target classes do not share voicing, manner, or place of articulation, and rather than a single articulatory condition being targeted, all three variables are changed. While the ambition of [Peperkamp et al.](#) is to compare a natural and an unnatural phonological rule, the patterns of alternation are so different in terms of complexity that naturalness cannot be meaningfully compared. The apparent bias may in fact be due to complexity, not naturalness.

Some patterns may be difficult to disassociate from complexity effects. Harmony patterns, for example, have been shown to be easier to acquire than disharmony patterns ([Finley 2012](#); [Martin & Peperkamp 2020](#); [Moreton 2008](#); [Pycha et al. 2003](#)). If disharmony is taken to be an unnatural pattern, then the bias in learning may be attributed to a bias against unnatural patterns. However, relative to a pattern of harmony, a disharmony pattern represents a kind of complexity. In harmony patterns what is dissimilar is changed to become more similar, such

that {+F-F} becomes {+F+F}—the difference in operators is removed, rendering the outcome relatively less complex. In disharmony, the opposite process takes place, such that what is already similar becomes less similar, {+F+F} becomes {+F-F}, and thus more complex relative to the harmony pattern. The bias in disharmony patterns relative to harmony patterns, then, can be explained as a domain-general bias against complexity, without requiring an explanation dependent on naturalness (as in for example [Pycha et al. 2003](#)).

In cases where complexity and naturalness are confounded, interpretation of results as a naturalness bias is not valid. Since the evidence for a learning bias against relatively more complex bias is robust ([Moreton & Pater 2012a](#)), interpreting experimental bias results as naturalness bias results creates the potential for mistakenly casting the domain-general bias as a domain-specific linguistic bias, reducible to a property of [UG](#). This despite the fact that the analyst cannot know whether the results should be attributed to naturalness or to complexity. In fact, [Beguš \(2018b\)](#) reports results which show evidence for a bias against complexity which is even stronger than the bias against unnatural patterns. Conscious of complexity effects, some studies take particular care to guard against them ([Finley 2017](#)). [Carpenter \(2010\)](#), for example, explicitly takes the problems posed by complexity into account by testing two stress patterns, one natural and the other unnatural, both of which are comparable in terms of formal complexity.

While complexity biases are a domain-general property, substantive naturalness biases may variously be attributed to non-linguistic channel biases, or directly to domain-specific naturalness bias in [UG](#) ([Hayes & White 2015](#); [Lin 2019](#); [White 2017](#)). In §4.4, I argued that there is no naturalness in phonological computation. If this is correct, then naturalness effects cannot be a domain-specific property of phonological architecture. This conclusion, however, is in direct confrontation with a number of empirical studies, and is worth looking at more closely. To that end, §6.2 proposes an overview of [AGL](#) protocol designs, and in particular the ways in which [AGL](#) acquisition ecology differs from natural language ecology.

6.2 AGL PROTOCOL DESIGN

6.2.1 *The two basic AGL paradigms*

[AGL](#) studies broadly follow two paradigms, referred to respectively as *poverty of the stimulus* and *surfeit of the stimulus* experiments ([Hayes et al. 2009](#)). In poverty of the stimulus experiments ([Berent et al. 2008](#); [Finley & Badecker 2009](#); [Glewwe 2019](#); [Myers & Padgett 2014](#); [White 2013](#); [Wilson 2006](#)), participants are tested on novel forms to which they were not exposed during a learning phase, but which conform to some aspect of the pattern presented during the learning phase. In this way, learners are tested on their ability to make generalizations from incomplete data and to extend those generalizations to novel

forms. For example, Myers & Padgett (2014) report results showing that participants exposed to a pattern of final devoicing will extend the pattern to novel items with final voiced consonants, while the formally-comparable pattern of final devoicing is not as easily extended to novel items with final voiceless consonants. When results show that participants learn patterns of which they cannot have knowledge from their native language or from the pattern to which they are exposed over the course of the experiment, this is taken to be evidence for innate knowledge about phonology. In this view, if, given two patterns differing only in one aspect where one pattern is learnable and the other is not, or one is less easily acquired than the other, poverty of the stimulus arguments impute the difference to something in the architecture of UG (Lin 2019).

In surfeit of the stimulus experiments (Becker et al. 2011; McMullin & Hansson 2019; White 2014), the data to which learners are exposed contains a full range of contexts in which a pattern is both present and absent, restricting participants' hypothesis space. When data is rich, it is expected that any divergence from the exhibited pattern, such as failure to learn the pattern or underapplication of the pattern is interpreted as a bias against that pattern. For example, Bergelson & Idsardi (2009) present infants with data that are equally compatible with either an attested (devoice a final segment if it is a consonant) or an unattested (stress a final segment if it is a vowel) rule to see if there was any indication of a preference for one rule over the other. If data can be described by more than one pattern, those which are easier to learn and produce may be reducible to a substantive bias.

This section provides an overview of common aspects in AGL design. While not every study is covered in detail, a summary is provided in Table 6.1). The principle ambition of this section is to highlight protocol design choices which are particular to laboratory settings and which diverge from natural language acquisition, especially where the question of naturalness in phonology is concerned.

6.2.2 *Materials*

6.2.2.1 *Natural and artificial languages*

AGL studies broadly aim to allow for experimenters to control for any prior knowledge participants may carry from experience of their native language. This can be done through the adaption of participant's native language, or through the construction of entirely artificial grammars. The former, which use modified natural languages, have been used to test morphological knowledge (Berko 1958), and are used in phonology to test well-formedness impressions (Becker et al. 2011; Hayes et al. 2009).

Semi-artificial languages can also be exploited for the purposes of experimentation by adapting natural language lexical items, morphology, or syntax. In Carpenter (2010) data from Mokša Mordvin (Finno-Urgic) (see also §3.15.1.1) is adapted to test the learning of stress patterns by

native speakers of English, representing a kind of natural-language study using non-native speakers to test for universal preferences. [Skoruppa & Peperkamp \(2011\)](#) test a putative bias for vowel harmony over disharmony in French speakers by using artificial French “dialects” with vowel harmony and disharmony. Since French does not have any phonological vowel harmony, any bias French speakers have towards one or the other pattern should not come from their knowledge of French, but they do not need to learn an entirely new grammar for the pattern to be tested. [Samara et al. \(2017\)](#) proposes a semi-artificial language in a protocol that tests patterns of regularization in children using real roots of the participant’s native language with added non-word affixes, potentially easing the memory burden on younger participants.

Perhaps the bulk of [AGL](#) experimentation uses grammars which are entirely artificial, consisting entirely of constructed lexical items, morphemes, and grammatical structures. Typically, the artificial languages make use of the segments of participants’ native languages, to ensure that alternations are not just learnable but also perceptible. To provide a semantic reference, pictures or images are shown along with the verbal cues. The advantage of artificial grammars is that they allow for fine-honed control over the nature of any patterns to be tested: the maximum number of superfluous elements can be excluded from the grammar so that only the elements of interest to the researcher are present. Where naturalness is concerned, an artificial grammar permits the testing of patterns which differ only in terms of their naturalness.

6.2.2.2 *Static and dynamic patterns*

In [AGL](#) experiments, participants are presented with phonological patterns which are either static phonotactic structures ([Carpenter 2010](#); [Glewwe 2017, 2019](#); [Greenwood 2016](#); [Koo & Cole 2006](#); [Kuo 2009](#); [Myers & Padgett 2014](#); [Nevins 2010](#); [Pertz & Bever 1975](#); [Saffran & Theissen 2003](#); [Seidl & Buckley 2005](#); [Skoruppa & Peperkamp 2011](#)), or dynamic alternations ([Beguš 2018b](#); [Do et al. 2016](#); [Finley 2017](#); [Gilker-son 2005](#); [Glewwe 2017](#); [Lin 2019](#); [Lysvik 2020](#); [McMullin & Hansson 2019](#); [Peperkamp & Dupoux 2007](#); [Zhang & Lai 2006](#)); in both static and dynamic patterns the focus may be on segmental or prosodic phenomena.

[Kuo \(2009\)](#) uses phonotactic patterns to investigate the question of whether or not all statistical regularities in phonological systems are equally learnable, or if phonetic groundedness may make some phonotactic regularities easier to acquire. In Mandarin, medial glides in onset clusters must agree in place with syllabic onsets, where palatal glides follow palatal onsets, and labio-velar glides follow velar onsets. [Kuo](#) tested native Mandarin speaker knowledge regarding this phonotactic restriction on place of articulation in onset-glide patterns by constructing two artificial languages which varied the pattern of onset-glide patterns. In one of the languages, bilabial onsets were paired with /w/ and alveolar onsets were paired with /j/, while in the other bilabial

onsets were paired with /j/ and alveolar onsets with /w/. Participants were exposed to each one of the two languages in an initial study phase, during which they heard 24 words exhibiting the respective patterns. After the study phase, participants were exposed to two words, one of which obeyed the phonotactic constraint presented in the study phase, and one of which violated it. Participants were asked to choose which of the two stimulus items sounded more like the language in the study phase.

Glewwe (2019) tests an implicational pattern in phonotactics, where if a language has a place of articulation contrast in word-final consonants (e.g. /ap/ and /at/ and /ak/), it is predicted to also have place of articulation contrasts in onsets (e.g. /pa/ and /ta/ and /ka/), though the reverse is not true. In Glewwe's study, participants were exposed to artificial languages with either word-initial or word-final place of articulation contrasts and then tested to see if they extended the exposure pattern to novel positions. Participants in the word-initial group were tested to see if they extended place of articulation contrasts to word-final positions, and participants in the word-final group were tested to see if they extended place of articulation contrasts to word-initial position. The two groups were then compared to see if one of them extended the pattern with more, less, or equal frequency to the other.

Other studies employ patterns of dynamic alternation (Baer-Henny & van de Vijver 2012; Beguš 2018b; Gerken & Bollt 2008; Glewwe 2019; Hayes et al. 2009; Martin & Peperkamp 2020). A typical example comes from Lysvik (2020), where all pseudo-words end in a consonant [p t k b d g]. When pseudo-words are followed by the plural morpheme, all six final consonants are possible. However, when the pseudo-words are not accompanied by the vocalic morpheme, only [p t k] are possible. All cases of plural forms with final [b d g] alternate with singular forms ending in [p t k], creating a dynamic pattern of final devoicing. Another often used method of creating dynamic patterns is to use vowel harmony or disharmony (Finley 2012; Martin & Peperkamp 2020; McMullin & Hansson 2019; Pycha et al. 2003). In Finley (2012) for example, participants are exposed to stems followed by a suffix form, where the stem triggers a harmony-based alternation in the suffix.

6.2.3 Participants: Critical-period effects

Participant pools in AGL studies tend to focus on three age demographics: infants, children and young adolescents, and adults (Martin & Peperkamp 2020). This parameter of experimental design may have a profound and under-appreciated consequence for experimental results since there are important differences in the way children and adults acquire language, known in the literature as *critical* (DeKeyser 2000; Hurford 1991; Hyltenstam & Abrahamsson 2003; Long 1990; Meisel 2013; Oyama 1976) or *sensitive* (Hartshorne et al. 2018) period effects. Descriptively, sensitive-period theories suggest that infants and children are equipped with cognitive tools that provide them with a

unique capacity for language acquisition, unavailable to older speakers who must rely on general cognitive skills to learn a language. The critical period was first proposed by [Penfield & Roberts \(1959\)](#), who argued that children's brains are specialized for language learning. [Lenneberg \(1967\)](#) hypothesized that language learning is constrained by biology, and that native language acquisition depends uniquely on age of exposure, rather than explicit learning strategies as is the case of L2 learning¹.

Classically, critical-period effects are seen as a developmental window during which an unfixed system can be structured or restructured on the basis of environmental input ([Werker & Hensch 2015: 175](#)). Another way of conceptualizing the critical period is proposed by [Balari & Lorenzo \(2015: 27\)](#), where critical-period effects are viewed as an emphasis on future events or states as opposed to unachieved potential and a closed window of opportunity. In this view, there is a sensitive or optimal period for acquisition, but potential is merely reduced, rather than being entirely unrealizable². Since first-language acquisition is subject to critical-period effects ([Meisel 2013: 71](#)), if AGL protocols are meant to test native-language (L1) acquisition, the age of participants is of fundamental importance: beyond a certain age the means of language acquisition changes proceeding rather as second-language (L2) acquisition ([Johnson & Newport 1989: 97](#)).

Grammatical domains subject to maturational changes are not all affected simultaneously ([Meisel 2013](#)). The critical-period threshold is earlier for phonology than for syntax and semantics ([Bever 1981: 195](#)). Thus while the critical period for syntax, for example, may continue through late adolescence ([Hartshorne et al. 2018](#)), the sensitive period for phonology seems to be much more restricted, beginning to diminish well before the onset of puberty ([Meisel 2013: 72](#)), with declines in learning capacity appearing as early as age six ([Long 1990](#)), and ulti-

1 Biologically, various mechanisms responsible for critical-period effects have been proposed, from decreasing brain plasticity beginning at about age nine ([Penfield & Roberts 1959](#)), to brain lateralization effects ([Lenneberg 1967](#)), or synaptic pruning and molecular triggers ([Werker & Hensch 2015](#)), while [Kuhl \(2004: 838\)](#) suggests that native-language speech produces dedicated neural networks and influences the brain's future ability to acquire non-native patterns (see [Friedmann & Rusou 2015: 28](#) for an overview of possible maturational changes in the brain resulting in critical-period effects, including a changing excitatory–inhibitory balance of neurotransmitters in the brain).

Some of these hypotheses have been discounted; for example [Lenneberg's](#) lateralization hypothesis has been shown to be non-viable, since lateralization begins very early and is completed by age five ([Meisel 2013](#)). Acknowledging age effects in language acquisition is not the same as arguing for neurological changes which manifest as a terminal critical period: critical-period effects may be purely due to acquired experience rather than direct biological development ([DeKeyser 2013: 85](#)). Whatever the origin of sensitive-period effects, phonology is among the least controversial domains in which its effects are manifest from a very early age, perhaps as early as four ([Meisel 2013: 81](#)).

2 While there seems to be a consensus regarding the advantages child learners have over adults, there is debate regarding the exact reason for this developmental difference; specifically, if it is biological or social/psychological in nature and whether or not it is a rigid limitation or can be overcome ([Hyltenstam & Abrahamsson 2003](#)).

mate attainment typically diverging from native competence (Moyer 1999).

Language acquisition depends on an intricate tissue of interrelated sensitive periods which do not begin and end abruptly and may potentially always be exploitable to greater or lesser degrees (Werker & Hensch 2015: 179). The sensitive period effect is relevant to several domains of phonological acquisition (Jusczyk 1997). Phonemic categorization itself is an ongoing process, completed after early childhood; beyond adolescence, performance in phonemic categorization tasks is comparable across age groups (Hazan & Barrett 2000: 393). Oyama (1976) shows that younger children have greater success in mastering phonological systems other than that of their native language, and that children between six- and ten-years old show the least influence of interference from L1 phonology, with performance increasing the younger the child is. Regarding contrast in particular, Werker & Tees (1984) show that infants discern phonological contrasts which are not present in their native language and to which adults are not sensitive. This sensitivity begins to decline rapidly as children age, such that by four years old children perform about as poorly as adults in discernment tasks. Werker & Tees (1984: 62) conjecture that the decline in discriminatory ability, or “tuning”, as they term it, coincides with the age at which children begin to understand, and “possibly produce” the sounds present in their native language.

Thus, L1 acquisition proceeds up to about age nine, a period during which children can acquire a first language uniquely by exposure to primary linguistic data (Penfield & Roberts 1959). Hurford (1991: 162) suggests that the steepest downward slope coincides “roughly” with puberty, the onset of which Lenneberg (1967) identified as an upper limit on L1 acquisition. There is then an age-imposed limit to L1 acquisition, after which any linguistic learning is L2 learning and does not proceed along the same path as native language acquisition.

L2 acquisition typically shows a strong ceiling effect which correlates with age. Experimental results corroborate the findings suggesting that at about age four, L2 learning effects begin to emerge in language acquisition (Meisel 2013: 79). For example, DeKeyser (2000) reports results from a study showing that a prepuberty group demonstrated a less restrictive upper limit in acquisition relative to those who began after puberty. Newport (1988) reports a striking difference in L1 and L2 acquisition in signed language. In this study, young learners acquired signs based on composition, using morphologically complex constructions. Late acquirers, in contrast, learned signs holistically, attributing meaning to each individual form but without comparing lexical items to each other. Earlier acquisition, then, correlates with a more complex task. The stark difference between L1 and L2 acquisition is perhaps best illustrated by the fact that, unlike L1 acquisition, L2 acquisition is not always successful (Meisel 2013: 76).

It is clear that adult L2 acquisition does not make use of the same cognitive capacities as L1 acquisition in children (Morgan-Short et al. 2014; Ullman 2004). Ullman proposes a model of language acquisition

which implicates two kinds of memory *declarative memory* and *procedural memory*, each memory system underlying different aspects of language acquisition. The latter is knowledge of *how*, which underlies both motor and cognitive skill and habit learning, and is not available to conscious awareness (Morgan-Short et al. 2014). It is gradual, a product of repeated exposure or experience with a task, requiring fewer attentional resources, and occurring even without the intention of learning (Morgan-Short et al. 2014; Ullman 2004). In turn, declarative memory is knowledge of *what*, of facts about the world and events (Morgan-Short et al. 2014). It is important in rapid learning (i.e. it can happen with only a single exposure) of arbitrarily-related information (Ullman 2004). Information processed by declarative memory can be consciously recalled, and learning with the declarative system is distinguished by being fast, requiring attentional resources such as working memory, and benefiting from that conscious attention (Morgan-Short et al. 2014).

Thus, for example, declarative memory underlies storage in the lexicon, and procedural memory underlies computational processes such as phonology (Morgan-Short et al. 2014: 58). Crucially, Ullman (2004) argues that L1 acquisition in children relies substantially more on procedural memory than does L2 acquisition in adolescents and adults, who depend on declarative memory to perform novel linguistic tasks. After puberty, Ullman (2004: 256) suggests that the computational/procedural system is less available to learners than is the lexical/declarative memory, meaning that the language acquisition systems of children and adults are fundamentally different. The consequences of this difference are profound for experimental design in AGL, since results from studies using data from adults cannot meaningfully be used to make conclusions about L1 acquisition or UG.

The implication for AGL experimental results is that any study using participants beyond the critical period threshold is not relevant for L1 acquisition, since AGL learning does not proceed in a manner comparable to that of L1 acquisition. Ettliger et al. (2015) suggest that it is a question whether or not AGL experiments are related to language-specific learning or rather general learning abilities or general intelligence capacities related to L2 learning. The relevance for AGL results and understanding the architecture of UG is, thus, unclear, since the biases inherent in L1 speaker knowledge cannot be controlled for. This is all the more true for phonology, since it is phonology which poses some of the most enduring difficulties for L2 learners, the majority of which never attain native-like phonological competence.

Some studies—in an effort to mitigate critical period effects—use young participants, either infants (Cristià & Seidl 2008; Cristià et al. 2011b; Gerken & Bollt 2008; Seidl & Buckley 2005; Seidl et al. 2007; White & Sundara 2014) or young children (Pertz & Bever 1975). In such studies, critical-period effects may play less of a role in data interpretation, but there is still scant evidence that AGL acquisition proceeds along a path comparable to native-language acquisition.

6.2.4 Procedures

6.2.4.1 Implicit and explicit training

One of the principle differences between natural-language acquisition and AGL is the way in which learners are exposed to linguistic data. In natural ecological contexts, children are exposed to a huge number of tokens over a period of months and years. In AGL settings, the same extensive exposure is not possible, and how stimuli are presented to participants is a key element of protocol design. Language data is presented in what is known as the *learning* or *acquisition* phase, during which participants are exposed to language data which instantiates the pattern researchers are interested in.

Experimental stimuli may be presented through explicit training, in which participants are told what the nature of the pattern is (Carpenter 2010; Pycha et al. 2003). This method has the advantage of greatly increasing the ease with which participants learn patterns, but is also far removed from the noisy and unstructured ecological context in which natural language acquisition occurs, where learners must extract patterns on their own. Rather more common is implicit learning, in which the nature of the pattern to be learned is not revealed to participants (Baer-Henny & van de Vijver 2012; Beguš 2018b; Carpenter 2010; Finley 2017; Lai 2015; Saffran & Theissen 2003). Presumably, this corresponds better to natural-language acquisition and thus any suggested bias more likely to be a product of the learning process itself.

6.2.4.2 Learning thresholds

Following the exposure phase is the *test phase*, in which participants are presented with novel stimuli in order to test their ability to distinguish and extend the exposure phase pattern. Some protocols include a *learning threshold* between phases, where participants are required to demonstrate a certain level of master of the test pattern before the test phase itself begins. The learning threshold prevents participants from being tested on a pattern they have inadequately learned, which would negatively prejudice the experimental results. Participants who do not attain the established success threshold either undergo an additional learning phase or are filtered out from results (White 2014). The former may result in unequal levels of learning across participant cohorts, as some participants benefit from more complete exposure than others. The latter biases results by removing participants with low rates of success from the statistical count, increasing the level of successful responses.

Thus, learning thresholds represent a further difference between natural language acquisition and AGL. Not all protocols, however, include a learning threshold, noting that in L1 acquisition, feedback cannot be counted on (see for example Gómez & Gerken 2000). Another potential way of avoiding screening-induced bias is to test participants on a pattern that is similar to the test pattern, but different in important

ways. An example of this is found in [Carpenter \(2010\)](#), who tested participants on a stress-based pattern to insure the participants could in principle acquire stress-based patterns, although the screening pattern was not actually used in the testing phase itself.

6.2.4.3 *Response tasks*

During the test phase, participants are tested for successful acquisition of the learning-phase pattern. There are two principle ways of recording participant responses. The first is through *production-tasks*, where participants are asked to produce appropriate forms given novel test-phase stimuli and based on learning-phase patterns ([Wilson 2006](#)). Production tasks constitute a kind of free-response task where participants can provide any response, or none. The principle disadvantage of production-task results is their variability, and the difficulties they pose for analysis. In this sense, they are quite like natural-language data, and more useful in that positive results are unambiguous since any pattern reproduced by participants is almost certainly the result of successful learning.

The other response-task paradigm is *forced-choice* response, in which participants are presented with a limited number of possible responses from which they must select the one which seems to them to match most closely the learning-phase pattern. The advantage of forced-choice tasks is that they always produce data, and that data is easy to analyze. However, they have the potential to introduce biases into results since participants can only select from a range predetermined by the experimenter. The principle disadvantage in forced-choice tasks is that it is not clear if participants are relying on implicit knowledge about phonological patterns, or a kind of explicit knowledge ([Dienes et al. 1991](#)). For example, participants may make use of general pattern-recognition capacities and then exploit those capacities to identify patterns in the data, but this may not require them to access any innate linguistic knowledge. Furthermore, they represent a radical departure from natural-language ecology where speakers are rarely presented with comparable situations in which they must select from a limited, predetermined range of output choices.

A subtype of forced-choice response paradigms is used in studies with infants, known as a preferential-listening paradigm or head-turn preference procedure ([Jusczyk & Aslin 1995](#); [Kemler Nelson et al. 1995](#)). These response-tasks are well adapted for measuring learning in infants, given in particular the tendency in infants to orient visually to sound sources, and the correlation between duration of a head turn and the extent of infants' attention to an auditory stimulus ([Kemler Nelson et al. 1995](#)). [Saffran & Theissen \(2003\)](#) and [Seidl & Buckley \(2005\)](#) are instructive examples of the use of head-turn paradigms in AGL experiments.

6.3 SUMMARY

6.3.1 *A survey of AGL results*

In §6.2 I discussed the general construction of AGL experiments, especially those concerned with substantive biases in phonology, and naturalness biases in particular. Table 6.1 presents a summary of results from 39 AGL studies investigating naturalness biases. It is organized by study and summarizes the methodology of each one in terms of the experimental design choices outlined in §6.2. The final column summarizes the kind of bias found in each study—categorized as a complexity bias, a bias for a typologically recurrent pattern as opposed to a rare one, a bias for one articulatory configuration as opposed to another, a bias for an acoustically salient pattern as opposed to a less salient one, or a null finding where no bias is found. As can be seen, the evidence for a naturalness bias is ambiguous. Robust phonetic naturalness effects are rare (Finley 2012; Kawahara 2005; Gilkerson 2005; Peperkamp et al. 2006b; Zhang & Lai 2006), and the more common result is a result for typological naturalness (Berent et al. 2008; Bergelson & Idsardi 2009; Carpenter 2010; Finley 2017; Lin 2019; Myers & Padgett 2014), or null results where no naturalness bias is found (Do et al. 2016; Finley & Badecker 2009; Greenwood 2016; Myers & Padgett 2014; Peperkamp & Dupoux 2007; Pycha et al. 2003; Saffran & Theissen 2003; Seidl & Buckley 2005).

In terms of articulatory or acoustic naturalness, only 13% of studies report clear results showing a bias. Typological bias is more frequent, being found in 23% of the studies cited here. Most frequent is a result demonstrating a complexity bias, present in 41% of study results. While the eight null results found represent 21% of results, it is likely that null results are underrepresented, since null-result experiments may never be written up or published. Mixed results come from some identified confounding factor other than complexity; for example Greenwood (2016) reports a bias for natural patterns when stimuli are low fidelity and noisy, but this bias seems to disappear as the recording fidelity increases.

Where naturalness and substantive biases in phonological computation are concerned, AGL studies suffer from two primary weaknesses. The first is that it is not clear if participants in laboratory settings acquire and exploit phonological patterns and computation in the same way that speakers of natural languages do (see §6.3.2 and Chapter 7). The second is that it is not clear what kinds of facts about language AGL studies bring to light. That is, studies which find a bias for naturalness in phonetics or typology do not, by themselves, reveal a fact about phonology *qua* computation. Evidence found in the laboratory for both typological and phonetic biases does not say anything about what the origin of those biases is: are they the effect of channel bias (§4.3.2), or do they arise from the architecture of UG?

As Braine (1963: 324) puts it: “[a]lthough experiments with artificial languages provide a vehicle for studying learning and generalization

Table 6.1: A summary of substantive biases in AGL results.

Study	Natural or Artificial	Kind of pattern	Participant age	Instruction	Threshold	Response paradigm	Bias found
Baer-Henny & van de Vijver (2012)	artificial	dynamic	adults	implicit	no	production	complexity
Beguš (2018b)	artificial	dynamic	adults	implicit	yes	forced choice	complexity
Berent et al. (2008)	artificial	static	adults	implicit	yes	forced choice	typological
Bergelson & Idsardi (2009)	artificial	static	infants & adults	implicit	no	head turn	typological
Carpenter (2010)	semi-natural	static	adults	explicit	yes	forced choice	typological
Cristià & Seidl (2008)	artificial	static	infants	implicit	no	head turn	complexity
Cristià et al. (2011b)	artificial	static	infants	implicit	no	head turn	null
Do et al. (2016)	artificial	dynamic	adults	implicit	no	forced-choice	null
Finley (2012)	artificial	dynamic	adults	implicit	no	forced choice	articulatory
Finley (2017)	artificial	dynamic	adults	implicit	yes	forced choice	typological
Gerken & Boltz (2008)	artificial	static	infants	implicit	no	head turn	typological
Gilkerson (2005)	artificial	dynamic	adults	implicit	no	forced choice	articulatory
Glewwe (2017)	artificial	dynamic	adults	implicit	no	forced choice	null
Glewwe (2019)	artificial	static	adults	implicit	no	forced choice	null
Greenwood (2016)	artificial	static	adults	implicit	no	forced choice	mixed
Hayes et al. (2009)	nonce	dynamic	adults	implicit	yes	forced choice	complexity
Kawahara (2005)	nonce	dynamic	adults	explicit	no	forced choice	acoustic
Koo & Cole (2006)	artificial	static	adults	implicit	no	production	null
Kuo (2009)	artificial	static	adults	implicit	no	forced choice	complexity
Lai (2015)	artificial	static	adults	implicit	no	forced choice	complexity
Lin (2019)	artificial	static	adults	implicit	no	forced choice	complexity
Lysvik (2020)	artificial	dynamic	adults	explicit	no	forced choice	typological
Martin & Peperkamp (2020)	artificial	dynamic	adults	implicit	no	forced choice & production	null
McMullin & Hansson (2019)	artificial	dynamic	adults	implicit	yes	forced choice	complexity
Moreton (2008)	artificial	dynamic	adults	implicit	no	forced choice	complexity
Myers & Padgett (2014)	artificial	static	adults	implicit	no	forced choice	typological
Peperkamp et al. (2006b)	artificial	dynamic	adults	implicit	no	forced choice	articulatory
Peperkamp & Dupoux (2007)	artificial	dynamic	adults	implicit	no	production	null
Pertz & Bever (1975)	artificial	static	children & adolescents	implicit	yes	forced choice	typological
Pycha et al. (2003)	artificial	dynamic	adults	explicit	no	forced choice	complexity
Saffran & Theissen (2003)	artificial	static	infants	implicit	yes	head turn	complexity
Schane et al. (1974)	artificial	dynamic	adults	implicit	no	production	typological
Seidl & Buckley (2005)	artificial	static	infants	implicit	no	head turn	null
Seidl et al. (2007)	artificial	static	infants	implicit	no	head turn	complexity
White (2014)	artificial	dynamic	adults	implicit	yes	forced choice	complexity
White & Sundara (2014)	artificial	dynamic	infants	implicit	no	head turn	complexity
Wilson (2003)	artificial	dynamic	adults	implicit	no	forced choice	complexity
Wilson (2006)	artificial	dynamic	adults	implicit	no	production	complexity
Zhang & Lai (2006)	nonce	dynamic	adults	implicit	no	production	acoustic

processes hypothetically involved in learning the natural language, they cannot, of course, yield any direct information about how the natural language is actually learned.” Phonetic biases may in principle be accounted for by channel bias if constraints on human auditory perception and articulation are reproduced in laboratory settings. In the same way that channel bias comes to be reflected in cross-linguistic typological patterns (§4.3.3), the evidence for typological bias in the laboratory may also be a reflection of channel bias. Ultimately, there are no conclusive arguments that suggest anything in AGL studies can be used to reveal the structure of UG.

6.3.2 *Interpreting AGL results*

Given the range of results summarized in Table 6.1, it cannot be said that AGL studies have succeeded in finding unambiguous evidence of substantive naturalness bias. The simplest explanation for null results, then, is that there are no naturalness biases in phonology. However, the fact that some studies do report naturalness effects merits some further discussion regarding their interpretation.

Glewwe (2019) suggests that one possible explanation for null results in AGL studies is that the term “substantive bias” is too broad, subsuming any kind of bias for phonetically natural patterns, in both articulation and perception. Glewwe suggests that while articulatory naturalness may not exist, there is evidence for perceptual naturalness based on an ease of learning effect related to patterns presenting robust phonetic cues. Mixing the two kinds of naturalness would produce weak evidence for a naturalness bias, while splitting the two apart would result in a null result for articulatory based naturalness, and a strong effect for perceptual naturalness. A robust result for a naturalness bias in perception, however, does not imply that phonology is in fact sensitive to perceptual naturalness. Channel bias (see §4.3.2) may explain apparent biases in perception without requiring recourse to any properties of phonology³. Interpreting perceptual naturalness effects as a reflection of the architecture of UG is unwarranted, contra for example Hayes & White (2015); Lin (2019) and White (2017).

In fact, any AGL study is confronted with the possibility that experimental results do not reflect phonology or phonological learning at all. If participants are using domain-general cognitive strategies to learn AGL patterns, the results of such studies are not valid for understanding UG. Where the ambition of AGL studies is to sound the architecture of UG, a critical assumption is that the data collected in AGL experiments is comparable to natural language data. In fact, this seems to be the position of most AGL studies, although it is rarely discussed or argued for (though see Ettliger et al. 2015: 823, Lysvik 2020: 50ff., and Zsiga & Tlale Boyer 2017: 349f. for exceptions).

³ Greenwood (2016) suggests that the clarity with which experimental stimuli are typically recorded and reproduced may introduce a kind of channel bias in experimental data since phonetic cues are exaggerated.

Any conclusion that AGL results bear on natural language computation is subject to doubt based on the ecological divergences between laboratory conditions and natural-language acquisition surveyed in §6.2. Natural languages are acquired over a long period of time with no explicit instruction; they result from rich, extensive input from a speech community. Natural-language comes about through long-term exposure to thousands of tokens over the course of normally developing acquisition by infants, a years-long process that occurs during a sensitive developmental period (see §6.2.3).

In contrast, in AGL studies the learning paradigm happens under explicit instruction, is highly guided, and looks very little like natural language acquisition—they are rather more like “extended psychological tests” (Odden 2013: 262f.). AGL data are presented in a highly constrained manner such that it can be argued that what is being tested is the participant’s capacity to make analogies, not to construct grammatical rules. Thus, AGL results are typically the reflection of patterns learned over a short time, based on a small number of tokens, in a lab by adult speakers with a subjacent, fully-formed phonological system. Further, AGL depends on a whole host of transitory non-linguistic performance factors that do not play a role in linguistic competence, including attention, fatigue, emotional states, and memory. While these aspects of performance do not concern phonological computation, they may play an outsized role in the quality of AGL results obtained.

AGL results are also fundamentally different from natural-language data: while AGL results tend to show a significant range in acquisition success in that some participants in both natural and unnatural groups will demonstrate a high rate of success in acquiring their group’s respective patterns, some participants in each group will demonstrate much lower rates of success. In contrast, in natural-language production, speakers show a remarkable homogeneity in competence. Further, AGL results must be interpreted in the light of a speaker’s non-phonological knowledge about spelling, general pattern recognition, the capacity for analogical thought, or simply their ability to understand the protocol itself (Odden 2013: 262). Ferman et al. (2009: 387) evoke the possibility that AGL experiments may not reflect the complexity of natural language or real-life learning conditions, but also suggest that this is an inevitable consequence of experimental control in laboratory research.

Even robust results interpreted as a naturalness bias do not necessarily reflect a bias in UG itself. Phonetic biases may in principle be accounted for by channel bias if constraints on human auditory perception and articulation are reproduced in laboratory settings. Finley (2012), for example, reports a robust substantive bias in rounding and backness harmony, where mid vowels are more likely than high vowels to trigger rounding harmony. But, while there is a phonetic precursor for this asymmetry in that the perception of mid vowels is more greatly enhanced in harmony relative to high vowels (Kaun 2004), the bias—like the precursor—can be attributed to channel bias effects (Moreton 2008). Further, if, as suggested by Ettliger et al. (2015) and Moreton & Pertsova (2016: 289), AGL is best used to sound L2 acquisition, then

any potential substantive bias may be a reflection of acquired phonetic knowledge (see [Kingston & Diehl \(1994\)](#)), rather than anything innate. Especially salient in studies using adult participants (see §6.2.3), native phonological and phonetic knowledge have a pronounced effect on L2 acquisition ([Moreton & Pertsova 2016](#)).

Thus, native phonetic and phonological knowledge may be interpreted as substantive bias. For example, [Berent et al. \(2007\)](#) report results suggesting that English speakers have an innate preference for sonority in onset clusters that are not a part of their native language. In a series of invented word tests, English speakers showed a tendency to perceive an intrusive schwa between onset sequences that violate sonority sequencing in English, although the schwa is not phonetically present; for example *lbif* would be perceived as *lebif*. [Berent et al.](#) interpret the illusory epenthetic schwa as a phonological strategy to break up disallowed onset clusters—a reflection of innate knowledge of a markedness scale for onset clusters.

This conclusion is questioned by [Peperkamp \(2007\)](#), however, who raises a number of methodological issues, concluding that participants' sensitivity to phonetic stimuli may be indistinguishable from any putative innate knowledge. That is, [Berent et al. \(2007\)](#) may be testing what English speakers know about English, rather than anything in [UG](#) or any universal substantive bias. [Berent et al. \(2008\)](#) in turn report results that suggest speakers of Korean exhibit a universal preference for initial consonant sequences of rising sonority (e.g. *bl*) over sequences of falling sonority (e.g. *lb*), although Korean lacks initial consonant sequences and thus this preference cannot be due to what Korean speakers know about Korean. [Berent et al.](#) interpret this finding as a linguistic universal reflecting universal linguistic knowledge active in speakers' brains.

Finally, robust results for substantive bias may be unrelated to phonetic naturalness. [Bergelson & Idsardi \(2009\)](#) report results showing evidence for a kind of typological naturalness supporting the observation that phonological processes are tied to the contexts that trigger them. Of particular interest here is the final position, of which [Bergelson & Idsardi](#) distinguish two kinds: *relative* and *absolute* final positions⁴. Absolute or relative final positions may trigger different processes in different languages. The results of this study show that, for example, stress-based processes tend to target relative-final positions, while voice-based processes tend to target absolute-final positions. [Bergelson & Idsardi](#) draw attention to the essentially arbitrary nature of this typological trend: there is no reason for such attested processes to be more easily learned by participants, since the unattested

4 In relative final positions, the targeted object in a string may be followed or not by other objects, such as the rule of stress in French which targets final vowels that may or may not be followed by other consonants. For example, both *petit* [pə'ti] 'small-MSC and *petite* [pə'tit] 'small-FEM' are stressed on their final vowels, though *petite* also has a following consonant. That final consonant in *petite* is in turn an example of an absolute final position since it is not followed by anything; absolute final positions can be the target of phonological rules, for example rules that devoice only string-final consonants.

conditions they test are formally equivalent. The reverse situation, they argue, where stress rules are applied in absolute-final positions while obstruent devoicing rules are applied in relative-final positions, is just as plausible. In this study, the segmental and prosodic phenomena investigated may provide evidence for innate bias, but that bias is unrelated to articulatory naturalness.

AGL studies, then, present important divergences from the way natural languages are acquired and used. There is no unambiguous evidence that results obtained from AGL studies answer any questions about naturalness in phonological representations or computations, since in virtually every case where evidence for a naturalness bias is found, there is some readily available extra-linguistic explanation for that bias. Their use in studying UG is especially dubious, since nothing suggests that AGL paradigms exploit the FL endowed human capacity for language use (see discussion in [Odden 2013: 260](#)). Tellingly, in a meta-study on infant phonotactic learning, where the influence from native phonetic and phonological knowledge is reduced, [Cristià \(2018\)](#) found an average effect size of zero; this suggests that there is no learning happening during AGL studies using static patterns and infants. Ultimately, while AGL can be used to test for potential effects of biases, they should not be used as evidence for the origin of those biases ([Glewwe 2019: 16](#)).

6.3.3 *On the use of AGL studies*

I argue that there is no evidence that AGL studies reproduce an ecologically valid environment for phonology, and thus its use in investigating phonological computation is limited. But this does not mean that AGL studies have no role to play in understanding language, since they have revealed a great deal about how infants learn phonology. For example, while it is known that infants begin processing speech immediately upon birth ([Jusczyk 1997](#)), at six months of age, infants do not seem sensitive to patterns in linguistic data, by nine-months of age the situation changes, and infants begin to show preferences for patterns present in their ambient language ([Jusczyk et al. 1994](#)). AGL studies have shown that the ability of infants to discriminate between phones declines over time, such that while very young infants can discriminate between any pair of phones, by the end of the first year of life infants are only sensitive to those contrasts of their ambient language ([Maye & Gerken 2000](#); [Seidl et al. 2009](#)). Thus, by the latter half of the first year, infants are already capable of acquiring knowledge about sound patterns ([Jusczyk & Aslin 1995](#)), before any knowledge of semantic categories upon which lexical contrasts can be built is acquired ([Cohn 2011](#); [Maye & Gerken 2000](#); [Pierrehumbert 2003](#)).

Importantly, AGL studies have been useful in understanding how infants are able to do this. [Saffran et al. \(1996\)](#), for example, report experimental results showing that 8-month old infants can determine transitional probabilities between co-occurring syllables, knowledge

which potentially could be used to determine the location of word boundaries; the ability to make use of probabilistic generalizations from linguistic data in the speech signal has come to be known as *stochastic learning*. AGL studies have revealed the importance of stochastic learning in the acquisition of phoneme categories (Maye & Gerken 2000), phonotactic regularities (Chambers et al. 2003), allophonic relationships (White et al. 2008), and sociolinguistic variation (Samara et al. 2017). Attention to statistical distributions is a critical element in the development of speech in the first year of life (Maye et al. 2002), and there is robust evidence for infant sensitivity to statistical patterns in language input (see Kuhl 2004 and Culbertson & Schuler 2019 for reviews and Cristià 2018 for a meta-analysis of infant AGL studies). Stochastic learning is almost certainly a domain-general capacity, at play in visual scenes (Fisner & Aslin 2001) and non-human primates (Hauser et al. 2001) (see discussion in Vihman 2014: 41 and Saffran & Kirkham 2018: 185).

Stochastic learning does not, however, constitute a full explanation for phonological acquisition, as statistically learned phonetic categories are not the end-state of phonological acquisition—phonemic categories based on contrast are (Dillon et al. 2013). In the view of Yang (2004), statistical learning must be constrained by domain-specific principles of linguistic structure, which delimit the potential learning space, ensuring that language operates on specific aspects of the input. For example, Peperkamp et al. (2006a) note that the exclusive use of statistical inferences would give rise to spurious allophonic rules: in French [ɥ] only occurs before vowels, and [œ] only in closed syllables, but their complementary distribution is not evidence for their allophonic relationship. In other words, any statistical algorithm needs to be complemented by some mechanism to constrain the set of candidate rules. Peperkamp et al. (2006a: B33) suggest that there may be a “linguistic filtering mechanism” at work, for example constraints that allophones must be neighbors in phonetic space, or that an allophone should be more similar to the context in which it appears than the default segment. An alternative explanation is that children do make spurious generalizations during acquisition, which they later sort out based on continued experience and further linguistic input, especially after the acquisition of semantic knowledge.

The use of AGL also extends beyond infants and the acquisition of phonology. Using a wug-test paradigm, Pierrehumbert (2006) found evidence for a frequency effect in speaker knowledge, suggesting that statistical inferences are exploited by adult speakers in extending generalizations, even unnatural ones, to novel forms. This conforms with a proposal in Yang (2016), who argues that speakers allow for some exceptionality in linguistic data when making generalizations.

AGL studies have also been used as support for the reality of basic phonological notions such as feature-based representations (Finley & Badecker 2009), and how those features emerge through language use. In a series of experiments with four month old infants, it was found infants can learn to generalize over an abstract class of sounds consti-

tuted by nasals and fricatives (Cristià et al. 2011a). However, by seven months of age, infants already begin to show a bias for feature-based classes—a class of nasals and stops is learned while the class of nasals and fricatives is not (Cristià & Seidl 2008). Since the bias for natural classes is absent in the younger cohort of Cristià et al., this suggests that any bias for natural-class based generalizations is not innate, but rather emerges along with feature-based contrasts (see §3.1). Even children as old as twelve do not categorize phonemic contrasts as consistently as adults (Hazan & Barrett 2000), suggesting that phonological systems are gradually constructed.

In short, AGL studies do reveal much about language, especially in the domain of acquisition of linguistic knowledge by infants. However, results must be interpreted carefully and with prudence. While AGL experiments can in principle be used to corroborate theoretical notions, their use in understanding phonological computation in adults and the structure of UG appears to be much more limited than has been acknowledged in the literature.

6.4 CONCLUSIONS

This chapter proposed an overview of AGL experiments, especially as used to investigate potential naturalness effects in phonology. The principle elements of protocol design were reviewed, where I argued that the exigencies of laboratory conditions mean that AGL studies present important divergences relative to natural-language ecologies. Principle among these are the age of participants and critical period effects, where it is suggested that what most AGL studies are probing is not natural language, but something closer to L2 acquisition.

While AGL studies have exhibited substantial evidence for a bias against formal complexity in phonology (Glewwe 2019; Moreton & Pater 2012a), the evidence for any kind of substantive, naturalness-based bias is scant (Moreton & Pater 2012b). Consequently, AGL results do not constitute a solid basis for making conclusions about any putative role of articulatory or typological naturalness in phonological computation. Further, in light of the ways in which AGL and natural-language learning differ, I argue that AGL studies do not exploit the phonological component of mind, and cannot be used to understand how natural-language phonology operates. In particular, using AGL results to make claims about the architecture of UG are unwarranted, given the number of non-linguistic resources that participants can potentially bring to bear when confronted with linguistic patterns in laboratory settings.

In particular, these conclusions have consequences for the interpretation of results showing evidence for a complexity bias in phonological computation. Since participants are argued to not have recourse to UG in laboratory settings, the substance of the attested complexity bias is in turn argued to not originate from the architecture of UG. Rather, it is a domain-general property of cognition and not isolated to phonology or even language.

Ultimately, [AGL](#) studies do not reveal much about how phonology functions in natural language. Despite the skeptical position adopted here, I review some ways in which [AGL](#) studies in infants have provided insight into the acquisition of phonology, and some evidence for the existence of phonological features and their emergence from the interplay of ambient language data and [FL](#).

EVENT-RELATED POTENTIALS AS A CORRELATE
OF PHONOLOGICAL COMPUTATION

The brain is just the weight of God,
For, lift them, pound for pound,
And they will differ, if they do,
As syllable from sound.

EMILY DICKINSON

Chapter 6 exposed a tension in the Artificial Grammar Learning (AGL) literature between naturalness and complexity—in particular a tendency to mistake a bias against complexity for a bias against unnatural phonological alternations—that has made the role of grammatical bias for natural phonological patterns in acquisition opaque. Further complicating the use of AGL in identifying a synchronic naturalness bias is the tacit assumption that grammars learned in laboratory conditions are learned in the same way that L1 phonology is acquired. While this assumption has never been tested, and is only infrequently discussed, it is the foundational pillar upon which the usefulness of AGL paradigms in sounding phonological grammars is posed. In §6.3.2, I argued that there are very good reasons to question this tacit assumption, and that AGL may occur in an ecologically invalid environment, seriously reducing its use as a tool for investigating the structure of synchronic grammars.

This chapter proposes a novel study intending to address both the issue of complexity and the ecological status of AGL pattern acquisition, using an approach from neurolinguistics. In this approach, correlates for phonological computation in brain tissue are sought out as and serve as a way of confirming the phonological status of a behavioral pattern. In the study proposed here, the specific correlates are Event-Related Potentials (ERP) which accompany the computation of phonological alternations. The pattern of lenition in Campidanese Sardinian (CS) described in §5.2.2 is proposed as a particularly well-adapted source of baseline ERP measurements, since the lenition pattern can arguably be categorized into three relevant subprocesses sharing a single triggering context: simplex (/f s/ → [v z]), complex (/p t tʃ k/ → [β ð ʃ ɣ]), and phonetically arbitrary or unnatural (/l/ → [ʁ]).

The simplex pattern is an uncontroversial phonological process, and serves as a useful metric by which the phonological status of the other two alternations might be measured. This study thus proposes measuring the Electroencephalography (EEG) activity of native speakers of CS as they produce the pattern of lenition described in §5.2.2 and extracting the relevant ERP component waveforms. According to the view of SFP articulated in §4.4, it is expected that no difference in ERP will be

found across the three classes of alternation, since arbitrary manipulation of emergent features means that naturalness is not a valid notion in the computation of L1 phonology. Complexity is a factor in phonological computation in this view, since a given process may manipulate n or $n+1$, but this complexity may not be reflected in phonetic correlates. This study is thus designed to shed light on a number of questions in phonology, including the status of complex “saltatory” alternations (§5.4.3) in computation, as well as that of unnatural processes and crazy rules.

The results obtained in this first study may then be extended to address the question of the validity of Artificial Grammar Learning (AGL) as an investigative technique into the structure of synchronic grammar. The ERP correlates of the pattern of lenition in CS can be compared to those of participants in an AGL experiment who learn a formally identical set of alternations. Behavioral results should reveal any differences in acquisition of the simplex, complex, and arbitrary patterns, and EEG recordings made during the AGL acquisition and test phases should provide ERP components for each of the three patterns, which can be compared to ERPs from an inert control condition serving as a baseline for comparison. Any significant difference between conditions across groups is reducible to differences in the way pattern learning and production proceed in native speaker phonological computation as opposed to laboratory settings. The principle hypothesis advanced here is that general learning strategies are used by learners in the lab, and that these same strategies are not available to learners in L1 acquisition, meaning that AGL results should not be extended to claims about the structure of synchronic grammar.

The principle ambition of the study proposed here is to contribute to the literature on the use of neurobiological correlates in theoretical linguistics. The proposed study consists of a novel extension of neurobiological techniques (EEG) to investigation of questions central to phonological theory and this thesis, as well as the use of AGL in phonological inquiry. The results should provide answers to a number of questions concerning the nature of phonological computation, how phonological computations are instantiated in human brains, and provide refinements to a widely-used tool for linguistic inquiry. It is in essence an effort to control AGL results by looking for significant differences between EEG activity in a natural language (CS) and EEG activity recorded in laboratory conditions on adult learners of an artificial grammar that is formally comparable to the natural language pattern.

The study is an extension of experimental protocols developed in Sahin et al. (2009); Scheer et al. (2020); Scheer & Mathy (in press), and White (2014) and seeks to test two principle hypotheses:

1. **Native Speakers** In L1 silent production, ERP components for natural and arbitrary phonological alternations will be comparable over cortical and sub-cortical brain areas (Janssen et al. 2020), thus demonstrating that phonological computation pro-

ceeds even when in phonetically arbitrary contexts, meaning that naturalness biases are not a part of formal theory. Complex alternations, in turn, may exhibit divergent ERPs, suggesting that complexity is an element in feature manipulation during the production of phonological alternations.

2. **AGL Learners** After learners master novel lenition patterns from an artificial language, learners' ERP components for the production of a pattern formally-identical to the natural-language pattern will show a statistically-significant divergence from those of the native-speaker group, supporting the idea that laboratory learning is ecologically different from natural-language acquisition. As a consequence, the results from AGL studies which are interpreted as a cognitive bias in *linguistic* cognition will need to be reconceptualized.

The proposed study has significance both for phonological theory and for experimental work. As concerns phonological theory, it has direct implications for the kinds of facts that theories should take into account and whether or not alternations that are not phonetically plausible should be within the remit of phonological theory. As concerns empiry, it should serve to directly confirm or disconfirm the validity of AGL experiments—one of the principle kinds of experimental work used to make conclusions about linguistic cognition.

7.1 CORRELATIONAL NEUROLINGUISTICS

7.1.1 *Lesion studies and early neurolinguistics*

The earliest functional neuroanatomical studies on language date to the mid-half of the 19th century, beginning with the foundational work of Broca, Wernicke, and Lichtheim (see [Arbib & Caplan 1979](#); [Burton 2001](#); [Poeppe & Hickok 2004](#); [Small & Hickok 2012](#) for summaries). These earlier studies were post-mortum lesion studies performed on the brains of aphasic patients. Lesion studies provided the first evidence for localized, language-specific task specialization in brain tissue. Although other aspects of language were unaffected, and patients were able to perceive non-linguistic sound normally, they had specific problems recognizing speech sounds ([Gazzaniga et al. 2014](#): 482). Such patterns are typical of specific-language pathologies like aphasia which leave general cognitive functioning unimpaired while seriously impacting narrow, well-defined aspects of the production or perception of language, and so provide insight into what kinds of specific processes “language” is built up out of (see [Lenneberg 1967](#): 188ff. for an overview). That is, the pioneering work in lesion studies showed that the production and perception of language is carried out in localized, specialized regions of cortical tissue.

Early functional studies on the neurobiology of language focused on identifying major language-related tasks related to language, viewing

them as unanalyzed, monolithic blocs that served broadly for production and comprehension (Arbib & Caplan 1979; Poeppel & Hickok 2004). Such coarse levels of description constitute a necessary first step in the development of early models of neurolinguistics, but cannot hope to provide an explanatory theory of how language is instantiated in brain tissue. Even finer-grained distinctions such as *syntax* or *phonology* are too coarse, not recognizing the multiple levels and rich structure of each domain (Poeppel & Hickok 2004). Poeppel & Monahan (2008: 81) summarize the situation by noting that “speech perception is mediated by a network of interconnected regions in the frontal, parietal, and temporal lobes, with the different areas making specific, task-modulated contributions in the mapping of sound to meaning and from sound to articulatory representation.” We may interpret “task-modulated contributions” as modular division of labor in language processing (see §1.3); there is no “language” processing, but rather processing of specific aspects of language.

Current investigation in neurobiology based on representational hypotheses focuses on aspects of neurological activity: activity located in spatial terms as functional neuroanatomy, and activity as it occurs over time (Philips 2001; Posner 2001). Tools used to measure neurobiological activity tend to offer either good temporal resolution but poor spatial resolution, or fine spatial resolution but poor temporal resolution. Both axes correspond to neurological activity, but of different kinds. Functional Magnetic Resonance Imaging (fMRI) and Positron Emission Tomography (PET), for example, are hemodynamic, showing increased blood/oxygen flow to regions of the cortex with corresponding increases in activity with relatively poor temporal resolution, but good spatial resolution. Magnetoencephalography (MEG) offers an alternative with very good temporal resolution and good spatial resolution, due to the nature of the magnetic fields it registers. Finally, EEG can be used to detect electrical signals correlated to neurobiological activity with very good temporal resolution. See Idsardi & Poeppel (2012) and Monahan et al. (2013) for reviews.

Since phonological activity is instantiated in human brains, it has neurobiological correlates which can be both localized in specific regions of brain tissue, and measured in time as they are carried out. Isolating those correlates means they can be used as an indicator of the presence or absence of phonological activity underlying a given pattern observed in behavior. In cases of observed behavior that permit analytic flexibility and whose phonological status may be questioned, those neurobiological correlates may then serve as useful tools of investigation, since neurobiological signatures exhibited by uncontroversial phonological computations, can be sought in marginal cases to either confirm or disconfirm their status as phonological.

Using neurobiological activity as a tool to test hypotheses about phonology is an example of what Embick & Poeppel (2015: 360) call *correlational neurolinguistics*, a way of asking if the “fact that human language is made up of certain computations (and not others) [is] explained by the fact that these computations are executed in neurobi-

ological structures that have certain properties (and not others)?” Here, neurobiological activity is put to use in the construction of linking hypotheses that explain the connection between linguistic primitives and neurobiological mechanisms (Poeppel et al. 2012). Neurobiological correlates do not by themselves explain phonological phenomena (see Chapter 2), rather they correspond to the algorithmic level of Marr (1982) (see §1.2). If we know what kinds of neurobiological correlates to look for, their presence or absence can be used to confirm or disconfirm hypotheses about phonology.

Correlational neurolinguistics provides more complete explanation of linguistic patterns: a theory of how knowledge is instantiated in the brain is a more complete theory than one of just knowledge (Monahan et al. 2013). Rather than reducing explanation to neurobiological structure, the Computational-Representational (CR) theory (see §1.2.2) provides a means of unifying cognitive science and neurobiology (see Poeppel & Embick 2005). That is, rather than assuming neurobiological data is more epistemologically valid than linguistic theory, the CR theory of phonology adopted in this thesis serves as a basis for neurobiological inquiry, providing a model for how phonology is represented in the mind and computed in the brain. In phonology, neurobiological investigation has found correlates for major class features (Idsardi & Monahan 2016; Monahan et al. 2021), distinctive features (Idsardi & Monahan 2016; Monahan et al. 2013, 2021), segmental length (Roberts et al. 2014), underspecification of features (Cornell et al. 2011; Eulitz & Lahiri 2004), and syllables (Idsardi & Monahan 2016).

7.1.2 *Event-Related Potential components*

EEG recording is among the methods with the best time resolution for recording activity in brain tissue, registering the electrical fields generated by the activity of large populations of neurons (10^5 – 10^6 neurons according to Idsardi & Poeppel 2012: 594). While EEG can be used to make coarse distinctions (between for example phonology and syntax), localizing cortical activity is more difficult (see Idsardi & Poeppel 2012). Its principle advantage is its good temporal resolution. Voltage fluctuations which are time-locked to an event, for example the onset of a stimulus or a response to a behavioral task, are recorded as ERPs: the sum of a set of the power and frequency of EEG oscillations at a moment in time, such that random oscillations between trials disappear when single trial EEG epochs are averaged together (Kappenman & Luck 2011).

ERP waveforms appear at the scalp as a series of positive and negative peaks varying in polarity, amplitude, and duration over time, and correspond to neural signals generated by brain tissue when a specific computational operation is performed (Luck 2014: 66). The conceptual definition of an ERP component given by Luck—a neural signal generated by a specific computational operation—is independent of any precise latency or amplitude of the waveform. As such, it is not

a useful operational definition; this is because ERP components are multiply-generated signals—recorded at many electrodes—potentially generated by different neurological processes, and there is no direct way of determining individual contributions to the waveform. Furthermore, since EEG waveforms are continuous, it is not necessarily the peak of an ERP waveform that corresponds to specific brain processes (Kappenman & Luck 2011). As a result, determining which component is influenced by experimental manipulation requires an operational definition (225):

(225) *An operational definition of an ERP component (Luck 2014: 66)*

A set of voltage changes that are consistent with a single neural generator site and that systematically vary in amplitude across conditions, time, individuals; a source of systematic and reliable variability in an ERP data set.

That is, ERP components can be identified as change along some axis of the waveform—time, frequency, or amplitude—that correlates with neurobiological activity¹. The ERP generated by phonological computations can be recorded and correlated with specific behavioral responses; if a correlate for uncontested phonological alternations can be found, then its presence in unnatural or crazy phonological alternations can be used to establish their status as phonological.

In addition, since multiple ERP components can be simultaneously generated and recorded, and their voltages can be summed together, multiple computations performed simultaneously will produce higher amplitude waveforms (Kappenman & Luck 2011: 6). If complexity (§6.1.2) in phonological alternations is reflected in multiple computations relative to simple alternations, then this could be reflected in the relative voltages of the ERP components produced by each (see for example Kramer et al. 1985). In sum, ERP represent an ideal way of testing a number of hypothesis related to naturalness and complexity in phonological computation.

7.1.3 ERP correlates of phonological activity

In order to use ERP as a potential way of distinguishing between natural and unnatural rules on the one hand, and simplex and complex rules on the other hand, a baseline for the time-course of phonological activity in production² has to be established. In a picture-naming study using MEG, Levelt et al. (1998) report activity in the left posterior temporal lobe (Wernicke's area) with prominent activity about 200 msec after picture onset, peaking at about 350 msec, with the onset of articulation about 538 msec after the stimulus presentation. In Levelt et al.'s

1 That neurobiological activity does not generally correspond to action potentials (see §1.2.1); instead it represents the inputs to groups of neurons rather than the output (see Kappenman & Luck 2011: 5 and Luck 2014: 39).

2 Production studies in EEG are very rare because the act of producing speech produces signals that correlate to the motor activity of the speech apparatus, a significant source of noise.

model, between presentation of the stimulus and the onset of articulation, participants must recognize the stimulus, retrieve the appropriate form from the lexicon, perform “phonological encoding”, and begin articulation. Phonological encoding means the construction of syllabic and other metrical structure, but must also include any manipulations to phonological features—what is referred to as phonological computation in this thesis; while picture namings tasks are not concerned with phonological alternations, phonology must take place between roughly 200-538 msec, with [Levelt et al.](#) identifying the 275-400 msec window as being where phonological encoding happens. In a similar experimental paradigm using ERP components, [Eulitz et al. \(2000\)](#) obtained amplitude and topographical effects between 275-400 msec after picture onset, based on stronger EEG activity in Wernicke’s area.

Show that all this evidence is converging for identifying a time window for phonology, and get rid of the idea that this has anything to do with Levelt’s model. This is the experimental evidence we have for identifying the time window, and it’s theory-independent.

In a meta-review of spatial and time-course correlates in picture-naming tasks, [Indefrey & Levelt \(2004\)](#) emphasize the importance of activity in left inferior frontal regions during phonological encoding. Experimental evidence also points to a time course for phonological activity:

1. Lexical selection occurs between 175-250 msec after stimulus presentation
2. Phonological encoding of lexical objects occurs between 250-330 msec
3. Syllabification occurs between 330-455 msec

This time-course corresponds to the model developed in [Levelt et al. \(1998\)](#), and is largely confirmed by [Indefrey \(2011\)](#) where it is noted that latency depends on numerous variables, including task variations, picture context, picture quality, the familiarity of participants with the depicted objects, and the length or frequency of the lexical item. Further confirmation that phonology happens between 250-450 msec comes from a study on anomic patients, where it was shown that patients with conduction aphasia and impaired phonological encoding exhibit normal electrocortical activity for the first 300 msec of a picture-naming task, but that after 300 msec and until 450 msec, electrocortical activity shows divergences relative to unaffected speakers ([Laganaro et al. 2009](#)).

In a task that made use of grammatically inflected words, [Sahin et al. \(2009\)](#) used intracranial electrophysiology³ to record local-field potentials while participants read words (the “Read” condition) and inflected past/present and singular/plural forms, engaging inflectional morphology and phonological computations when those inflected forms

3 The implants were placed in Broca’s area for medical evaluation.

Table 7.1: The three conditions in Sahin et al. (2009).

CONDITIONS	Lexical Access	Concatenation	Phonology	Timing
Read	yes			~200 msec
Null Inflect	yes	yes		~320 msec
Overt Inflect	yes	yes	yes	~450 msec

result in phonological alternations. Sahin et al. tested two conditions requiring grammatical computation. In the “Read” condition participants were just asked to repeat a word in isolation (i.e. *rock*), which requires lexical retrieval of a morpheme from long-term memory. In a “Null-Inflect” condition, speakers are presented with a carrier phrase and asked to insert a word-forms, which must be inflected for past/present or singular/plural though those forms are not overtly marked (i.e. *This is a rock*), and are thus pronounced as in the “Read” condition, requiring concatenation of morphemes but not phonology. In the “Overt-Inflect” condition, participants were again presented with a carrier phrase that requires adding a suffix to a base form and phonological modification of the concatenated suffix (i.e. *Those are the rocks*).

The results reported in Sahin et al. (2009) are summarized in Table 7.1, and indicate an activity pattern at ~320 msec modulated by the inflection of words, whether the stem is overtly inflected or not; activity absent in the Read condition. The Overt-Inflect condition, in contrast, exhibited a component at ~450 msec, which was not present in the Null-Inflect or Read conditions. Sahin et al.’s interpretation of this activity is that it correlated to phonological, phonetic, and articulatory programming, which is sensitive to the number of syllables in the base form.

Scheer et al. (2020) use ERP to investigate the dynamic aspect of phonological alternations in an effort to distinguish between phonological and morpho-syntactic computation (see §1.3.2.3). In an extension of the protocol developed by Sahin et al. (2009), which allows for phonological activity to be isolated, Scheer et al. sought to determine if ERP could serve as a diagnostic for patterns of alternation which are multiply analyzable⁴. Specifically, the pattern of alternations in English known as velar softening (e.g. *electri[k]/electri[s]ity*) is amenable to suppletive, allomorphic, or phonological analyses. In a suppletive analysis, both *electri[k]* and *electri[s]ity* are considered to be distinct morphemes stored in long-term memory, each of which is retrieved when appropriate. In an allomorphic analysis, there are again two forms in long term memory, *electri[k]* and *electri[s]*, but the latter form is selected when the suffix *-ity* is used. Finally, in a phonological analysis, there is only one stored form, *electri[k]*, and the alternation between *electri[k]* and *electri[s]ity* is the product of phonological computation. Scheer et al. (2020) exposed English speakers to the three conditions in Table 7.1

⁴ Scheer et al. (2020) also sought to find out if the results in Sahin et al. (2009) could be reproduced with scalp electrodes instead of implants.

using lexical items subject to velar softening when concatenated with velar softening triggering affixes, as in Table 7.2.

Table 7.2: The three analytic options for English velar softening.

CONDITIONS	Analytic option	Read	Null Inflect	Overt Inflect
Electricity	lexicalized	yes	no	no
Electri[s], electri[k], -ity	allomorphy	yes	yes	no
Electri[k]-ity	morpho-phonology	yes	yes	yes

Scheer et al. (2020) used three data sets of 80 words each, with every word in each condition being presented three times in carrier phrases, for a total of 720 randomized trials per participant, of which there were 23. Scheer et al.'s results show that the protocol used by Sahin et al. (2009) can be adapted to use with electrodes placed on the scalp. While still an exploratory study, the results also suggest that ERP is a reliable correlate for phonological alternations and can be used to distinguish between phonological and non-phonological activity, as shown in Figure 7.1 where the activity corresponding to the Overt condition can be distinguished from the non-phonological processes.

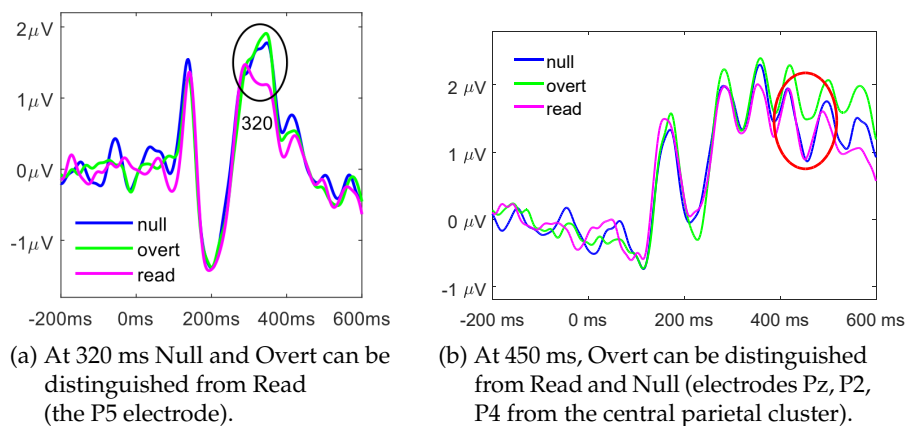


Figure 7.1: Velar-softening ERP results from Scheer et al. (2020).

These converging results, especially those results reported by Sahin et al. (2009) and Scheer et al. (2020), all suggest that phonological alternations correlate with electrophysiological activity at ~450 msec. If this is correct, then ERP components at ~450 msec can be used as a test for the phonological status of alternation patterns. This means that it can be used to compare unnatural alternations to natural ones. In addition, it may potentially reveal divergences between the phonological computation of alternations produced by native speakers and the computation used to produced to laboratory-learned alternations in AGL experiments.

The study outlined in §7.3 proposes to show just how these two things can be done.

7.2 NEUROBIOLOGY OF NATURAL LANGUAGE AND AGL

7.2.1 *Neurobiological techniques*

A number of previous studies have used techniques discussed in §7.1, in particular ERP, to compare AGL patterns to natural-language patterns produced by native speakers. Friederici et al. (2002) exposed two groups of participants to an artificial language in order to study the effects of grammatical violations in grammars acquired later in life. The first group was trained on an artificial language and tested to ensure a high level of proficiency. The control group was exposed to the same vocabulary, but was not trained on the language's grammar. Each group was then exposed to a set of grammatical and ungrammatical sentences in the language, and asked to provide grammaticality judgments. The group with extensive training on the artificial grammar showed a clear amplitude difference between grammatical and ungrammatical sentences, with a characteristic negativity between 100-200 msec followed by a long-lasting positivity between 350-500 msec. No equivalent activity was exhibited by the control group.

Friederici et al. (2002) suggest these results are comparable to ERP patterns reflecting automatic syntax parsing in native speakers of natural languages, who also exhibit an early negativity and late positivity response to syntactic violations, drawing a comparison between the neurobiological activity underlying L1 and L2 syntactic processing. Similarly, Morgan-Short et al. (2010, 2012) found that learners of an artificial language with noun-article and noun-adjective gender agreement showed N400 and P600 waveforms as a response to violations of the acquired pattern under implicit learning conditions (see §6.2.4.1). Learners who learned the artificial language with explicit instruction exhibited only P600s. Morgan-Short et al. (2012) argue that anterior negativity followed by a P600 and late anterior negativity is a pattern typical of native speakers.

McLaughlin et al. (2010) report on the use of ERP to investigate the responses to violations of morphosyntactic agreement in L2 learners of natural languages with the goal of determining whether or not (and when) learners process L2 knowledge as online language processing similar to L1. They review a series of results showing that learners show a reliable N400 effect to verb agreement violations after only a few weeks of learning, while those learners who have completed an academic year of study show P600 response to the same violations, a native-like response to grammar violations and assumed by McLaughlin et al. to mean that the relevant structure has been grammaticalized. McLaughlin et al. suggest that the lack of the P600 response in the beginning learner cohort means that grammatical processing resources exploited in L1 production are not initially transferred to L2 learning. McLaughlin et al. suggest that the later appearance of the P600 is evidence that learners progress through distinct stages of grammatical learning.

In sum, [Friederici et al. \(2002\)](#), [McLaughlin et al. \(2010\)](#), [Morgan-Short et al. \(2010\)](#), and [Morgan-Short et al. \(2012\)](#) suggest that L2 acquisition exploits some of the same neurobiological resources as L1 acquisition, for both natural language as well as artificial grammars. There are two reasons to not extend these interpretations to phonology. The first is that all of the aforementioned studies treat the acquisition of syntax in L2. However, in §6.2.3 I discussed evidence that critical-period effects are more pronounced in phonology than in other domains of language acquisition. Thus, results for syntax should not be applied to phonology without discussion or further investigation.

The second reason is the nature of the ERP results obtained in these syntactic studies: all of the studies report classic Mismatch Negativity (MMN) responses ([Näätänen et al. 1978](#)), which have been found in a wide variety of perceptual domains ([Näätänen et al. 2007](#)), making it unlikely to be a domain-specific effect of linguistic processing. One widely accepted view of the MMN sees it as a reflection of comparisons between traces in short-term memory ([Näätänen & Kreegipuu 2012](#)). In this case there is nothing particularly phonological at play. The P600 in particular has been reported as a response to anomalous sequences of rule-governed abstract systems, including musical structural incongruities ([Patel et al. 1998](#)) and violations in arithmetic tasks ([Núñez Peña & Honrubia-Serrano 2004](#)).

While the presence of the P600 does indicate that some kind of learning has happened (something must have been learned to be compared), since its presence seems to be generalized and not dependent on native acquisition, its use as a neurobiological correlate for native-language processing is seriously reduced. The question of whether or not learners of artificial grammars are processing language in a native-like manner is not resolved, since there is no reason to suppose that whatever the former are learning proceeds along the lines of L1 acquisition rather than some domain-general pattern recognition strategy.

7.2.2 ERP, phonology, and AGL

In phonology, ERP recoding has been used in studies of phonotactics and violations of phonotactic patterns ([Avcu 2019](#); [Breen et al. 2013](#); [Dehaene-Lambertz et al. 2000](#); [Domahs et al. 2009](#); [Moore-Cantwell et al. 2017/in submission](#)). For example, in an MMN study [Dehaene-Lambertz et al. \(2000\)](#) use ERP to compare how knowledge of phonotactic properties of French and Japanese affects the perception of stimuli which differed from precursor stimuli in the presence or absence of a vowel [u] between two consonants, e.g. *ebuzo ebuzo ebuzo ebzo*. In speakers of Japanese, where a sequence such as *ebzo* violates native phonotactic patterning, no significant ERP reaction to the phonotactic violation was found. In contrast, speakers of French, in which both *ebuzo* and *ebzo* are phonotactically licit sequences showed an initial negativity at 139-283 msec, followed by a positivity at 291-419 msec and a final late positive component at 523-651 msec. [Dehaene-Lambertz et al.](#)

argue that phonotactic knowledge then plays a fundamental role in early speech processing.

Domahs et al. (2009) report evidence for an N400 effect followed by a late positivity effect in native speakers of German when exposed to novel words that violate a well-formedness constraint in German where words of the form CC_iVC_i must contain dissimilar consonants in the position of C_i . For example, while *Stall* “barn” and *Schliff* “grinding” are well-formed words with different consonants in the two C_i positions, a pseudo-word such as [ʃpɛp] is ill-formed since both consonants are identical. The biphasic ERP effect that results from identical consonants in this position is taken by Domahs et al. to reflect the psychological reality of the well-formedness constraint in German.

In a study with similar ambitions to the one described in §7.3, Moore-Cantwell et al. (2017/in submission) report results in which ERP components were used as correlates to phonotactic generalizations learned in a laboratory. Adult, native speakers of English were taught 16 word-object pairings, where each word was consistent with a phonotactic pattern of the form CVCV, where each C was a stop (as in Moreton 2008). Two sets of words were built on this template, with one set consisting only of words that agreed in voice, and the other set in words that disagreed. For example, the first set consists of words like [dugi] and [tikɔ] while the second consists of words like [kædu] and [tigæ]. Participants were put into one of two groups, one of which was tested on a phonotactic pattern of voicing agreement, and the other on a phonotactic pattern of voicing disagreement.

The study consisted of two phases of which the initial one was a training phase in which participants matched objects from one set of words to pictures, intended to familiarize them with the phonotactic pattern where consonant voicing matches across consonants. During this phase, participants were asked to match the spoken stimuli to pictures of objects, knowing that their initial responses were guesses. After each response, they were given the “correct” response, though the true purpose of this phase was to expose them to words which either agreed or disagreed in voicing. During the following test-phase, participants were presented with novel, prerecorded oral stimuli. Each group was exposed to a trail stimulus, of which the consonants either agreed or disagreed for voicing. After exposure to the stimulus, each participant was asked to rate how likely it was that any stimulus word was a part of the language they had just heard while EEG recordings were made.

The ERP results from this study demonstrate several things. Participants in the AGL experiment demonstrated a decreasing N400 over the five training blocks, suggesting that participants learned the words of the training set. This conclusion is corroborated by the behavioral results, where participants were able to distinguish between high- and low-probability licit forms. The ERP results during testing also showed a large positivity component between 600-1000 msec, corresponding to the classic P600 MMN pattern.

Moore-Cantwell et al. (2017/in submission) interpret this late positivity component as evidence that learners can apply an abstract phonological rule in a way that is comparable to proficient learners, as in McLaughlin et al. (2010). They further suggest that the observed MMN pattern is similar to the effects seen in processing of novel-word phonotactic patterns, as in Domahs et al. (2009). Moore-Cantwell et al. argue that this lends support to the phonological nature of laboratory-learned AGL, where phonotactic generalizations learned in the laboratory are represented abstractly and similarly to natively acquired syntactic and phonological rules.

Avcu (2019) reports results from a series of similar studies seeking to use ERP to see if phonological pattern acquisition in laboratory settings is comparable to native-language pattern acquisition. Avcu reports the results of a number of phonotactic studies, where sibilant harmony versus disharmony are compared over short and long distances (but all are non-adjacent or non-local). Avcu shows that learners exhibit a clear neurophysiological reflex in response to violations of learned phonotactic patterns of simple non-adjacent sibilant agreement, and that this response can be evinced after relatively short training periods. Principally, this reflex takes the form of a positive wave peaking at around 300 msec followed by a later positivity component. Avcu suggests that participants categorized stimuli as grammatical or ungrammatical according to an acquired phonological generalization.

However, in both Moore-Cantwell et al. (2017/in submission) and Avcu (2019) there is a tacit assumption that any learning of phonotactic patterns is done by phonology, so that any demonstration of a pattern being learned is *ipso facto* phonological learning. The MMN pattern reported by Moore-Cantwell et al., discussed in §7.2, is not domain specific to phonology, or even language, and may simply represent a domain-general response to incongruous or aberrant patterns of any kind. Similarly, the P3 component reported by Avcu is not an unambiguous correlate of domain specific phonological processing; indeed it is a characteristic property of recognition tasks that exploit working memory (Polich 2007), and not strictly linguistic. While both studies demonstrate that learning has occurred and learners are able to recognize pattern violations, they are confronted with the same objection to behavioral AGL studies: they are not able to show that the patterns learned are learned as domain-specific *phonology*.

The study proposed in §7.3 differs from the above studies in that it attempts to reduce the impact of domain-general artifacts. Rather than exposing learners to aberrant tokens of agrammatical sequences of static phonotactics and looking for the correlate of responses to anomalous sequences, in an extension of the protocol used by Sahin et al. (2009) and Scheer et al. (2020), this study proposes to use correlates exhibited by the computation of phonological alternations to compare alternations produced by native speakers and participants in an AGL experiment conducted in a laboratory. The use of patterns of alternations insures that phonology—rather than some domain general capacity—is being engaged. This is the ambition of Scheer et al., and what other

studies that use static patterns cannot control for. If AGL pattern acquisition is like L2 phonological acquisition in adult participants, then the ERP signatures underlying both kinds should be directly comparable.

7.3 A PROPOSED ERP STUDY

7.3.1 *A study in two wings*

This section outlines a proposed study which has a double ambition. The first is to use ERP recording to compare three patterns of alternation in a natural language, Campidanese Sardinian (see Chapter 5), in order to confirm the results reported by Scheer et al. (2020), where ERP was found to be a reliable correlate of phonological activity, using an uncontested pattern of allophonic computation in this language ($s f \rightarrow z v / V_V$) to establish a baseline. The ERP correlate of this pattern of allophony will then serve as a basis of comparison for two other alternations in CS: an arbitrary pattern of allophony ($l \rightarrow \text{ɸ} / V_V$, see §3.10.4.1 and §5.4.3), and a complex saltatory alternation ($p t k \text{tʃ} \rightarrow \beta \delta \gamma \text{ʒ} / V_V$, see §5.4.3). The principal advantage of these three patterns of alternation is that they share a triggering context, and differ only in the details of their particular structural changes.

The principle hypothesis is that the characteristic ERP component of an uncontested pattern will closely match that of the unnatural pattern as well as that of the saltatory pattern. That is, the substance-free view of phonology outline in §4.4 predicts that all three structural changes will exhibit comparable ERP components. This would entail two consequences. The first is that the unnatural and natural alternations will exhibit comparable ERP signatures, meaning that both are phonological in nature. The second is that the complex and simplex alternations will exhibit comparable ERP signatures, meaning that complex, saltatory patterns are no more cognitively demanding than non-saltatory patterns.

The second wing of the proposed study is to make use of the three ERP components obtained in the trails using native speakers of CS to those of a group of non-native speakers taught a formally comparable pattern of alternations in a laboratory setting (see Chapter 6). That is, participants will be taught a pattern of alternations with a singular triggering context, and three conditions: simplex involving a single articulatory change, complex involving two articulatory changes, and phonetically arbitrary where there is no plausible link between the change and the context. Participants will be tested behaviorally to ensure that the pattern of alternation has been learned, and EEG recordings will be made of the testing session in order to extract ERP components corresponding to each condition. The hypothesis is that the ERP components for the natural and arbitrary conditions will be broadly comparable, while the complex alternation will show a relatively larger change in amplitude than the other two conditions. A secondary hypothesis is that the ERP components for the three condi-

tions will show a statistically significant divergence from those of the native-speaker group, supporting the idea that laboratory learning is ecologically different from natural-language acquisition.

7.3.2 A Campidanese Sardinian EEG experiment

The pattern of obstruent lenition in CS described in §5.2.2.1 can be categorized into three conditions according to the structural change of each (226):

- (226) a. $f s \rightarrow v z / V_V$
 b. $p t tʃ k \rightarrow \beta \delta \zeta \gamma / V_V$
 c. $l \rightarrow \mathfrak{B}, \mathfrak{I} / V_V$

The CS pattern is well-suited to this purpose because a single context (the intervocalic) produces three kinds of changes: a “simple” pattern of allophony voiceless fricatives are realized as voiced fricatives where only mode is concerned (226a), a “complex” pattern of allophony where voiceless stops are realized as voiced spirants where the mapping between input and output concerns both manner and mode (226b), and a seemingly arbitrary pattern where /l/ is realized as [ɸ] or [ʎ] (226c). In addition to the segments subject to lenition, there is also a set of non-leniting segments, /m n ts dʒ v m n ʃ ts dʒ v/, which are not subject to the intervocalic pattern of alternations in (226). The four conditions and contexts are summarized in Table 7.3; they allow for substantive hypotheses regarding the nature of complex and phonetically arbitrary phonological alternations to be tested.

Table 7.3: Lenition outcomes in Campidanese Sardinian.

Memory	V_V	Condition name
m n ts dʒ v	m n ʃ ts dʒ v	INERT
f s	v z	SIMPLEX
p t tʃ k	β δ ζ γ	COMPLEX
l	ɸ, ʎ	ARBITRARY

Each condition can be realized in an intervocalic triggering context, or in a non-triggering context, in which case there is never any process of lenition and the underlying target phoneme always surfaces faithfully. The non-leniting segments can be used to create a control, or INERT, condition in which there is no alternation. ERP components resulting from the production of the INERT condition can be compared to that of the SIMPLEX condition in order to establish a baseline correlate for phonological computation. In turn, the SIMPLEX condition ERP component can be compared to that of the COMPLEX condition, and both may be compared to that of the ARBITRARY condition. The four conditions and contexts are summarized in Table 7.4.

Table 7.4: Conditions in Campidanese Sardinian lenition.

	Non-triggering context	Triggering context	Gloss
Inert	mak:u	su mak:u	‘crazy, the crazy one’
Simplex (226a)	sor:ri	sa zor:ri	‘sister, the sister’
Complex (226b)	puɖ:a	sa βuɖ:a	‘hen, the hen’
Arbitrary (226c)	lati	su βati	‘milk, the milk’

As in the results reported by Sahin et al. (2009) and Scheer et al. (2020), it is expected that the SIMPLEX, COMPLEX, and ARBITRARY conditions should exhibit characteristic ERP signatures at ~450 msec, providing a correlate for phonological activity, distinguishable from production of the INERT condition. In turn, ERP components exhibited by the production the COMPLEX and ARBITRARY conditions can also be compared against the INERT and SIMPLEX conditions. Any significant difference in ERP components across the conditions will serve as confirmation of substantive theories that say complexity and phonetic unnaturalness play a role in phonological computation. Conversely, if only the INERT condition differs from the three other conditions, this will constitute evidence for abstract theories of phonology which abjure phonetic complexity and naturalness.

7.3.2.1 Participants

Participants will be recruited from among those used the field work project described in §5.2.1. Approximately 20 adult, native speakers of CS will be recruited for this study.

7.3.2.2 Material

Based on the corpus constructed from our field recordings, 20 items (article and noun pairs as in Table 7.4) from each of the three conditions in Table 7.4 will be recorded by a native speaker of CS. Each lenitable word will begin with an initial lenitable consonant, and be disyllabic. Words with medial spirants or nasals will not be used, because of the potential for making the ERP components difficult to distinguish as a result of sequential phonological operations over a short time-span—this restricts the stimulus set to words with inert medial consonants. The words for the Inert conditions will also be disyllabic, but begin with a non-lenitable consonant or geminate.

In all cases, the triggering context will be the adjunction of an article, either *su* or *sa*, depending on the gender of the noun in question: *su/a+noun*. Both articles are similar in duration, meaning that phonological computation should happen approximately at the same time across all three conditions.

7.3.2.3 Procedure

Participants will be seated in a comfortable chair in a room with the EEG recording equipment, and a high-fidelity audio setup for presenting the audio stimuli. Participants will wear an eye mask so as to reduce ocular movement. Each participant will be told, in CS, that they are going to hear a number of words, and their task is mentally chose the appropriate article (*su* or *sa*) for each stem. Participants will hear a recording of a word, followed by an auditory tone, after which they will repeat out loud the appropriate noun phrase.

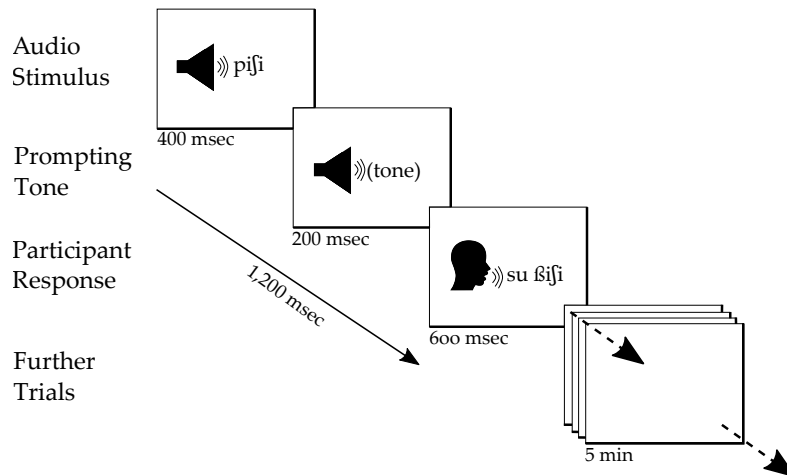


Figure 7.2: An experimental protocol for the production of lenition in Sardinian.

For example, upon playback of a recording of the word *terra*, the participant will silently repeat *sa terra*, and upon the auditory tone, produce the noun phrase. In every instance of a lenitable object, phonological computation should take place over the C₂ with the same timing across all three positions, generating a characteristic ERP component.

Each participant will be exposed to a tone pretest to evoke an automatic auditory response, the N1. Next, each participant will be exposed to randomized trials across all four conditions. Continuous EEG records will made throughout stimulus presentation. Electrodes are to be placed on the scalp consistent with the International 10-20 system, including Fp1/2, F3/4, F7/8, FC1/2, FC5/6, FT9/10, C3/4, T7/8, CP1/2, CP5/6, TP9/10, P3/4, P7/8, O1/2, Oz, Fz, Cz, and Pz. A ground electrode will also be placed at Fpz. The auditory stimuli will be sent through the EEG machine so that EEG epochs can be time-locked to stimulus presentation.

7.3.2.4 Analyses

The EEG signal will be analyzed using the EEGLAB toolbox. Epochs will then be extracted and average ERP components calculated for each of the four condition. The significance of any difference between con-

ditions will be established using a one-way ANOVA and Tukey's HSD (honestly significant difference) test (Tukey 1949).

7.3.2.5 *Interpretation of results and predictions*

If the substance-free view of phonology is correct, the ERP components exhibited during the production of the phonetically arbitrary pattern should show no significant divergences from the phonetically natural one. This would bolster the claim that phonological computation is not constrained by substantive factors. Substance-free theories differ in the predictions made regarding the complex alternation.

In the orthodox view of SFP, the set of features is universal and feature exponence is invariant (Hale et al. 2007; Volenec & Reiss 2017, 2020). In this view, the complex change should involve more feature changes than the natural condition, since in the former both mode and manner are changed, while in the latter only mode is. Thus, the ERP component correlate for the complex change, if it is indeed phonological, should exhibit a significant difference relative to the natural change. Since multiple ERP components can be simultaneously generated and recorded, and their voltages can be summed together, multiple computations performed simultaneously will produce higher amplitude waveforms (Kappenman & Luck 2011: 6). If complexity in phonological alternations is reflected in multiple computations relative to simple alternations, then this should be reflected in the relative voltages of the ERP components produced by each (see Kramer et al. 1985).

In the so called "radical" view of SFP, features emerge in acquisition and are a function of the patterns that learners are confronted with during that process (Blaho 2008; Odden to appear). In this view, the complex change is complex only in articulatory terms: in phonology it does not necessarily concern more features than the natural or arbitrary conditions. Complexity is not a fact about phonetic exponence, but about how segments interact in a system of rules and contrasts. As such, the prediction made by the radical view is that the ERP components exhibited across the natural, arbitrary, and complex conditions will show no statistically significant variation. The results obtained from Experiment 1, then, serve a double purpose: to adjudicate between different hypotheses advanced in theoretical work—both within and across schools—and to establish a baseline correlate for phonological activity to which laboratory learning can be compared.

7.3.3 *An Artificial Grammar Learning experiment*

The ambition of this AGL experiment is to generate EEG recordings of participants learning an artificial rule of allophony, from which ERP components can be extracted and compared to those of the native speakers of CS. In contrast to previous studies searching for neurological correlates of artificial grammar learning in phonology (§7.2.2), the present study is an investigation not of violations of learned static

Table 7.5: Three patterns of alternation for an artificial grammar.

Memory	V_V	Condition name
f s	v z	SIMPLEX
p t	v z	COMPLEX
l	m	ARBITRARY

patterns, but of production of learned dynamic patterns. To my knowledge, no such study has been reported in the literature.

To do so, a grammar containing an pattern of alternation which is formally identical to that of CS will be constructed. The exact grammar depends on the native language of the participants recruited for the study. Assuming those participants are native speakers of North American English, a pattern of alternations such as that in Table 7.5 would be appropriate, since it contains only phones which are familiar to English speakers, and is formally comparable to that of the one illustrated in Table 7.4⁵. The context for lenition will be in the intervocalic position—created with a preceding vowel final nonce article—and the targeted consonant will be the initial consonant of the nonce-word stems.

The study reported in White (2014) presents some fundamental divergences from the pattern of alternation CS. White’s stimulus set trains participants on stem-final alternations, while the alternations in CS are stem-initial. In the light of evidence which suggests that stem-final and stem-initial positions may not be processed in the same way (Usishkin et al. 2017), the results reported by White may not be valid for the natural-language alternation in CS. Next, White only considers alternations among stop consonants, providing participants with explicit evidence that fricatives are not subject to the pattern of alternation in the stimulus set, while in CS fricatives alternate in precisely the same context as stops. Thus, the artificial grammar used by White would be difficult to learn for speakers of CS, even though they are quite capable of producing the saltatory alternation. Finally, White has no analogue for the arbitrary change in CS.

The present study thus proposes an extension of the methods used by White (2014) to investigate whether or not ERP reveals any difference between the production of a simplex change and a saltation in an AGL paradigm. A secondary aim of this study is to see if the ERP produced during the AGL paradigm and the production of formally similar patterns in the natural-language setting of CS exhibit any significant differences.

⁵ The arbitrary change is not the same as in CS, since there is no directly comparable phone in American English. The change l→m is arbitrary in that it is unexpected for a dental lateral to be realized as a bilabial nasal in an intervocalic context.

7.3.3.1 Participants

Since a great deal of the AGL literature assumes that laboratory learning in adults is phonological in nature and the ambition of this study is to test that assumption, approximately 20 adult speakers of English will be recruited to participate. Presumably, they will be university students.

7.3.3.2 Material

The context for lenition will be VCV, as in CS, and the targeted consonant will be the initial consonant of the nonce-word stems, again as in CS. 80 disyllabic nonce words of the form CVCV will be constructed for each condition in (7.5)—that is, simplex, complex, and arbitrary—and 80 disyllabic nonce words of the form CVCV for an Inert condition. Each will be recorded by a native speaker of North American English. For each lenitable word, C₁ will be the intended lenition target. In all cases, the triggering context will be the adjunction of an “article” or “prefix”, *sa*, e.g. *pomo/sa vomo*, again following CS. Phonological computations are expected to unfold in the same time-frame across all three lenition conditions.

7.3.3.3 Procedure

Participants will be told that they are participating in an experiment on language learning, but with no further details. This AGL experiment consists of two phases, an acquisition phase and a test phase. During the acquisition phase (Figure 7.3), participants will be told that what the word for *the* in the language they are learning is: *sa*. They will be told they are going to hear a number of words in the language they are learning, and their task is simply to repeat what they hear. Each trial will begin with a recording of a bare stem.

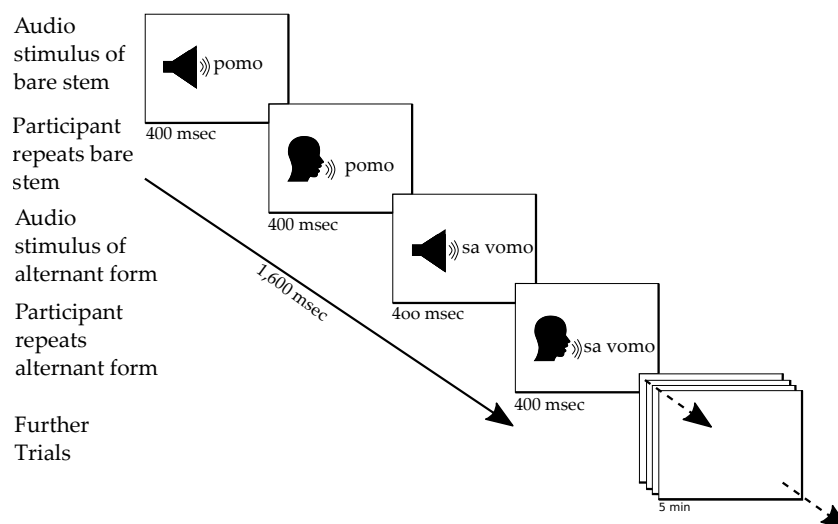


Figure 7.3: Phase 1: Acquisition of an AGL.

Participants will be asked to repeat that bare stem. Next, participants will hear an audio recording of the article *sa* followed by the same stem. If that stem begins with a consonant that is part of the pattern of alternation then the recording stimulus will present the appropriate alternating form so that the participant is exposed to both bare stems and alternating forms. Participants will then be prompted to repeat the full phrase, with the article followed by the stem. In this way, they will hear both bare stems and the surface variant. The acquisition phase will consist of 120 such stems, with stems from each of the four conditions randomly chosen but controlled for such that each condition is represented 30 times.

Once the acquisition phase is completed, the test phase will begin (Figure 7.4). During the initial part of this phase, participants will hear a novel stem, and be asked to adjoin, out loud, the article *sa* before each novel word. EEG recordings will be made continuously during acquisition and the test phase. The EEG data acquisition and analysis proceeds exactly as in Experiment 1.

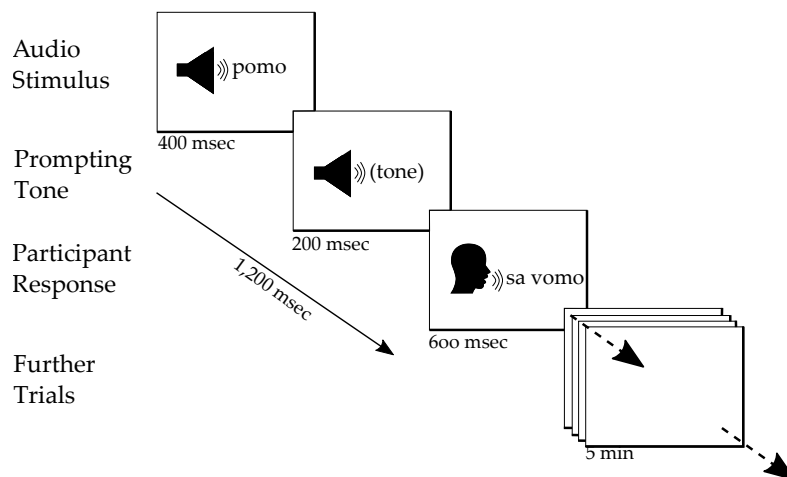


Figure 7.4: Phase 2: Test of an artificial-grammar pattern.

Experiment 2 provides two kinds of data: the behavioral data which can be measured in terms of accuracy of responses given during the test phase, and the neurophysiological data provided by the EEG recordings. Because participants in Experiment 2 are exposed to pattern that is not present in their native language, it cannot be, by nature, be acquired natively. As such, the pattern is acquired on the backdrop of all knowledge participants have about their L1. This means that the behavioral results may not correspond to the predictions made by Substance-Free Phonology regarding naturalness: since English does not have the same kind of phonetically arbitrary alternations as CS, the phonetically natural pattern may be easier to acquire.

If, as suggested by Ettliger et al. (2015) and Moreton & Pertsova (2016: 289), AGL learning works more like L2 acquisition, then the ERP components exhibited during the production of laboratory-learned patterns should show statistically significant divergences from those exhibited during the production of L1 patterns. This result would dis-

confirm the validity of AGL for probing native language cognition, though its use in understanding how L1 and L2 acquisition proceed would not be impacted.

7.3.4 Discussion

Upon completion of the experiments with both groups of participants, ERP analyses will be performed on the EEG recordings made *in situ*. Several comparisons will be made looking for statistically significant differences: across the four conditions within each group, and between the four conditions across the two groups.

The goal is to see if, within the natural group, the neurobiological correlate of the computations which produce the complex alternation and the unnatural alternation are comparable to those that produce the simplex alternations, taken to be unambiguously phonological in nature. The second goal is to compare the set of ERP components which correlate with phonological computation in native speakers to those of the participants in the AGL experiment in the laboratory.

In this way, it is hoped that evidence can be brought to bear on three related questions:

1. Can ERP be used to determine the phonological character of unnatural alternations?
2. Can ERP be used to determine if the computational processes underlying simplex and complex alternations in the language of native speakers are significantly divergent?
3. Can ERP be used to determine if alternations learned in the laboratory have a neurobiological correlate comparable to that of natural language phonological alternations?

CONCLUSIONS

Et puis je n'aurai plus
 Ce phosphore un peu mou
 Cerveau qui me servit
 A me prévoir sans vie

BORIS VIAN

This thesis is a contribution to work on phonological features and rules, the most basic representational and computational tools in phonology. As a way of orienting through the vast expanse of research in this domain, it proposes an examination of features and rules in the light of crazy rules. One of the basic guiding principles is a commitment to a view of phonological inquiry that is minimalist in spirit, asking just how impoverished a model of features and rules can be, and still be used to gain insight about phonological patterns and what human beings know about those patterns.

The basic ontological commitment of phonology is to model something that exists in nature: knowledge of linguistic sound patterns, instantiated in human brains. Phonological theory allows us to understand that knowledge through models of phonological grammars that reflect the breadth of human languages. But, if it is to be interesting, phonological theory has to go beyond describing the scant evidence we have for how human languages are spoken in the present, how they were spoken in the past, and how they will be spoken in the future. The real power in a theory of phonology is its predictive power: it can tell us things not just about attested languages, but also about possible languages. A theory of phonology that makes predictions allows us to discover new things about phonology, and thus novel facts about human languages and the nature of linguistic knowledge.

Overly powerful formal system can generate a great many languages that are not attested, and perhaps a great many languages that are impossible. The remit of phonological theory is possible languages—of languages that *could* be instantiated in human brains. But a theory of phonology predicts an unbounded set of possible languages, it loses predictive power, unable to distinguish between possible and impossible languages. A theory which cannot make predictions about the set of impossible languages does not reflect any object in nature, since our own phonological capacities surely limit the range of possible phonological grammars we can acquire as natural language. Even more seriously, such a theory threatens the entire phonological enterprise, since it is not easily falsified.

In an effort to curtail the raw-power of formal systems, phonetic naturalness has recurrently been used in generative phonology. Nat-

uralness is a potent tool, restricting the bounds of possible phonological processes: a phonetically unnatural process is impossible in phonology. These related themes are the backdrop of the discussion of crazy rules in this thesis. I argue that crazy rules show that synchronic phonological computation is perfectly capable of producing phonetically arbitrary processes. As such, there is no phonetic naturalness in phonological grammars.

In Chapter 2, I identified three kinds of naturalness that have been built into formal theory: symbolic naturalness, functional naturalness, and typological naturalness. Ultimately, both typological naturalness and symbolic naturalness can be reduced to functional naturalness, which derives explanations for phonological patterns from functional principles related to the production and perception of spoken language. The classic view holds that physical exigencies of speech production and principles such as ease of articulation are recapitulated in grammar, such that phonological processes are only possible insofar as they reflect those functional principles.

In this view, an unnatural synchronic process, for example a sonorant that is devoiced when preceding a voiced consonant, is impossible. I review a number of phonological theories that have made phonetic naturalness a formal principle. In particular, I review how those theories exclude crazy rules from the set of possible phonological grammars. If phonetic naturalness is taken to be an axiomatic principle of a theory of phonology, then crazy rules cannot have any status in the phonological grammar: phonetically arbitrary patterns must be placed in some other domain: to morphosyntax, to the lexicon, derived by analogy or otherwise shunted out of phonology.

Chapter 3 provides an empirical census of crazy rules reported in the literature. In a theory with formal naturalness, such unnatural patterns cannot be the reflection of synchronic grammar. I argue that the census shows that a number of these processes are the product of phonology, are phonetically arbitrary, and must be taken into account by any theory of phonology.

I identified four kinds of crazy rule:

- I Those that have as input a crazy class of segments (/p n ʋ/)
- II Those that are triggered by a crazy class of environments (/p n ʋ/)
- III Those that are have a crazy structural change (/j/ → [k])
- IV Those which reflect a crazy relationship between the change effected and structural description (p → b / _æ)

These patterns have in common a lack of phonetic coherency: their is no phonetic unity in these crazy classes and processes. Limiting the census to the two latter kinds of synchronic processes, the census describes 34 patterns of alternation that are phonetically arbitrary. Some of the patterns, may, in fact ultimately prove to be non-phonological in nature; impostors from morphology or the lexicon. However if just one of them is shown to be phonological then it can be shown that it

is an error to include naturalness-enforcing devices in phonological grammars. Theories that do not build naturalness into the grammar are a tighter fit to the empirical record, able to produce phonetically natural patterns as easily as crazy patterns. As a consequence, the set of possible phonological grammars expands; phonological computation, no longer yoked to phonetic naturalness, becomes more powerful in its generative capacity. Concomitantly, the power to distinguish between possible and impossible grammar is reduced.

There is a solution to this problem: the empirical census allowed for a generalization to be made about crazy patterns in phonology that indicates that phonology is not entirely unbounded in its generative capacity (227):

- (227) All crazy-rule candidates show melodic craziness. There are no cases on record that involve crazy alternations regarding syllable structure or stress, properties located at and above the skeleton.

This observation suggests that craziness is restricted to the domain of melodic computation: there is no craziness in syllabic structure or prosodic timing. The census is essentially a random sample of crazy rules, shaped by the vagaries of historical forces and linguistic research, limited to well-documented languages and published research. If syllabic craziness were distributed like melodic craziness, then it would be expected that the typological record would reflect both with about equal frequency. But the census suggests a striking absence of arbitrariness from the suprasegmental domain of phonology. If this is true, then phonology is after all limited in the patterns that it can generate. It is, at least in part, non-arbitrary.

If phonology is arbitrary in the melodic domain, capable of mapping between any input and any output in any segmental context, it appears to be non-arbitrary in the suprasegmental domain. A theory of phonology that captures this difference can make predictions about possible and impossible languages. An impossible language is one with a crazy syllabic rule, but a possible language can certainly be phonetically unnatural.

Anderson's Paradox is a useful lens through which to consider the recurrent observation that for all the phonetic naturalness reflected in the phonological processes recorded in the literature, all phonological theories must confront phonetically arbitrary patterns. Crazy rules may be rare, but they do exist. On the other hand, the effect of phonetics on most phonological patterns is so striking as to demand some kind of explanation. If phonetic naturalness is not built into the phonological grammar, then then an alternative explanation for the apparent influence of phonetics must be found.

Nothing precludes this explanation from coming from outside of the theory of phonological computation, as I argue in Chapter 4. Third-factor explanations provide a ready explanation for the apparent effects of phonetics in phonology. In a diachronic account of phonetic naturalness effects, phonological alternations are the grammaticalization

of phonetic cues, automatic and mechanical artifacts of articulation and perception that are phonologized by speakers over time. Freshly phonologized, a pattern of alternation is the reflection of those facts about phonetics that caused it to come about, but nothing demands that those facts be carried into phonological computation *qua* cognition.

I used a substance-free approach to reconsider Anderson's Paradox, suggesting that once a pattern becomes a part of a phonological grammar it becomes a symbolic formal process, isolated behind a modular firewall from any information about phonetic facts. I also used the substance-free approach to explore the nature of the suprasegmental domain, a realm of perfectly lawful phonology.

I argued for a conceptual division between melodic phonology and suprasegmental phonology. The former interfaces with phonetics through spell-out, which works like a look-up table and maps between inputs and outputs in a phonetically arbitrary way. Since phonological features are interpreted in spell-out and are phonetically arbitrary, those phonological computations which work over features can produce arbitrary patterns. Suprasegmental phonology, on the other hand, is argued to be symbolic, universal, and innate; here there is no arbitrariness and phonological processes are perfectly regular.

I argue that the substance-free model can be used to make predictions about impossible languages without appealing to naturalness or other phonetic stipulations: impossible languages are those with impossible suprasegmental processes. For example, one prediction of the model adopted here is that there is no formal device for multiplying or reducing timing positions as a function of the number of timing positions elsewhere in a single string. In other words, there is no length harmony because phonology does not have any way of producing it.

In Chapter 5, I applied the substance-free model to a pattern of lenition and fortition in Campidanese Sardinian. The analysis reveals a novel fact: in Campidanese Sardinian (CS), fortition of voiced stops results in them being realized on the surface as spirants. This is a kind of crazy rule where the output is unexpected given the input, and a potential counter-example to the generalization in (227), since fortition is a syllabically-driven effect. However the analysis shows that this process does not delete or otherwise modify melodic content; the spreading of melodic material into empty timing slots is a perfectly conventional fortition effect carried out above the skeleton. The substance-free model shows, then, that this process is perfectly regular on the suprasegmental domain, but that the arbitrary mapping between input and output in spell-out results in geminate voiced stops surfacing as spirants.

In the second part of this thesis I provide an overview of experimental work relevant to the question of naturalness in phonology.

In Chapter 6, I survey a body of experimental work in Artificial Grammar Learning (AGL) which investigates the role of naturalness in phonological grammars. I argue that the results these studies is difficult to interpret, and that there is no clear evidence for naturalness effects in phonological pattern learning in laboratory contexts. Results do, however, show a robust bias against complexity, a bias found throughout

cognition and not domain specific to phonology. I argue that one of the principle weaknesses of AGL studies is that it is difficult to show that any pattern learning that happens is comparable to natural-language acquisition. That is, nothing in AGL studies shows that it is actually phonology that is being studied, seriously reducing their usefulness for isolating any putative naturalness biases in phonology.

I conclude this thesis by proposing a neurobiological study that may be useful in detecting differences in cognitive activity during the production of natural-language phonology and patterns learned in AGL studies. The study proposes recording the Electroencephalography (EEG) activity of participants producing phonological alternations in their native language and comparing the Event-Related Potentials (ERP) patterns to those produced by adult learners of an artificial grammar. If there is any neurobiological difference between the two kinds of pattern production, then it could potentially be found in the ERP patterns and be a reflection of different cognitive strategies used in the two contexts. It would, for example, be expected that native speakers would be using phonology, while learners of an artificial grammar may use some general pattern-learning strategy in the second.

The study proposes that CS would be an ideal natural language to use for testing this hypothesis, since the exhibited pattern of lenition discussed in Chapter 5 produces different output depending on the input: voiceless stops are voiced and spirantized, voiceless fricatives are voiced, and the lateral is realized as an uvular or pharyngeal fricative. These three changes represent a complex change of two features in the first case, a simplex change of a single feature in the second, and an arbitrary change in the third.

The three conditions correspond to the tension in AGL studies between complexity bias and naturalness bias. If the ERP patterns correlated to the simplex change are significantly divergent from either the complex pattern or the naturalness pattern, then this may bolster the arguments that complexity biases and naturalness biases are built into phonological grammars. On the other hand, if no difference is found, then the substance-free view of phonology—in which any feature can be changed into any other and phonetic naturalness plays no role—will be vindicated.

Finally, a formally comparable grammar could be taught to adults in an AGL experiment. ERP activity associated with the production of the learned phonological alternations in that grammar could be compared to the ERP patterns produced by the native speakers of CS to see if any significant difference can be found between the two. If so, then this would validate the use of AGL studies in sounding phonological grammars and what their results can tell us about Universal Grammar. If, on the other hand, significant differences are found, then AGL results will need to be interpreted with great care, since they may have no bearing on phonology at all.

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